OPTIMUM SIZING AND TRIPLE BOTTOM LINE ANALYSIS OF INTEGRATING HYBRID RENEWABLE ENERGY SYSTEMS INTO THE MICRO-GRID

By

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Dedicated to my teachers........

गुरुर्ब्रह्मा गुरुर्विष्णु र्गुरुर्देवो महेश्वरः

गुरु साक्षात परब्रह्मा तस्मै श्रीगुरवे नमः||

To my husband, Ramnarayan Parameswaran, who has supported and encouraged consistently and assisted me finish this thesis. To my parents, to my new born daughter Varenya, family and my in-laws who have supported me during this entire journey.

Thank you for your immense support and encouragement.

Nithya Saiprasad

Table of Contents

Abstract

There have been growing concerns over global warming, and this has increased the awareness towards the reduction of Greenhouse gas (GHG) emissions. Many countries including Australia have signed the “Paris Agreement” to try and combat global climate change. This agreement aims to restrict global temperature rise under 2ºC above pre-industrial levels and further limit the temperature rise to 1.5ºC. In December 2018, the United Nations Climate Change conference was held in Katowice, Poland and a framework called the United Nations Framework Convention on Climate Change (COP24) was agreed upon to help in implementing regulations of 2015 Paris Agreement. The agreement also ensures boosting support to developing countries to counter this threat. In order to help the developing and the most vulnerable countries achieve these rather ambitious goals, this new framework will focus on technology, financial flows and capacity improvement.

The global reliance on fossil fuels, which contributes approximately 80% of primary energy, has resulted in the rise of global temperatures. Several countries have begun to reduce their reliance on fossil fuels and thus GHG emissions, by shifting their focus towards Renewable Energy (RE). Thus, RE has become a “go to” energy source to solve the aforementioned global issues with a pronounced focus on the guiding energy policies

Energy, economics and environment play a crucial role in ensuring the sustainability of a country. Adoption of RE would be the key to ensuring energy sustainability and also reducing the environmental impact, thus helping RE to reach the citizens. Having acknowledged these global challenges and thus relying on RE for the energy needs, sustainability can be achieved by modernising the present micro-grids by integrating RE into them. In order to integrate RE into the existing micro-grid, sizing of Distributed Energy Resources (DERs) using RE sources are investigated to improve their energy production mechanism and enhance the overall efficiency.

There are several approaches to size the RE sources into a micro-grid. Two approaches are followed for sizing HRES based on analysing the electricity consumption of the area of interest relying on: (i) Hybrid Optimisation of Multiple Energy Resources (HOMER) software and (ii) improved Hybrid Optimisation using Genetic Algorithm (iHOGA) software. This study highlights the issues related to the optimal sizing of the

DERs by investigating their use of the novel application in micro-grids, using both photovoltaic (PV), wind turbine (WT) as the RES for supplying power to the grid for residences and commercial building at Aralvaimozhi, India and Warrnambool, Australia. These two chosen locations are bestowed with good sunlight and wind. The average solar radiation in Warrnambool 4.16kWh/m^2/day and annual average wind velocity 5.96m/s. The wind speed and the average solar radiation at Aralvaimozhi are 7.16m/s and 5.05kWh/m^2/day respectively. Aralvaimozhi has been spotted as a potential wind farm location according to the Government of Tamil Nadu.

India being a developing country and Australia, a developed country, their respective energy policies are scrutinised to understand their energy policies status. Suggestions to improve RE adoption by understanding the energy policies laid by other RE developed counties like Germany, USA, etc. have been conducted. Triple Bottom Line (TBL) analysis is conducted to understand the feasibility of adopting RE into a micro-grid. It focuses on the Techno-economic, environmental and social perspectives to understand the feasibility of RE adoption from the perspective of a developed country (Australia) versus a developing country (India). In this respect, a prototype model of the micro-grid is studied and used at Victoria University, Footscray Campus for various scenarios.

Declaration of Originality

"I, Nithya Saiprasad, declare that the Ph.D. thesis entitled *"OPTIMUM SIZING AND TRIPLE BOTTOM LINE ANALYSIS OF INTEGRATING HYBRID RENEWABLE ENERGY SYSTEMS INTO THE MICRO-GRID*" is no more than 100,000 words in length excluding quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

[redacted]

Nithya Saiprasad 25/03/2019

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I would bow to the Almighty for giving me good health, wisdom and courage to plan my path in this challenging journey.

List of Figures

List of Tables

List of Nomenclatures

RE: Renewable Energy

HRES: Hybrid Renewable Energy Systems

RES: Renewable Energy Systems

RET: Renewable Energy Target

GHG: Greenhouse Gases

JNNSM: Jawaharlal National Solar Mission

NSM: National Solar Mission

NPC: Net Present Cost

LCOE or COE: Levelised Cost of Energy or Cost of Energy

HOMER: Hybrid Optimisation using Multiple Energy Sources

iHOGA: improved Hybrid Optimisation using Genetic Algorithm

PV: Phot-voltaic or solar cell

WT: Wind Turbine

SCR: Silicon controlled rectifier

LPSP: Loss of Power Supply Probability

LOA: Level of Autonomy

EENS: Expected Energy Not Supplied

LOL: Loss of Load

TAC: Total Annualised Cost

CRF: Capital Rector

ACS: Annualised Cost of System

IRR: Internal Rate of Return

PBP: Payback Period

DER-CAM: Distributed Energy Resources Customer Adoption Model

CHP: Combined Heat and Power

HAWT: Horizontal Axis wind Turbine

VAWT: Vertical Axis wind Turbine

GDP: Gross Domestic Product

GA: Genetic algorithm

FL: Fuzzy Logic

IC: Incremental Conductance

MPPT: Maximum Power Point Tracker

I_{SC}: Short circuit Current

V_{OC}: Open circuit Voltage

ANN: Artificial Neural Network

PSO: Particle Swarm optimisation

AI: Artificial Intelligence

RRP: Renewable Energy Power Percentage

REC: Renewable Energy Certificates

MNES: Ministry of Non-Conventional Energy Sources

IREDA: Indian Renewable Energy Development Agency

MNRE: Ministry of New and Renewable Energies

RPO: Renewable Purchase Obligations

EA: Electricity Act

NEP: National Electricity Policy

NTP: National Tariff Policy

SAD: Special Additional Duty

REC: Renewable Energy Certificate

CERC: Central Electricity Regulatory Commission

NAPCC: National Action Plan on Climate Change

SIP: Special Incentive Packages

M&V: Monitoring and Verification

MNRET: Mandatory Renewable Energy Target

CEIF: Clean Energy Innovation fund

CEFC: Clean Energy Finance Corporation

ARENA: Australian Renewable Energy Agency

SA: South Australia

ACT: Australian Capital Territory

NSW: New South Whales

NT: Northern Territory

WA: Western Australia

TAS: Tasmania

NEM: National Energy Market

AGL: Australia Gas and Light Company

STP: Small-scale Technology Percentage

USA: United States of America

EU: European Union

CEIF: Clean Energy Innovation fund

CEFC: Clean Energy Finance Corporation

EITE: Emissions-Intensive Trade-Exposed

STC: Small-scale Technology Certificate

LGC: Large-scale Generation Certificate

AARA: American Recovery and Reinvestment Act

ITC: Investment Tax Credit

MTC: Manufacturing Tax Credit

AEMO: Australian Energy Market Operator

NASA: National Aeronautics and Space Administration

FiT: Feed in Tariff

A$: Australian Dollar

INR: Indian Rupee

W: Watt

Wp: Watt Power

kW: kilo-Watt

kWh: kilo Watt hour

TWh: Tera watt hour

EJ: Exa-Joule

Ah: Amp-hour

A: Ampere

V: Volt

m/s: metres per second

M: Million

Hz: Hertz

% : Percentage

SoC or SOC: State of Charge

O&M: Operational and Maintenance

LF: Load Following

CO_2: Carbon dioxide

CO_x: Carbon monoxide and its derivatives

SO_x: sulphur oxide and its derivatives

NO_x: Nitrous oxide and its derivatives

AWS: Australian Wind and Solar

DOD: Depth of Discharge

A.C.A.C..: Alternate Current

D.C.: Direct Current

EV: Electric Vehicle

HEMS: Home Energy Management System

G2V: Grid-to-Vehicle

V2H: Vehicle-to-Home

V2G: Vehicle-to-Grid

List of Publications

1. N. Saiprasad, A. Kalam, and A. Zayegh, "Techno-economic and environmental analysis of hybrid energy systems for a university in Australia," Australian Journal of Electrical and Electronics Engineering, pp. 1-7, 2018. (Found in Chapter 5)
2. N. Saiprasad, A. Kalam, and A. Zayegh, “Comparative study of optimization of HRES using HOMER and iHOGA Software” JSIR, vol .77, pp 677-683, 2018. (Found in Chapter 5)
3. N. Saiprasad, A. Kalam, and A. Zayegh, "Optimum Sizing and Techno-Economic & Environmental Analysis of Renewable Energy Sources Integration into a Micro-Grid for a University: A Case study," Lectures on Modelling and Simulation; A selection from AMSE # 2017, vol. 2, pp. 11-20, 2017. (Found in chapter 5)
4. N. Saiprasad, A. Kalam, and A. Zayegh, "Optimum Sizing and Economic Analysis of Renewable Energy System Integration into a Micro-Grid for an Academic Institution—A Case Study," in Modelling and Simulation in Science, Technology and Engineering Mathematics. MS-17, Calcutta, 2017, pp. 227-238. (Found in Chapter 5) [WON THE BEST PAPER AWARD]
5. N. Saiprasad, A. Kalam, and A. Zayegh, "Optimal sizing of renewable energy system for a university in Australia," 2017 Australasian Universities Power Engineering Conference (AUPEC), 2017, pp. 1-6. (Found in chapter 5)
6. N. Saiprasad, A. Kalam, and A. Zayegh, "Zero-emission renewable energy system model for a community in India," 2017 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), 2017, pp. 1-6. (Found in Chapter 5)
7. N. Saiprasad, A. Kalam, and A. Zayegh ,”Feed-In-Tariffs – An Australian Case Study”, Modelling, Measurement and Control D, 2018, Vol. 39, No. 1, pp. 15-24 (Found in Chapter 4).
8. N. Saiprasad, A. Kalam, and A. Zayegh, “Comparative Study of Optimal Sizing of Renewable Energy System and Triple Bottom Line (TBL) Analysis for a University in Australia” 2018 Australasian Universities Power Engineering Conference (AUPEC), 2018. (Found in chapter 6)

9. N. Saiprasad, A. Kalam, and A. Zayegh, "Triple Bottom Line Analysis and Optimum Sizing of Renewable Energy Using Improved Hybrid Optimization Employing the Genetic Algorithm: A Case Study from India," Energies, vol. 12, p. 349, 2019. (Found in Chapter 6)
10. U. Datta, N. Saiprasad, A. Kalam, J. Shi, and A. Zayegh, "A price-regulated electric vehicle charge-discharge strategy for G2V, V2H, and V2G," International Journal of Energy Research, 2018. (Found in Chapter 9)

Chapter 1

Thesis Overview

1.1 Introduction

1.2 Research Aims & Objectives

1.3 Contribution to the Knowledge and Statement of Significance

1.4 Methodology and Conceptual Framework

1.5 Result Analysis using TBL (Triple Bottom Line) analysis techniques

1.6 Thesis Organisation

1.7 Summary

1.1 Introduction

This chapter is an overview of the present work and the motivation behind this research study. It showcases on the aims and objectives this research addresses and methodology used to achieve these aims and objectives. Contribution to the knowledge and justification of this research study has been discussed. This chapter also comprises the overview of each Chapters' structure and the organisation of the dissertation.

1.2 Research Aims & Objectives

A crucial task of delivering energy using Renewable Energy Systems (RES) using a micro-grid has always been challenging both technically and financially, supplementing the acceptance of this new technology by the public. This project mainly aims at catering the following objectives:

i. Develop a prototype energy source-consider and synchronize it; one or more than one electricity generating source can work in parallel according to the output requirement.
ii. Study the electrical properties of the Distributed Energy Resources (DERs).
iii. Promote Renewable Energy (RE) by the production of electricity based upon new emerging technologies.
iv. Assess the present and future electricity/energy demands.
v. Estimate the potential for various RE technologies in the specific areas.
vi. Identify technically and economically viable technologies.
vii. Support towards design and development of suitable RE based micro-grid.
viii. Study the social and environmental impact of the designed system.

1.3 Original Contribution of the work

1.3.1 Contribution to Knowledge (Academic Contribution)

There has been a significant amount of discussions about green energy alternatives. The current research discusses not only the green energy alternatives to two communities, namely a university building in Australia and residential units in India but also discusses the complications in implementing these in the communities. The topic is mainly chosen to compare the energy policies, the social acceptance, and technical viabilities at two different locations namely Warrnambool, Australia, and

Aralvaimozhi, India. This study provides a broader view of these two countries' contribution to RE at the global level. While no two countries will have the same ideologies and purview, comparing their paths in achieving their goals will be insightful.

1.3.2 Statement of Significance (Practical Contribution)

The study tackles the concept of designing, development and optimisation of RE to reach the common people's household and community (example, university) at two different locations. This study will help to scrutinize the present RE market, policies and further developments required from the perspective of technical, social and economic background.

The energy consumption of Australia and GHG emission trend data recently published has forecasted up to 14% increase in consumption by university buildings. It is purported that the emission from university buildings will be only second compared to other buildings such as hospitals [1]. By implementing RES for energy production such as solar, wind, hydrogen fuel cell (HFCs), etc., significant contributions of GHG emissions from such buildings can be minimised. However, HFCs need a constant monitor, and there is a constant scare of adopting this source, especially in buildings like universities, due to occupational health and safety (OH&S) issues. This research will clarify the pros and cons of the systems used, the viability of reaching the technology to the public domain and thus the adoptability of the technology for two real-life scenarios.

1.4 Methodology and Conceptual Framework

The study aims at understanding the feasibility of integrating renewable energy systems for a commercial building (University) and residential units in Warrnambool, Australia, and Tamil Nadu, India respectively. The two locations have good sunlight and wind. The average solar radiation in Warrnambool 4.16kWh/m2/day and annual average wind velocity 5.96m/s. The wind speed and the average solar radiation at Aralvaimozhi are 7.16m/s and 5.05kWh/m2/day respectively. Aralvaimozhi has been spotted as a potential wind farm location according to Government of Tamil Nadu. Figures 1.1and 1.2 represent the solar energy and wind energy availability in Warrnambool, Australia, and Aralvaimozhi, India. The solar energy radiation and wind velocity were noted from the

NASA surface and solar energy database while the wind velocity at Aralvaimozhi was noted from a wind site near Aralvaimozhi from an engineer, Indowind Energy Limited [2].

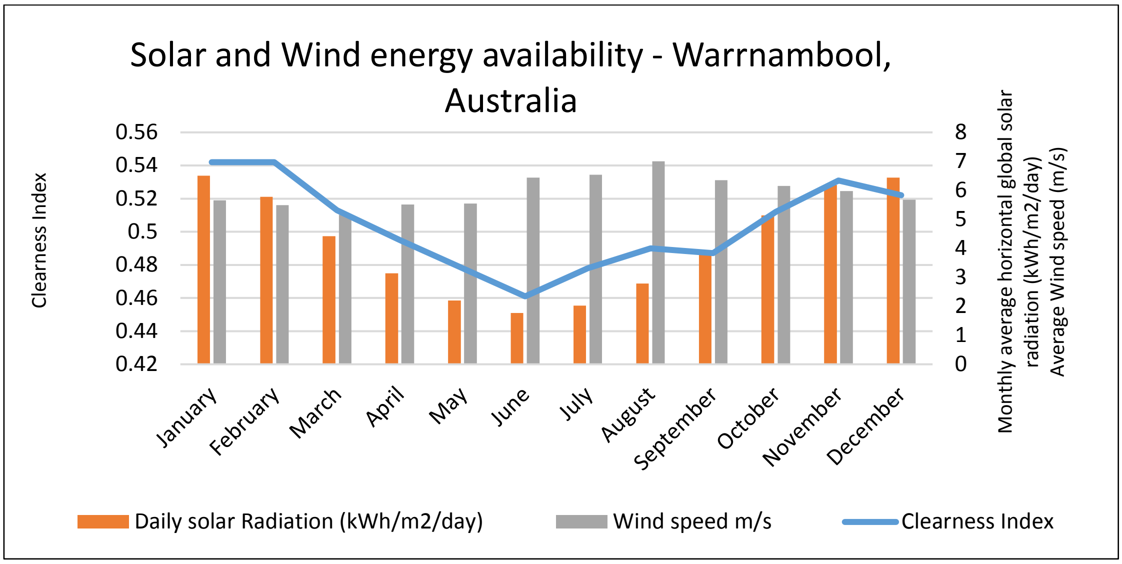


Figure 1.1 Solar and Wind energy availability in Warrnambool, Australia

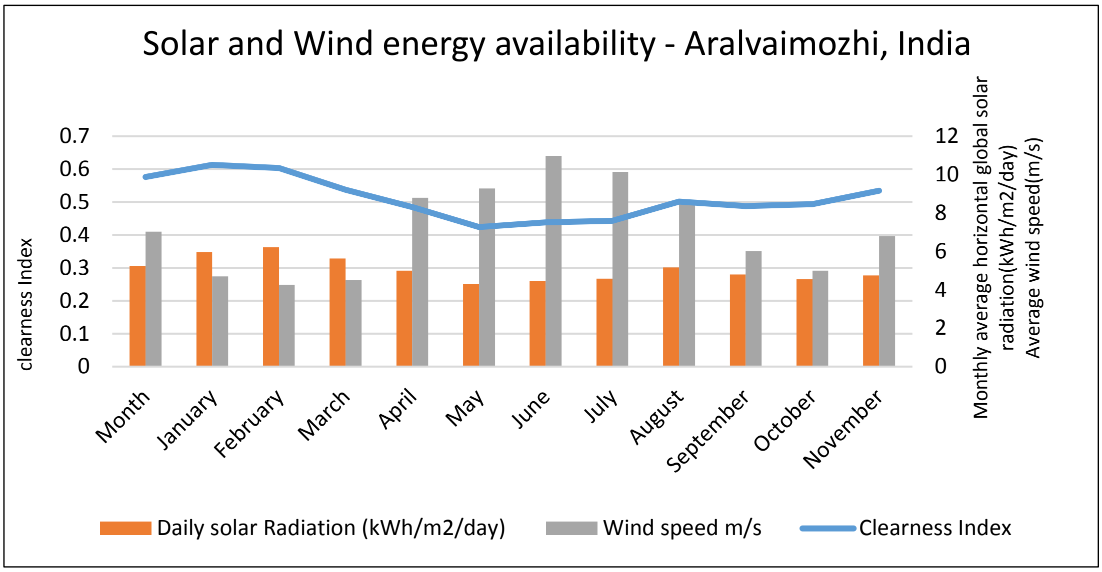


Figure 1.2 Solar and Wind energy availability in Warrnambool, Australia

1.5 Result Analysis using Triple Bottom Line (TBL) analysis techniques

Several case studies in the literature have been conducted for different locations, including hotels, universities, isolated villages, etc. While this study; though aims at sizing the RES it will contrast the RE scenario from Australia and India perspectives.

Although energy policies laid by the government are distinct, the acceptance of these policies in expanding the RE applications and the barriers in this expansion will be discussed. The people's acceptance in integrating the RE will be analysed to understand and make this project practical. Figure 1.3 represents the step by step procedure of the methodology involved in this study.

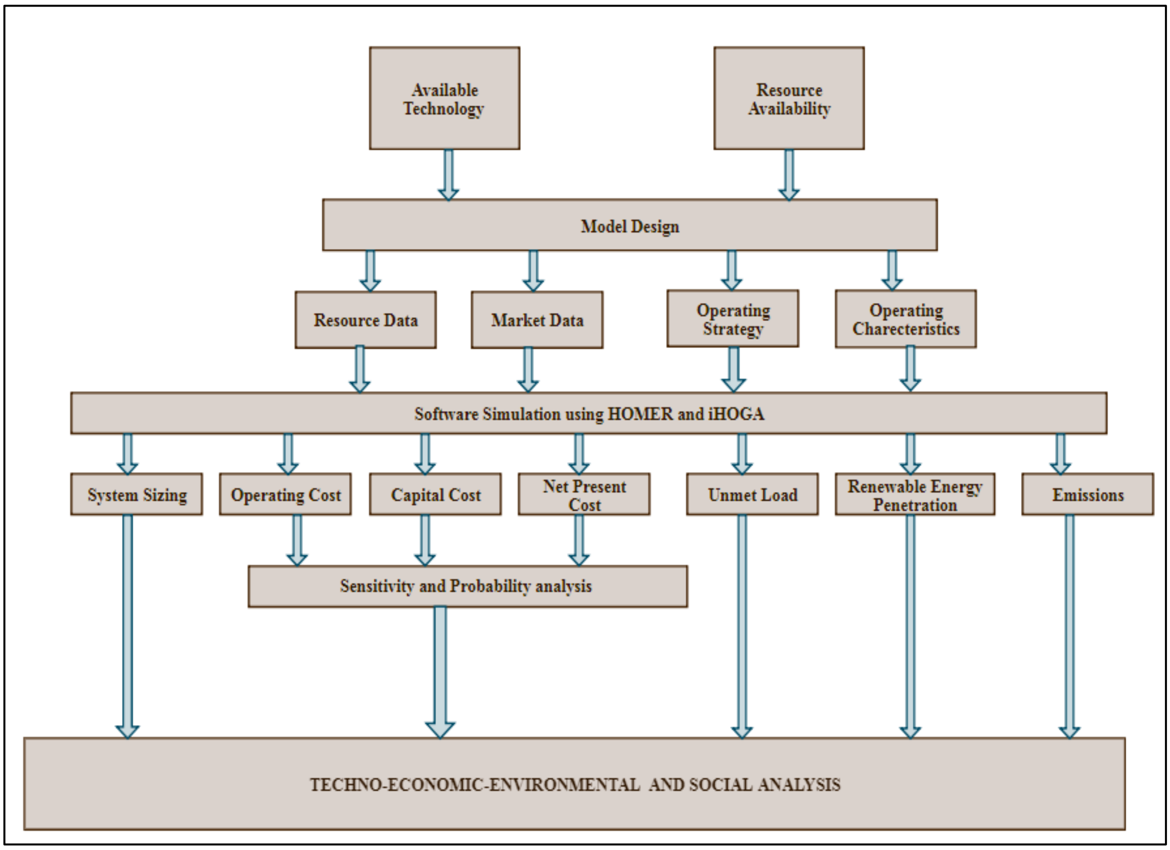


Figure 1.3 Methodology: Triple Bottom Line Analysis

- *Electrical load analysis*

The electrical consumption of a household and commercial building differs according to the nature of consumption and the location of the place considered. For a country like India which has a tropical climatic condition, the energy consumption is primarily due to lighting and electronic equipment (e.g. television, fan etc.) whilst for a commercial or residential building in Australia electricity consumption is due to heating/cooling along with the usage of electronic gadgets. It should also be noted that the Indian scenario of load shedding which happens as a daily routine is also a motivation to integrate RE sources in the places where the availability is abundant. Electrical load analysis is the crucial task in designing an RES as any underestimating or overestimating the load may result in an overpriced setup or unmet load either of which is dangerous. Thus, critical scrutiny of the energy consumption for a minimum of one year is desired to understand the energy consumption trend.

- *Ascertain the RE behavior*

RE sources are not uniformly distributed nor can their behavior be predicted accurately. A very indispensable understanding of the RE source is an ultimate task. A long-term weather report needs to be analysed before designing the RE setup. This information can be procured from NASA meteorology database. The information analysis would lead to understanding the desired RE setup. Critical examination of solar energy map and wind energy availability for the desired location will be analysed to design the setup.

- *Designing the model for the RE system*

There are two possibilities to design a RE for a micro-grid, and they are:

1. Grid-Connected: The grid-connected system takes additional support from the grid instead of RE storage devices and can feed the excess RE generated if any, to the grid through net metering and create revenue in the form of Feed-in Tariffs (FiTs).
2. Stand Alone: A stand-alone system is a completely isolated system from the grid and can independently match the load requirements through energy storage systems, like a battery. However, the existence of a battery as energy storage would make the system bulky.

This work includes a grid-connected Hybrid Renewable Energy System (HRES) along with the battery storage to efficiently utilise the RE sources. The configuration also helps in meeting the load demand in the absence of the RE through storage systems like batteries and an A.C. grid.

- *Choosing the Performance indicators*

The performance indicator has to be chosen to size the desired RE set up (This will be explained in detail in Chapter 2). This includes: Expected Energy Not Supplied (EENS), Net Present Cost (NPC) and Annualised Cost of system (ACS) and gas emissions. The chosen performance merits serve both technical and environmental viabilities for the desired project.

- Market Data

  Choosing the current market price of the energy systems considered and electricity price for both the countries to perform the economic analysis is an important task. Consulting the installation companies and comparing their competitive prices for integrating RES including the labor and other installation costs are to be incorporated into the analysis. This study comprises the project lifetime to be more than a decade; hence the inflation rates and bank discount rates are involved in addition to the predictive changes in the market prices of the system components.

- Software simulations using HOMER and iHOGA

  HOMER and iHOGA are the software to be considered for nonlinear and multi-objective analysis. These two software packages can be used to simulate a large number of distinct technologies and the variation in technological costs and availability of energy resources which would otherwise result in the decision making arduous.

  a. HOMER: To design a micro-grid, different configuration choices are to be considered. These could include design of the system components, size of the components etc. When it comes to decision making, there are many options which depend on technology options and the availability of the energy resources. HOMER software has optimisation and sensitivity algorithms which make the options for evaluation easier. HOMER also simulates the operation of the system by making energy balance calculations and displays configurations which can be used to decide which system configurations to use and also help in comparing the same to the design [3].

  b. iHOGA: iHOGA optimises a HRES using Genetic Algorithms. The program can be used to optimally size the system according to the number of panels and type of the panels, inclination of the panels, type of wind turbine and hub height, number of batteries etc. Like HOMER, this software can optimise the solution according to NPC and other related costs of the system, however iHOGA can do multi-objective optimisation including system emissions.

However, unlike HOMER, iHOGA optimises despatch strategy along with SOC set point.

1.6 Thesis Organisation

The thesis comprises of nine chapters which are organised as shown in Figure 1.4.

- **Chapter 1-Thesis Overview**

  This chapter provides the synopsis of the research. It emphasises the aims and objectives of the research. The original contribution including the practical and academic contribution is defined. A brief review of each chapter in the thesis highlighting the essence of each chapter and organisation of the thesis is provided.

- **Chapter 2- Literature Review**

  This chapter highlights the works which have been developed in academic research and industries showcasing the role and importance of RE in the micro-grid. The challenges involved in adopting the RE technology and contextual studies from the literature are studied. Understanding the RE availability in India and Australia; the current status of RE adoption in India and Australia is reviewed. Importance of sizing of RE adoption and different methodologies used for RE adoption is also examined. The shortcomings of the study undertaken in the literature survey conducted have been summarised and the contribution of this research to overcome these shortcomings are highlighted.

- **Chapter 3- Role of HOMER and iHOGA in HRES Design and Optimisation**

  This chapter introduces the role of the two software packages HOMER and iHOGA used in this study. The two software packages use different methods to size the HRES optimally. However, both the software packages consider NPC as the essential economic criteria for optimisation. The working methodology and modelling of HRES of both the software and their advantages are analysed. Subsequently, investigation on the different case studies using these software packages in the recent years is conducted.

- **Chapter 4-Renewable Energy Policies Assessment**

  To ascertain the RE adoption, exploring the RE Policies and its current situation is necessary. This Chapter focuses on the RE Policies globally, in India and Australia in particular and its importance in RE adoption. Exploring RE Policies of Australia and India, and their statuses are discussed. The means taken by both the countries to achieve their respective targets, e.g., Renewable Energy Target (RET) of Australia and National Solar Mission (NSM) by India are explored. In contrast, a review of the RE Policies of developed countries (e.g., USA, Germany, and Denmark) are conducted. Understanding the advantages of FiTs using HOMER software is conducted for an Australian case study. The drawbacks of Australia and India in terms of RE development are explored.

- **Chapter 5- Simulation and Analysis for sizing and optimisation using HOMER And iHOGA**

  This chapter investigates the modelling, sizing, and optimisation of the HRES for specific Case Studies in Australia and India. The electric load of university and community in Australia and India respectively are considered; for the available RES, optimum sizing of HRES is performed using HOMER and iHOGA software. The market data from the suppliers and engineers at these locations are considered. This data is used for the economic analysis of the HRES in Australia and India. Finding the compatibility between the results obtained from both the software packages is the main objective of this Chapter. Comparison of the optimised results produced by both the software packages and analysing the discrepancy in their result (if any) is also another aspect of this Chapter.

- **Chapter 6- Probability and Sensitivity analysis using iHOGA software and Triple Bottom Line Analysis of the results**

  For the optimised set of results found for both the case studies, the probable variation in the load and HRES prices are discussed. The influence of these probable variables on the Techno-Economic aspect of both the case study areas are analysed. Consequently, for the optimised set of results found for both the case studies, the Techno-Economic analysis considering the sensitive variables like wind speed, solar radiation, inflation rate are discussed. The influence of these probable variables on the Techno-Economic aspects are highlighted for the case studies. This chapter concludes with the TBL analysis (Techno-Economic, Environmental analysis, Social factors) of optimised results. The TBL analysis consists the analysis of the price of the RE technology and the NPC of the total system as Techno-Economic analysis. The environmental analysis includes the discussion on the poisonous gas emissions on integrating the HRES into the micro-grid whilst the social analysis consists of job creation and Human Development Index (HDI) factor when the HRES is integrated to a micro-grid.

- **Chapter 7- Experimental Study of a prototype HRES at Victoria University Footscray Campus: Part -1**

  This chapter summarises the experimental study of HRES conducted at VU and is separated into three sections:

  a. The first section of this chapter introduces the preliminary study of the available HRES already connected to the VU grid (without battery storage units).
  b. The second section describes the upgraded HRES set up, and scrutiny of the working of the individual system in the micro-grid.
  c. The third section is the experimental study of HRES setup connected to the different load values, data collection, and analysis with the 4 sets of available batteries.

- **Chapter 8- Experimental Study of a prototype HRES at Victoria University Footscray Campus: Part -2**

  This chapter is the continuation of the previous Chapter 7. Four new Century AGM batteries (aiding to the additional discharge of power to the load) each of rating 12V, 270Ah were added of the existing model (discussed in Chapter 7). Experimental study of HRES setup connected to the different load values, data collection, and analysis with the 8 sets of upgraded batteries for various scenarios have been discussed. Currently, the utility grid supplies energy to the Campus and helps meet its energy demands. The overall performance of HRES connected to the micro-grid is also analysed.

- **Chapter 9- Conclusion and Future work**

  This chapter summarises the research study and the results achieved in meeting the aforementioned aims. Optimum sizing of HRES for both the case studies and exploring the benefits of possible adoption is emphasised. The importance of possible adoption of RE and hurdles in meeting them in Australia and India are reviewed. This chapter also focuses on the possible future work this research may lead to in detail.

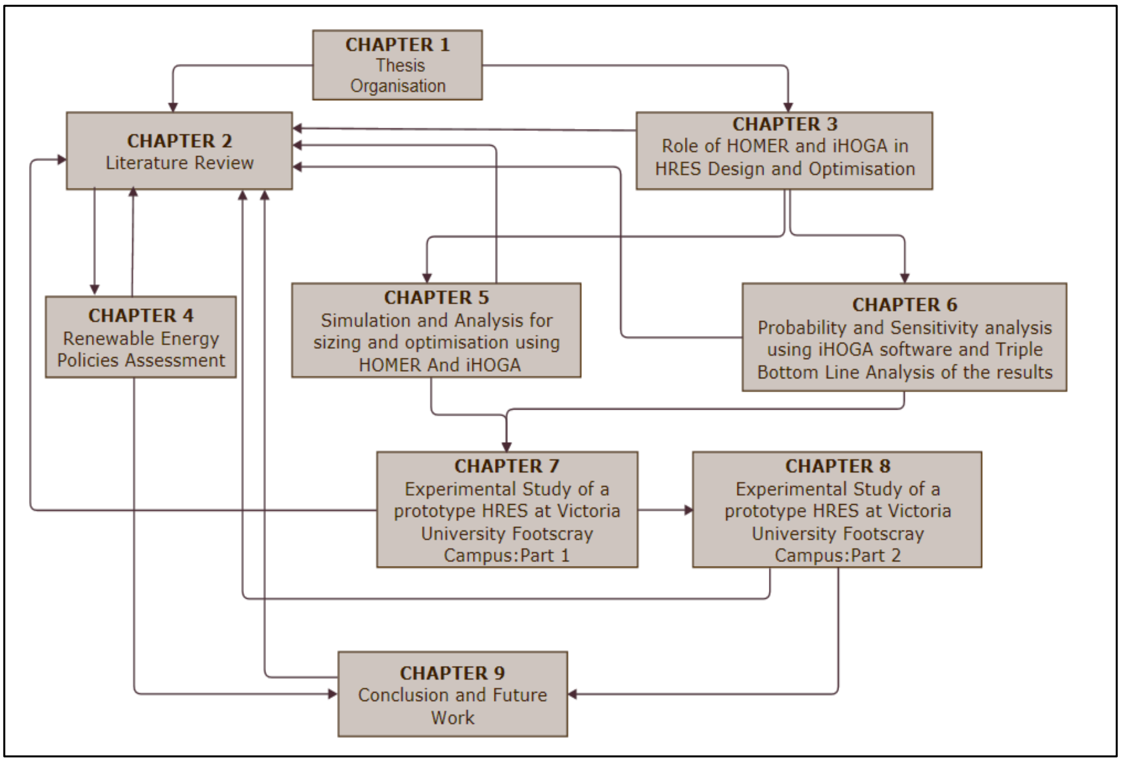


Figure 1.4 Thesis Organisation

1.7 Summary

To mitigate GHG emissions, application of RES in micro-grid has been regarded as a model for a small community and university building in India and Australia respectively. The HRES is modelled using HOMER and iHOGA software packages for both the locations and the economically optimised solution is discussed. For a grid connected system, some amount of inflow of revenue through FiTs occurs due to the energy penetration to the grid from HRES. However, this grid connected HRES configuration could lead to problems in times of grid failure. Although, complete reliance on the stand-alone system could result in unmet load during peak load demand or could terminate in larger sized HRES. Considering these factors, battery connected to the grid through RES has been explored in this research. Factoring the FiTs (which are fluctuating), rebates provided by the respective Governments, stochastic behaviour of RE, HRES is modelled to answer the aforementioned ambiguities. In the last few years the RE sector has made such remarkable progress that, RE can be used as the primary source of energy thereby reducing CO2 emissions and resulting in green energy solution.

Chapter 2

Literature Review

2.1 Introduction

2.2 Global Energy Status

2.3 Distributed Generation

2.4 Renewable Energy and its Availability

2.5 Renewable Energy Scenario in Australia's context

2.6 Renewable Energy Scenario in India's context

2.7 Electrical Load Analysis

2.8 Renewable Energy Integration for a micro-grid

2.9 Performance Indicators

2.10 Optimum Sizing Methodologies

2.11 Shortcomings in the literature survey and contributions from this research work

2.12 Conclusion

2.1 Introduction

The electrical grid is evolving over time, and this is due to the various types of power generations involved in the energy mix. There is a need for an energy source that is reliable, indispensable and easy to use. This source must be helpful in mitigating the GHG emissions. As the conventional energy sources are depleting and the energy market is volatile, there is a continuous focus on an alternative energy sources. The power network is being confronted with many challenges in the transmission and distribution sectors to satisfy the electrical load requirement. This is due to the unpredictable variations in the weather seasonally and on a day to day basis. There is a definite need to address these issues. RE has become a promising technology that has evolved itself to meet the aforementioned issues faced by the conventional energy sources. This chapter presents a roadmap of RE development and its adoption into micro-grids over the time in a global scenario. Subsequently, it focuses on RE scenario of the case study areas: India and Australia. The chapter also elucidates the state of art study in the analysis and classification of sizing methodologies used to size RES, which depends on the load demand and the location of the place where the RES must be adopted.

2.2 Global energy status

Energy is very crucial to a country's progress. It is the basic requirement for a country's economic growth and development and its progress. Continuous or inexhaustible availability of energy, its affordability, energy security, easy accessibility as well as being environmentally friendly are the significant aspects that reflect upon the country's economic growth. Every sector of the economy is dependent on energy per capita energy consumption of a country has a direct correlation with the standard of living. In recent years, the energy crisis is ascribed to a surge in population and an improved standard of living. The per capita energy consumption is also directly correlated to two factors, per capita income and a nation's prosperity. Energy is very much needed for productive activities such as commerce, manufacturing, industry, mining, and agriculture. On the other hand, poverty, deprivation of leading a quality life would consequently impact the economic status quo [4]. Increase in the use of energy and reduction in poverty have a very close connection, which is the development in the socio-economic spectrum that involves an increase in productivity, the growth of income, education and improved health [3]

A country's Gross Domestic Product (GDP) is indirectly dependent on the energy while the choice of the energy reflects on the environmental impact of the country. Thus, Energy, Economics and Environment are entangled to understand a country's progress. This section gives an overview of the energy status of the world and the top players in the world energy production and consumption. It provides an insight into the position of the world energy trend and helps in understanding the means taken by the different countries to reach their energy efficiency.

a. World Energy Production

   The world energy production has seen to be escalating, however, approximately a decent of 2.4% of the global energy production was observed since 2017. China's coal production escalated compared to its coal production trend since 2014. The global energy production declined due to the increase in the oil and gas prices. This trend was observed due to the countries like European Union (EU) focusing on the alternate methods due to the depletion in the availability of these resources and trying alternate energies due to the awareness of environmental impact; these energy resources were resulting by means of strict energy policies. A further decline in the primary energy production like hydro and nuclear energies is observed. Thus by the end of 2017, the world noticed a decline in the energy production through fossil fuels through countries like EU. Although, in 2017 the increase in the energy production was observed mainly by the developing countries like India, Brazil, Turkey, etc., and other oil and gas exporting countries like Russia, Canada. Table 2.1 summaries the top players in the energy and electricity production and consumption globally [5]. China, US, and India have been the top three players in the electricity production and consumption.

b. World Energy Consumption

   In terms of energy consumption, it is observed that China's energy consumption has reduced. Drastic uptake in energy consumption was due to the economic rebound in China which has been the largest consumer of energy since 2009, which triggered a sustained growth in the economy. Energy consumption in China jumped two-fold in 2016; which was due to strong industrial demand. This jump in consumption compensated for the previous three years of low consumption. Energy consumption has been on the rise in most Asian countries. India has seen steady growth since 2000 and the same for other countries like Indonesia, Malaysia, and South Korea. Since 2013, Japan has also seen an increase in energy consumption which has been driven by economic growth. Economic growth has been a cause of the increase in energy consumption in Europe with Germany, Italy, and Turkey being the main drivers. A similar trend has been observed in Canada and Russia. The United States has seen stable energy consumer for two years running and this has been due to a decrease in electricity demand and an increase in energy efficiency. Energy consumption has increased in Brazil after a few years of decline and has reduced in Argentina and Mexico [5].

Table 2.1Top countries energy and Electricity Producers and Consumers in the world [5]

Total Energy Production		**Total Energy consumption**		**Electricity Production**		**Electricity Consumption**	
Countries	**Mtoe**	**Countries**	**Mtoe**	**Countries**	**Twh**	**Countries**	**TWh**
China	2499	China	3105	China	6,529	China	5683
United States	2018	United States	2201	United States	4,251	United States	3808
Russia	1418	India	934	India	1541	India	1156
Saudi Arabia	652	Russia	744	Japan	1101	Japan	1019
India	596	Japan	429	Russia	1090	Russia	889
Canada	504	Germany	314	Canada	712	Canada	572
Indonesia	429	South Korea	296	Germany	653	South Korea	534
Iran	401	Brazil	291	Brazil	585	Germany	531
Australia	386	Canada	287	South Korea	579	Brazil	522
Brazil	293	Iran	253	France	551	France	445
Nigeria	250	France	243	Saudi Arabia	345	Saudi Arabia	311
United Arab Emirates	229	Indonesia	240	United Kingdom	336	United Kingdom	305

The Global Energy consumption trend is shown in Figure 2.1. The trend shows that the energy consumption of the world has considerably increased since 1990, with 8,761Mtoe in 1990 to 14,126Mtoe in 2017. A similar trend has been observed in the electricity consumption being double to 22,106TWh in 2017 compared to 1990. There has been a greater dependence on the fossil fuel to source the daily needs. Coal and lignite has consistently been the primary source of energy in the past three decades. This ever-increasing energy consumption is attributed to the population explosion and daily demands in the reliability of energy from increase in population.

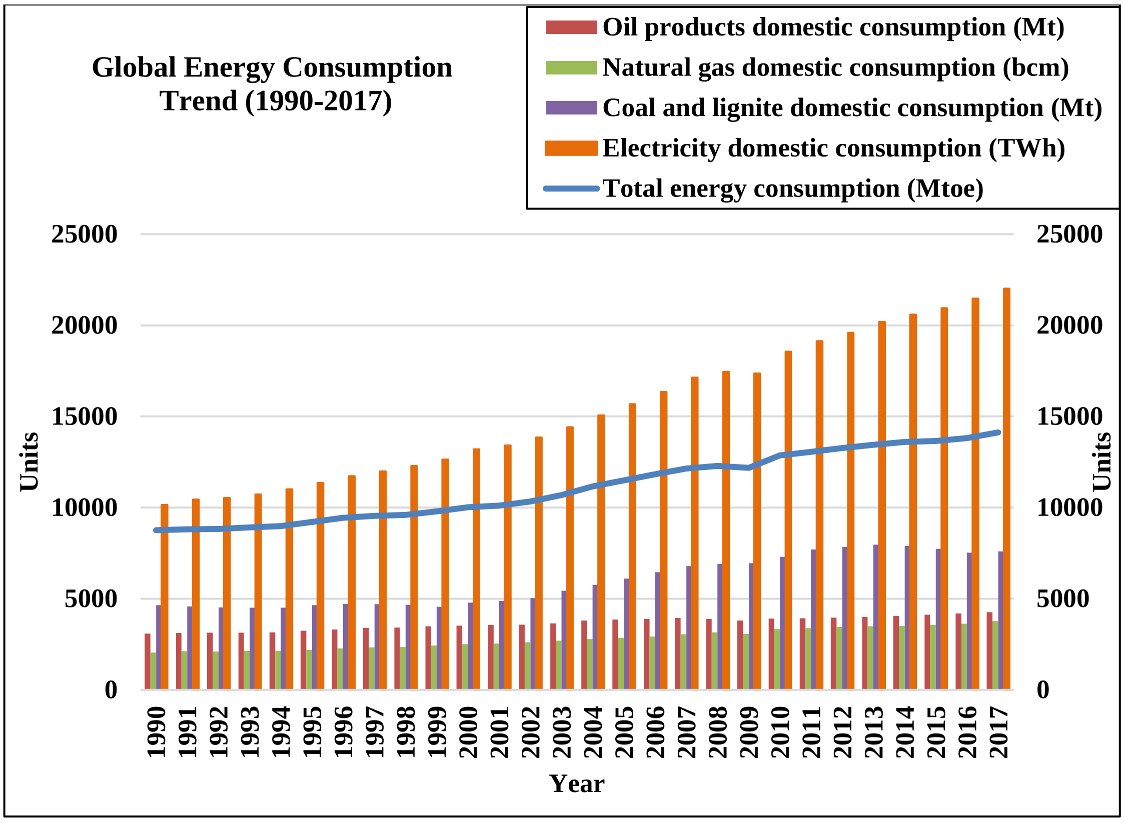


Figure 2.1 Global energy consumption trend 1990- 2017 [5]

(Permission taken from Enerdata to access the data available)

Figure 2.2 illustrates the share of the RE in the electricity production since 1990. Since the year 2000, the trend shows that the global RE share in electricity has been consistently increasing. However, the Latin American countries produce a maximum share of RE. In 2017, nearly 25% of the energy production was from RE while the rest 75% was from the fossil fuel.

From the trend discussed in Figure 2.1 and Figure 2.2 it can be understood that due to the escalating population, the energy consumption is high over time, the dependence on fossil fuels still prevails. However, the increasing awareness of adopting to RE, through stringent energy policies has aided in RE dependence.

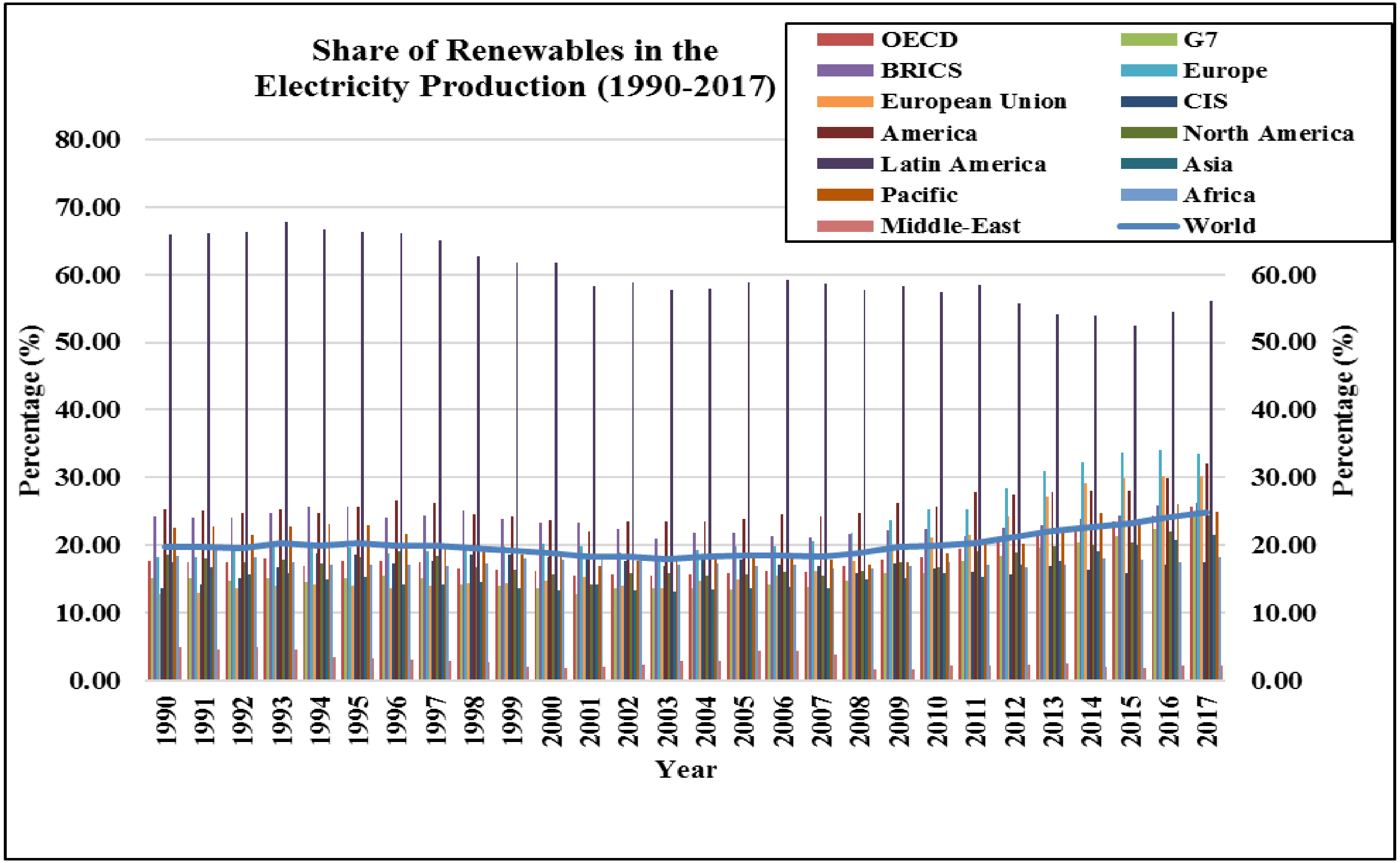


Figure 2.2 RE share in the electricity production (from 1990 to 2017).
(Permission Taken from Enerdata to access the data available)

2.3 Distributed Generation

Distributed generation (DG) unit shown in Figure 2.3 is a cluster of small energy resources at a given site of consideration. These units widely comprise of PV, Fuel Cell (FC), WT and other energy resources along with internal combustion engines accompanied by generators. This implies that either fossil fuels or alternate energies act as the energy providers [6]. According to the nature of DG, converters and/or inverters are included to provide better compatibility to the voltage and frequency when connected to the grid in the design. The complete micro-grid design comprises of a protection system to complete the setup and parallel and disconnect from the electric power system. The application of distributed storage has been widely studied including batteries, flywheel, supercapacitors, etc. to satisfy the generation and the load [7, 8].

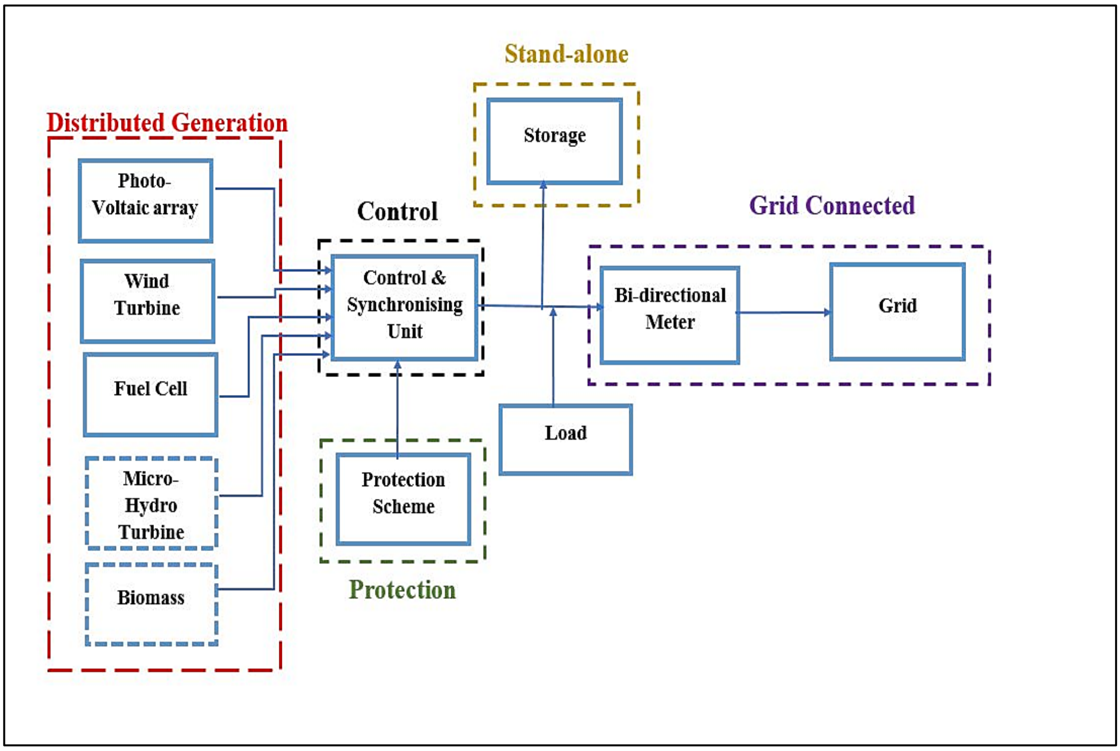


Figure 2.3 Block diagram of a micro-grid

Distributed Energy Resources (DERs) or Hybrid Energy Systems (HES) for DG have enormous benefits in the working of a micro-grid system. The application of DERs has the potential to reduce demand for distribution and transmission facilities. This clearly shows that if the DG is located near to where the load is needed, then it will reduce the flow of transmission and distribution circuits. This can reduce losses and also act as a replacement for network assets. The presence of generation close to demand can also increase the quality of service experienced by the end consumers. In times of stress on the network, micro-grids can help in alleviating network congestions and can also help in restoring power after a fault event. In terms of reduction of emissions, micro-grids can contribute positively in this area; as well, the concept of micro-grids revolves around generation units being based on renewables and other micro sources which are of low emissions [9, 10].

DG could be considered as one of the effective and efficient ways to exploit the advancement in energy generation technologies as compared to individual generators. However, they present many complications as it involves several types of generations. Contemplating to the fact of exploiting different types of energy sources, these can help in meeting the associated loads and minimising the problems related to the economics of the conventional generator by integrating them into a single entity called a micro-grid. The concept of micro-grid helps in achieving greater penetration of DG without needing to overhaul the existing distribution systems completely. DG thus involves different types of energy sources, they also help in the process of using heat recovery and improve the power quality for specific loads for a micro-grid [11]. Though DG and micro-grid is not a new concept, there have been several contemplations involving RE as DG. The renewed interest in the RE adoption due to energy deregulations and environmental benefits around the world has helped in the development of such micro-grids. DG cannot be integrated into a micro-grid without examining the type of available energy sources and their viability for a geographical location. This analysis can be achieved using optimisation techniques that has been suggested in [12].

Despite the aforementioned advantages, there are several challenges faced in adopting a micro-grid technology, for example, fault detection, islanding mode operation, etc. [6, 13]. The micro-grid has not been clearly defined with respect to the size of the DG. However, the localisation and the level of autonomous operation with respect to the transmission grid defines it [14].

Advantages of DERs for DG

There are many advantages in integrating DERs for DG in micro-grid, they are:

- The presence of DER in an independent micro-grid would ease the dependence on the national electricity grid by reducing the transmission of electricity from the generation site to the consumer [14].

- The presence of HES as DERs in DG helps in encompassing the daily and seasonal variations thus increasing the system accessibility.
- Such systems help in reducing the reliability on fossil fuels [10], leading to least impact on fuel price fluctuations.
- Considering the stochastic behavior of the HES, one resource supplements the other resources when they are less available.
- This results in efficient energy output, thus reducing the reliability of the storage units.
- By reducing the reliability of the storage units and consideration of HES in the micro-grids, a reduction in the COE of the system can be achieved.
- These systems are quite often employed in areas where there is an inconvenience to access the grid, and these systems are also observed to reduce the reliability on the grid.

2.3.1 Applications of HES as DG in a micro-grid

There are a range of applications of HES used for micro-grid applications; they are as follows:

i. Application of HES started with power supplying facilities mainly for irrigation purposes, which further developed in the application of water desalination, purification, etc.
ii. HES are vastly used in providing electrification to the remote villages where there is difficulty in grid accessibility.
iii. HES is also observed to be used in industries and telecommunication sites etc.
iv. There have been broad applications of HES to provide back-up during the grid failure or blackouts.
v. The application of HES, mainly the application of RE has been observed in hospitals, school building, hotels and also during the electricity crisis for lighting purposes.

However, it is also observed that the diesel generator was a part of DG units initially, has now been gradually substituted by alternate energy sources including combined cycle power plants [15]. A more extensive application of RE systems as DG called as Hybrid Renewable Energy Systems (HRES) is coined.

2.4 Energy Storage Systems used in a micro-grid

Energy storage systems are commonly used in the micro-grids to improve the power quality and energy management functions. The presence of energy storage has improved the efficiency of the micro-grid system; thus increasing the reliance of the system due to its capability to store the energy for reserve. There are different energy storage systems used in a micro-grid when RE is integrated; they are as follows:

a. *Pumped hydroelectric storage system*: This is the most primitive form of energy storage known to mankind. It consists of two reservoirs (or tanks) at a different level. The water from the lower level reservoir can be pumped up to the higher level reservoir, to be stored there. The difference between the heights of the reservoirs decides the energy storage capacity of the system. These storage systems have proven to have an efficiency between 65- 85%. The only drawback of the hydroelectric storage system is its site availability to build the reservoirs and its high capital cost.

b. *Batteries*: The most commonly used storage system is the batteries. The different types of batteries and their salient features are highlighted in Table 2.2.

c. *Fuel Cell (FC)*: FC comes under the indirect energy storage systems. Although FC is electrochemical energy devices with the constructional feature similar to battery energy storage systems, the principle of operation varies. The energy generated by a FC is due to the fuel consumption (hydrogen, ethanol, methanol, and hydrocarbons). The working principle of FC is comparable to the working of a battery. Hydrogen stored in an external system is released according to the requirement to produce electricity. Water and heat are the other end products of the electro-chemical reaction that takes place within the reactants. During this reaction process, the reactants flow in; while the products of this reaction flow out, and the electrolytes remain in the FC. Depending on the different types of electrolyte and the fuel of the cell, there are different varieties of FC, they are Proton exchange membrane FC (PEMFC), Direct methanol (DMFC), Direct ethanol (DEFC), Phosphoric acid (PAFC), Alkaline Fuel Cell (AFC), Molten carbonate (MCFC), Solid oxide (SOFC).

2.5 Renewable Energy and its Availability

REs are the energy sources which do not get depleted and are naturally replenished over time. They are either directly (solar energy) or indirectly (wind energy, bioenergy) produced form Sun or by any other naturally occurring mechanisms (tidal, geothermal energies). They do not include any conventional energies like fossil fuel or oil. RE technologies tap the available sources and convert them into other usable energy (like electricity). It is understood that the RE can supply approximately 3,078 times the present energy needs of the world [16]. The ability of the RE resources available to meet the world demand is shown in Figure2.4. Globally, the predominant source of RE is solar, while the wind is the next available RE source globally. Biomass, geothermal, marine and hydro energies are least available RE compared to solar and wind energies.

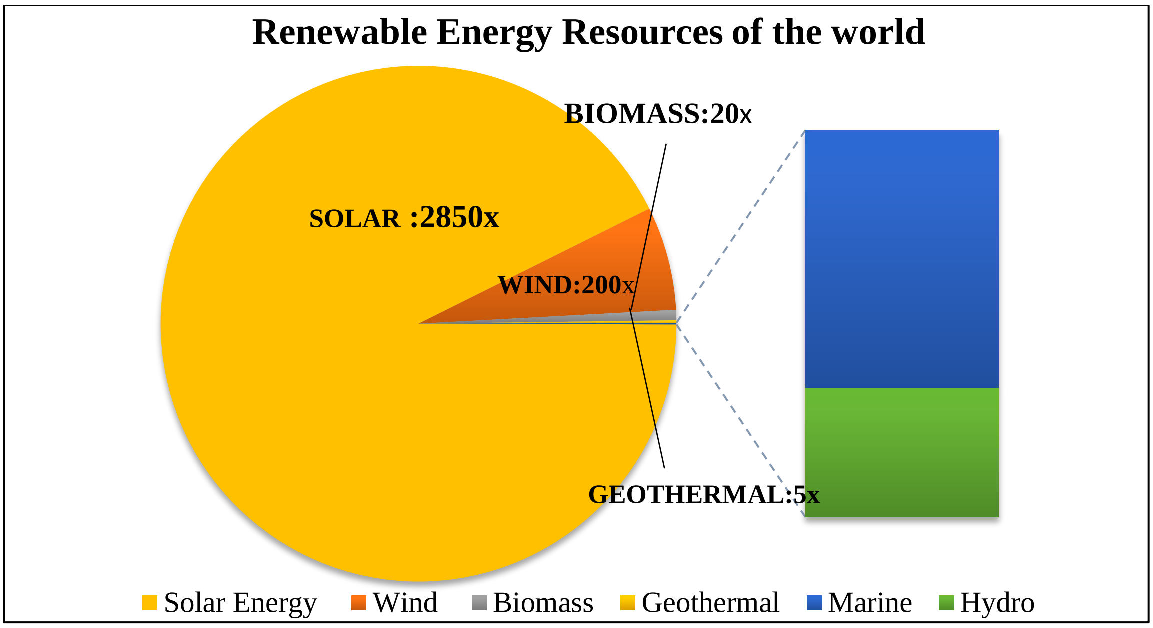


Figure 2.4 Illustrates the ability of renewable energy sources to provide over 3000 times the current global energy needs [5].

World energy demand has been projected to exceed 800 EJ by 2050. Reviewing the present scenario of escalating oil prices, RE is a promising alternate energy option [17]. International Energy Agency 2015 (IEA 2015) reports the contribution of power generated through wind, solar and hydro adding up to 45% globally in 2014 [18]. To meet the global demand, RE is expected to mature over next five years and would reach 12.4% in 2023 (according to IEA 2018 [19]).

Table 2.2 The different storage systems and their salient features [20-22]

Storage System		Properties	Working Process
Batteries	Lithium ion	• Used in high power and low power devices, • The highest energy density of 110-140Wh/kg, • Specific energy 170-300Wh/l, • Fast charge and discharge ability, • Low self-discharge rate, • Expensive.	Anode: carbon graphite Cathode lithiated metallic oxide $$LiCoO_2 \leftrightarrow Li_{1-x}CoO_2 + xLi^+ + xe^-$$ Negative electrode: $$xLi^+ + xe^- + C \leftrightarrow Li_nC$$
	Nickel Cadmium	• Rechargeable batteries, portable, • High energy density and large life cycle, • Expensive, • Due to the metallic material, disposing of the batteries may have a negative impact to the environment, • Memory Effect-Battery has to be completely charged and discharged.	Cadmium electrode reaction: $$Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$$ Nickel electrode Reaction $$2NiO(OH) + 2H_2O + 2e^- \rightarrow 2Ni(OH)_2 + 2OH^-$$ Net discharge reaction: $$2NiO(OH) + Cd + 2H_2O \rightarrow 2Ni(OH)_2 + Cd(OH)_2$$
	Sodium sulphur	• Expensive, • High energy density, • High operating temperature (270-3000C), • High depth of discharge, larger life cycle.	Inside the casing of the battery exists the electrolyte of NaS, this is a BASE membrane also referred as beta-alumina solid electrolyte. This solid electrolyte selectively allows positive ions of Na^+ ions are initiating an electrochemical reaction with the sulphur to produce sodium polysulphides (Na_2S_4).

	Lead Acid (LA)	• Most commonly used rechargeable batteries (mostly used in household and commercial buildings), • Cheaper, reliable, extended lifespan, fast response, • Efficiency (70%-)90%, approximately 5 year lifespan (or 250/ 1000 charge/discharge cycles), • There are two types of LA batteries flooded lead-acid (FLA) and valve regulated lead acid (VRLA) batteries.	The electrons migrate in the LA during the charging to the negative plate from the positive plate, while the reverse occurs in the discharging process. During the discharge of the batteries, the electrodes become lead sulphate resulting in dilution of sulphuric acid and producing excess water. However, with the timely maintenance of such batteries (flooded batteries) by replacement of distilled water is often observed.
	Sodium Nickel chloride	• Rechargeable, • High energy density, sustainable efficiency, • Better performance at low temperatures.	Cadmium electrode reaction: $$Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$$ Nickel electrode reaction: $$2NiO(OH) + 2H_2O + 2e^- \rightarrow 2Ni(OH)_2 + 2(OH)^-$$ Net discharge reaction: $$2NiO(OH) + Cd + 2H_2O \rightarrow 2Ni(OH)_2 + Cd(OH)_2$$
	Flow Batteries	• Also called redox batteries, • Mostly used in power applications • Expensive • Operation and maintenance cost is high	Flow battery works like both FC and electrochemical battery. These batteries are rechargeable fuel cell batteries with the electrolyte present externally. These electrolytes are pumped through the cell (having the ability to convert chemical energy to electricity).

RE is expected to meet the global power demand of 30% by 2023.

Figure 2.5 illustrates the global RE scenario by 2040. It forecasts that by 2040 RE will approximately have half of its share in energy supply with significant advancements in PVs and wind energies in addition to biomass [23, 24].

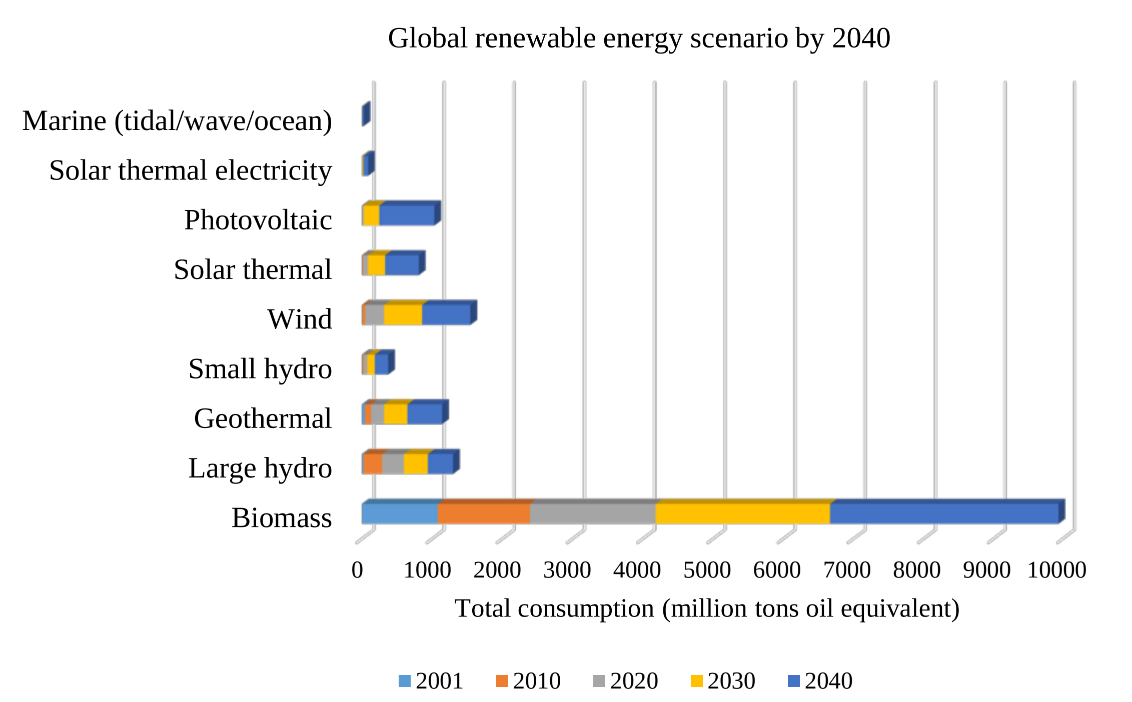


Figure 2.5 Global Energy Scenario by 2040 [23]

A renewed focus on RE is due to its sustainable nature; a means to mitigate the GHG emissions while the conventional energy market gets volatile [25, 26]. Due to the government's planning and promotion of RE, a more extensive job market and economic improvement have been established [27]. This has resulted in exploring diverse RE sources, in particular, improve access to energy in rural areas [28-30]. With these benefits targeting RE, a technological advancement over time would play a pivotal role in thrusting the RE in the energy market [31]. While understanding the importance of RE in the current scenario, it is equally important to discuss the RE availability status in the world, which will be discussed in Section 2.5.1.

RE, which originates from inexhaustible energy sources, provides the biggest challenge to the existing conventional energy source. The years between 2014 to 2024 have been declared as the Decade of Sustainable Energy by the United Nations. This is due to the stupendous growth of RE as seen in the past few years [32]. The RE will change the energy market and would gradually encroach on the present conventional energy systems; the year 2016 was an example to this. In 2016, EU presented 86% of renewable installations whilst China topped the global RE adoption. Emerging economies and developing countries will be the leading operators for RE adoption with more the 50% of the investments. Figure 2.6 elucidates the RE growth seen globally in the year 2016 compared to 2015. Like the usual trend, hydropower capacity was 1096TW in 2016 when compared to 1071TW in 2015. Wind and Solar PV capacity raised to 487GW and 203 GW in 2016. There was not much increase in the Biopower capacity and Geothermal power capacity. However, they remained to be 112GW and 13.5 GW respectively. Thus there was a consistent increase in the RE capacity by 92% (from 1856GW to 2017GW).

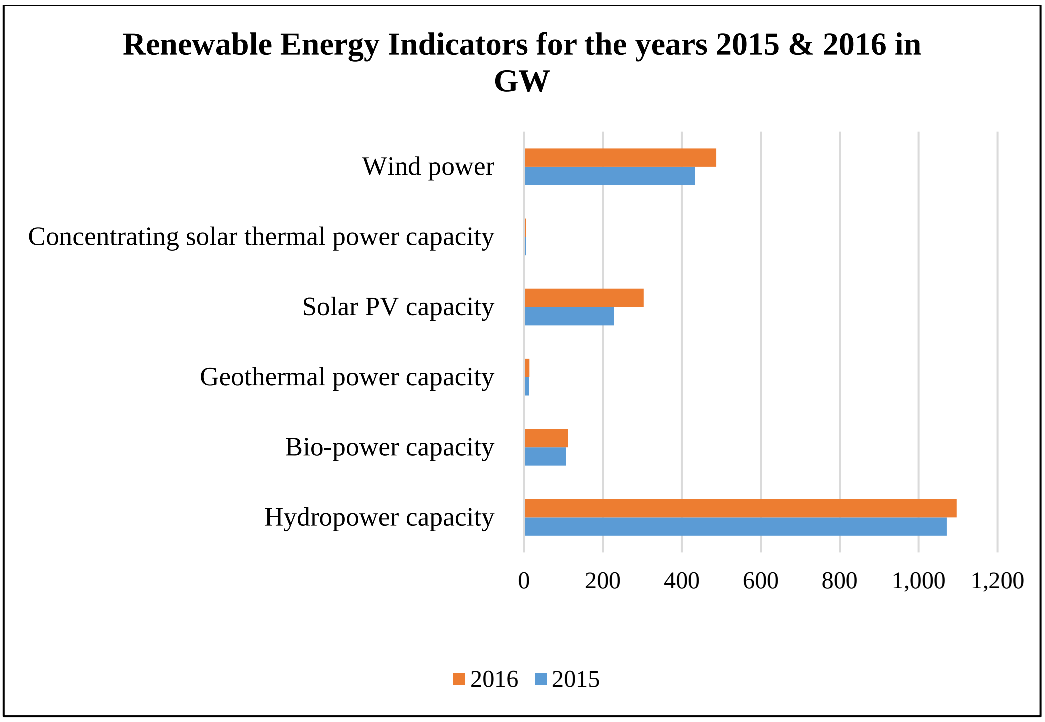


Figure 2.6 Renewable Energy Indicators for the years 2015 & 2016 in GW

2.5.1 Types of Global Renewable Energy and its current Status in the Energy Market

Despite the volatile oil market and inconsistent energy policies by various countries, a consistent improvement in the RE sector has been observed. The different types of RE investigated in the energy market to provide energy options that are both, reliable and beneficial. The following types of RE sources exploited globally is shown in Figure 2.7. The global contenders for the types of energies will be discussed further in this section.

2.5.1.1 Solar Energy

Sun is the principal source of RE. Due to the thermo-nuclear reaction of Hydrogen and Helium atoms, sun produces enormous energy of $1.67*10^5$kWh from its surface. With the surface temperature of 5800°K, its distance of 149.6million km from earth, it is estimated to incident 1kW/m^2 of energy on the earth's surface. This incident solar energy can be tapped efficiently from the solar Photovoltaics (SPV) or Concentrated Solar Power (CSP) systems [24].

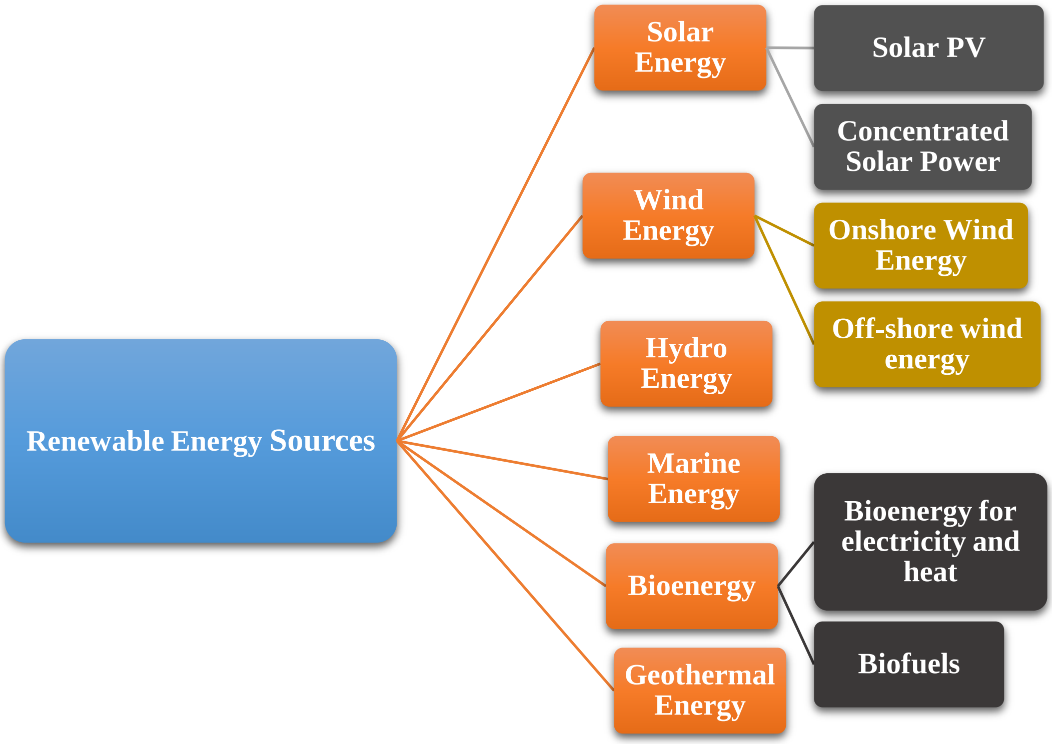


Figure 2.7 Types of Renewable Energy

Harnessing solar energy from PV has been considerably increasing over the years. 33% (402GW) overall increase in the PV installations to harness solar energy has been observed globally. This is equivalent to 40,000 PV panel installations every hour, which is purportedly greater than the combined capacity additions of fossil fuels and nuclear power. China has proved to provide a significant contribution to PV installations compared to other countries. In 2018 PV capacity magnified at 97GW, with the majority of contribution from China. By the end of 2017, China contributed to a significantly more than 50% PV installations influencing the global PV installations. China's total PV capacity accounted to 131GW, exceeding the minimum target announced in 2016 for

2020 of 105GW. However, the US continued to contribute second with the addition of 10.6 GW of PV totaling about 51 GW. Other significant contributors to the PV installation or adoption other than China and the US are India, Japan, and Turkey. These top 5 countries' PV contribution was approximately 84% of newly installed capacity

Energy harnessed from CSP is considerably prospering and has touched 4.9GW in 2017. Drop in prices of the technology accompanied by the competition has helped in the overall cost reduction in this technology. Spain and the US have their significant contributions to this technology globally. However, approximately 2GW of new plants are in the pipeline; China is building 300MW and Morocco is building 350MW of CSP plants. South Africa's inclusion in the CSP contribution of 100MW was the highlight last year.

2.5.1.2 Wind Energy

Due to the sun's uneven heating of the atmosphere, earth's rotation and unevenness in the earth's surface causes wind. Wind can also be regarded as a form of solar energy. Wind pattern is variable and is dependent on the topography of the earth. This wind flow when harnessed efficiently using wind turbines can generate electricity.

In countries where access to power is at a premium, wind energy is very much a viable option to produce electricity. These can be installed and transmitted at a very rapid pace. These can also be installed in remote, hilly and inaccessible areas. Electricity generated from wind does not deplete and does not increase in price either. The electricity thus produced could help save much oil being used for the same purpose and many tons of emissions such as carbon and others can be avoided.

Emission mitigation potential depends on the wind speed potential. For diesel substitution, the potential of mitigating emission is least at a mean wind speed of 4.5 m/s and for the GM-II model and highest for the SICO model at 2,874kg and 7,401kg respectively. Similarly, where electricity is substituted, for both GM-II and SICO models at the same wind speed of 4.5 m/s, the estimated emission mitigation potential is 2,194kg and 5,713 kg respectively [33].

Wind energy from both onshore and off shore contribution have been impressive on global RE scenario. Wind capacity estimated to reach 839GW by 2023, with 10% increase in the offshore wind [19]. Compared to wind energy global output in 2016, wind energy addition dropped by 4% even though there was an additional 52GW of wind power. The total wind energy extracted by the end of 2017 was about 539GW. In spite of many countries like UK, Uruguay, Costa Rica and Nicaragua meeting at least 10% of their electricity consumption through wind energy in 2017, there has been decline in the wind energy installations in China, which is one of the global wind energy leaders. For the second year in a row, in 2018, the onshore wind additions further declined, mainly due to the lower contribution in wind energy by China and USA [19]. This decline in the global wind energy output was considered to be the effect of impending regulatory changes despite the existing wind energy utilisation benefits. However, when the offshore wind energy deployment was considered, Scotland commissioned world's first ever commercial floating wind farm and China's onset of offshore wind market has started in 2017.

2.5.1.3 Hydro-Power

One of the oldest known energy extraction method with water as the source. The kinetic energy of the water is utilised to produce power. There are different types of energy extraction using hydro power, they are:

- Conventional hydroelectric where the kinetic energy of the water from the dams are being used to generate power.
- Run-of-the-river hydroelectricity- In the absence of reservoir and dams, the kinetic energy of the river is tapped to generate power.
- Pumped-storage hydroelectricity: the potential energy of the stored water which is pumped uphill is released, and electricity is generated by converting the kinetic energy of this water.

The sum total of hydropower capacity incremented by 19GW to a total of 1114GW globally in 2017. This was the smallest augmentation noticed since 2012, however a significant impact of the total RE output has been observed. Nonetheless, pumped-hydro storage has been creating a significant improvement in 2017 with an increase of 3GW in 2017 totalling up to 153 GW. China being the top leader in hydropower, it retained its position in 2017 by increasing the hydropower installation by 40%. The other contenders for hydropower extraction are India, Brazil, Turkey and Angola. However, the recent prediction by IEA 2018 predicts that the hydropower is expected to escalate 125GW, which is approximately less than 40% in 2012-2017. This is because of the lesser contribution towards hydroelectric projects by countries like China and Brazil [19].

2.5.1.4 Bio-energy

Energy produced from different biological origin feed-stocks (bio-mass) through various methods for different applications, including production electricity, transportation (bio-fuels), and heat. Bio-mass is an organic matter including wood, seaweed, animal wastes which forms the source of energy. Breaking the chemical bonds in such bio mass materials and are converted to kinetic energy to produce heat that can be utilised to either run the gas turbine or gas turbine generators to produce electricity. The different types of bio-mass includes wood and agricultural products like wood, logs, sawdust, solid wastes, ethanol, bio-diesel etc. There are many ways to produce bioenergy. Depending on the type of raw materials used, there can be different types of bioenergy. The process to produce bioenergy can be as simple as combustion or complicated as algae production.

Bio-energy has the largest renewable contribution of 13% of the total global energy demand. In developing countries, conventionally they are used for cooking and heating, this reports to about 8% against the modern use of 5%. From the modern bioenergy application, approximately 4% of energy contribution from biofuels for heating the building a, 6% for industrial application. 3% of energy demand for transportation is contributed by biofuels whilst 2% of contribution is in electricity generation from the modern bio energies. There has been a gradual increase in the electricity production from biofuels totalling about 11% in 2017, with China and the United States being the top runner in producing electricity from bio energy globally. The other major biofuel producers are Brazil, Germany, Japan, the United Kingdom and India. Brazil and the US endured being the largest producers of ethanol and biodiesel. Biofuel production for using in transport increased 2.5% in 2017. In a recent prediction by IEA 2018, bio-energy is expected to increase by 37GW and reach 158GW in 2018-23, this is approximately 10% decline in bioenergy exploitation between 2012-17 [19].

2.5.1.5 Ocean Energy

70% of the earth’s surface is covered by the oceans and it promises to be one of the promising yet challenging energy source. Energy from ocean includes the mechanical energy of the waves and tides and thermal energy from Sun are the two types of tidal energy. The movement of waves and tides are captured due to their variations perpendicular to the surface of sea or ocean. This energy is tapped and are converted to electricity. Meanwhile, the temperature difference between the surface of the ocean and the water deep inside the ocean can be harnessed to produce electricity [34].

By the end of 2017, 529MW of ocean energy was deployed, with more than 90% of this being generated from two tidal facilities. Out of all the ocean energy technology that has been deployed, those facilities that operate in deep ocean water have started to take off and new capacity has been added by tidal stream and wave energy and these have contributed to the total energy capacity. Most of this has been off the coast of Scotland. In 2017, many of these technologies have advanced enough to be on the verge of commercialisation. The promise of greater scale of production and reduced cost are being presented by the new manufacturing plants that have started construction. These have been largely due to support from the Government through investment in research and development and assistance in setting up the infrastructure.

Ocean energy has not been tapped much as RE source despite years of effort on developing it. There are many new open water technologies that are under development. Some of these are tidal stream and waver energy convertors. Among these, only tidal stream technologies are close to maturity technologically. Wave technology on the other hand has not seen much improvement, mainly due to the complexity of extracting energy from waves. Wave technology projects are currently in the pre commercialisation phase. Whereas, the other technologies such as ocean thermal technology and salt water gradient technology are far off from commercial deployment. Most of the deployments of the ocean energy devices have been in Europe and a few elsewhere in the world.

These oceanic technologies, markets are currently being driven by international cooperation and government support. Commercialisation has faced challenges which are mainly surrounding finance as oceanic energy projects carry high risk and have very high initial cost and need very detailed planning, consenting and licensing to take place.

2.5.1.6 Geo-thermal energy

The thermal energy in the earth's crust is a source of energy that generates electricity using either hydro thermal sources (hot water or steam flowing through permeable rock and hot rock). Tapping this available energy and converting it into electricity is used in this technology. Geothermal energy is a very expensive technology although it is more advantageous compared to the other sources of RE due to its availability to produce power all the 24hours, without intermittence [35]. Geothermal power plants now exist in 19 countries, and new plants are commissioned annually, e.g. Indonesia, Italy, Turkey, and the United States. Due to the nature of its availability when efficiently utilised can reduce the GHG emissions. Three technologies are available to extract energy from geothermal resource to produce electricity depending on the temperature, fluid state that comes from the reservoir, they are: Dry Stream, Flash Stream power plants and Binary power plants [36].

Considering the global scenario of geothermal energy, steam coming from underground has been used in countries such USA, Italy, New Zealand, Mexico, Japan, Philippines and some others. By the end of 2017, 0.7GW of new geothermal energy was added with Indonesia and Turkey accounting three fourth of the additional capacity. A total of 12.8GW of geothermal energy was estimated by the end of 2017, with countries like Mexico, the United States, Japan, Chile, Iceland, Honduras, Portugal and Hungary contributing to the total global geothermal energy output. The restrained geothermal energy development is due to the lack of technology innovation, high resource risk, long project durations involved. Cost effectiveness and technological innovations could further aid in the development of geothermal energy

2.6 Renewable Energy Scenario in Australia's Context

Australia has had it easy in terms of catering to the electricity demand due to its near limitless coal reserves. Nearly 80% of Australia's energy demand has been has been satiated by using fossil fuels such as coal along with contribution to exports such as uranium and natural gas resulting in one of the world's highest per capita GHG emission rates. Australia's energy production through fossil fuels is about 161TWh and is in the 9th place. Fossil fuels are very easily available and they are inexpensive, this has proved a major challenge to the push towards the growth of alternate energy sources. Despite this, the share of energy production from RE sources is approximately 14.6% and this includes hydroelectricity and wind energy [37]. Australia's RET to produce 20% electricity through RE by 2020. To complement the ability of Australia to harness renewable sources, several studies have been undertaken to bolster the prospect of Australia's energy sector turning green. [38-40]. Although, its practical application has always been an interesting topic of debate. A study confirms that, if a PV power station in Central Australia considers 15% efficient PV panels, it has the ability to trap 1.05kWh/m^2/day of solar energy and could supply a continuous and uninterrupted energy of 44kW/m^2/day, while it can harness 32kW/m^2/day of energy considering transmission losses [41, 42].

Figure 2.8 represents the availability of Australia's abundant solar radiation potential. Comparing Australia's solar energy disposal with its population figures, the solar radiation per capita is beyond par when compared to the rest of the world. This signifies Australia's readiness to cater to the energy requirements [43]. Subsequently, in 2011, Australia's Clean energy Council reported the PV panels reaching the rooftops of the houses rocketed to 35 times and more, which is further foresighted to reach 24PJ by the year 2029-2030, considering the annual energy advancement by 5.9% [42]. Contrasting to these findings, there are studies claiming negative results for Australia's energy sector to reach 100% through RE [41, 42]. However, several studies ponder into RE meeting Australian grids [44-49].

In 2016, Australia experienced RE sources contribution growing multi-fold due to hydro-energy sector contributing significantly. It was considered a notable "come-back" in the energy sector for hydro-energy providing 26% of its share amongst other RE sources, as Australia experienced abundant rainfall in 2016. RE contributed to almost 17.3% in 2016, with a significant growth of 14.6% compared to 2015. Australia's RE share showed a considerable improvement in the last decade with increases PV and WT adoption due to the downfall of its prices. When Australia's energy storage sector was considered, in 2016, approximately 6750 batteries were installed which estimated to a capacity of 52MWh. Thus, Australia simultaneously matured even in its energy storage sector [50].

In 2017, Australia experienced a slightly less RE contribution of 17% as compared to 2016 (which was 17.3%). This decline validated to scant rainfall in the catchment areas resulting in fall of hydro-energy contribution. However, for the first time in 2017 a significant share of 5.7% in the rooftop PV apart from wind energy and hydro-energy sectors was established. Table 2.3 elucidates the summary of Australia's total RE generation.

In 2017, approximately 17% of energy share was by RE. Figure 2.9 illustrates the state-wise RE contribution. It is observed that Tasmania with 88% share is a front-runner in RE contribution compared to other states largely due to hydro-energy contribution. However, RE contribution from Tasmania plunged from 93% in 2016 to 88% in 2017.

Due to the higher RE availability, SA‘s contribution towards RE increased from 45% to 48% within 2016-17. In contrast, Queensland’s RE contribution increased from 5% to 8% within 2016-2017. WA contributed 11% while NSW and Victoria contributed 16% and 14% of RE share respectively. These RE contributions from the Australian states indicate the available opportunities to investigate and explore RE adoption at these locations. Although these states are bestowed with surplus RE potential, they lack the urge and support for RE deployment.

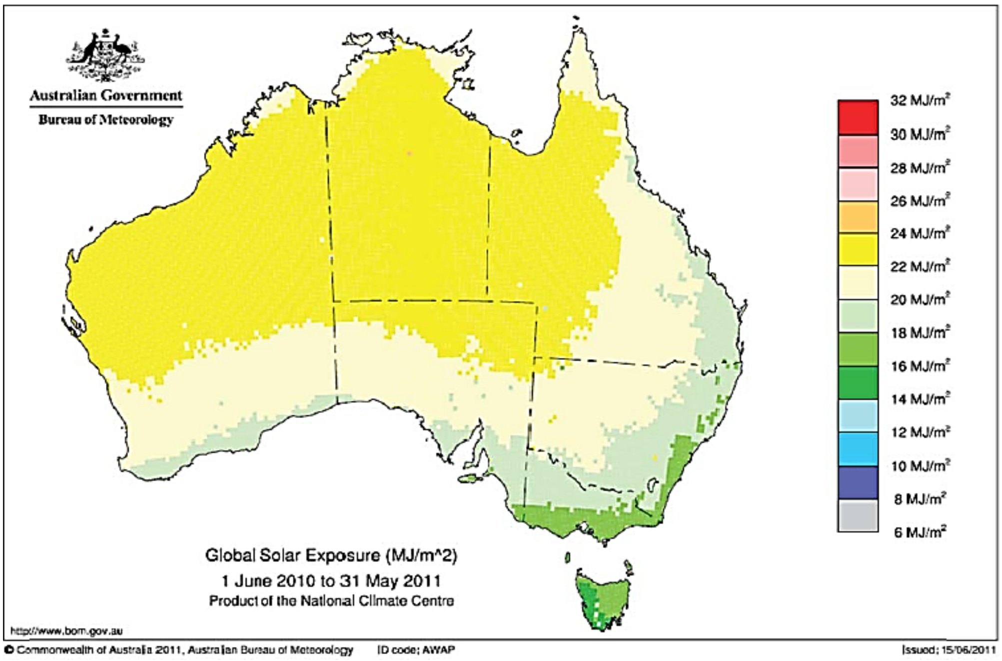


Figure 2.8 Annual average of daily solar exposure in Australia [51]

Table 2.3 Australia’s Total RE generation in 2017

RE Technology	Generation (GWh)	Percentage of Renewable energy Generation	Percentage of Total Generation
Hydro	12920	33.90%	5.74%
Wind	12873	33.80%	5.725
Small-scale solar PV	7723	20.30%	3.43%
Bio-energy	3713	9.70%	1.65%
Medium scale Solar PV	197	0.50%	0.09%
Large Scale Solar PV	695	1.80%	31.50%
Solar Thermal	16	0.00%	0.01%
Geothermal	1	0.00%	0.00%
TOTAL	38138	100.00%	16.94%

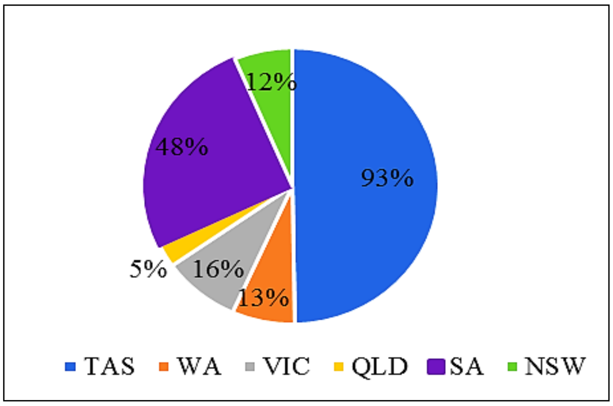


Figure 2.9 State-wise Renewable Energy utilization in Australia till 2016

In 2017, Australia was in the limelight for installing the world's largest Li-ion battery installation in SA. The increase in the PV installation to 12% along with the battery installations by the household was a supplementing factor. Around 42% of the battery storage installations was achieved by Australia. Amongst this 42%, 19%of installations were made in NSW 195 in Queensland, 17% in Victoria and 11% in SA. There is a persistent and continuous drive by Australia to achieve RET, however Australia lacks in amendment of long-term unifying energy policy or climate policy. Nonetheless, every state has planned to achieve RET as a part of the Nation's RET with its own energy policing being put in place [52]. This is the drive behind this research, which aims at RE adoption in turn contributing to achieve Australia's RET.

2.7 Renewable Energy Scenario in India's Context

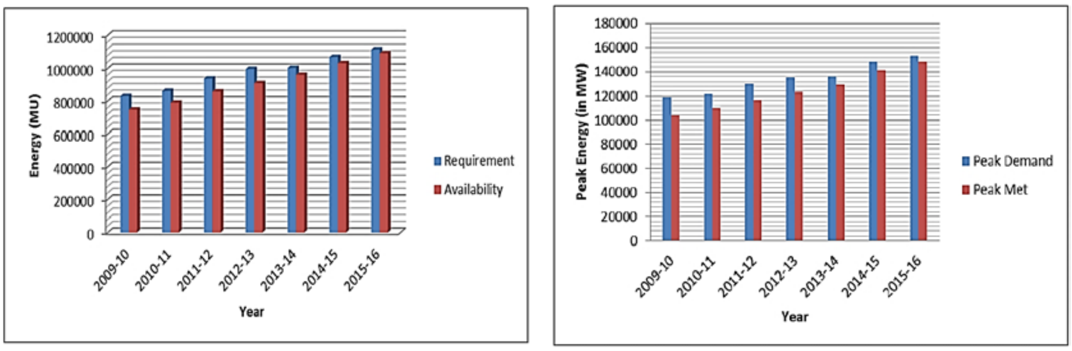
India's development has resulted in stupendous advancement in energy sectors and opportunities affiliated to it. There is a considerable progress in the installed power capacity from 30,000 MW to 126,990 MW (till 2011), India is the 3rd largest electricity producer globally succeeding China and USA. India is the 7th largest producer of RE in the world and is among the largest electricity consumers [53], while the majority of those live in rural areas still lack electricity access. Nearly 500 million people are still reliant on biomass for cooking. Coal contributes to about half of the energy mix in the country making it a second-largest coal producer in the world. Studies suggest by 2020, India would be the world's largest coal importer, overtaking Japan, the EU and China and its oil import dependence would escalate to beyond 90% by 2040. In regard to other conventional energy sources, India has gas reserve of 0.6% and oil reserve of 0.4% globally. Although, its per capita fossil fuel production is comparatively lowest compared to other emerging markets India's fossil fuel dependency with respect to its energy demand is around 75% [54].

CO_2 emissions have increased 2.5 times in India between 1990 and 2014, even though the per-capita emissions are still below the average level in Organisation for Economic Co-operation and Development (OECD) countries. The per capita electricity consumption in India is 1,010kWh as compared to the per capital electricity consumption of 3,200kWh. India is world's fourth-largest source of energy-related CO_2 emissions, as fossil fuels such as coal continue to play a major part.

By 2035 India is likely to contribute 30% to the global energy demand, thus overtaking the domestic energy supply. According to India's energy forecast, it is estimated to grow approximately 4.5% annually until 2035 as compared to 3.5% from the year 2000-2017 [54]. Electricity demand is estimated to grow in all the four major energy sectors: industry, agriculture, transport and household. Figures 2.10 (a) and (b) highlights in detail the statistics regarding the peak power deficit situation and energy deficit being faced by India. For 2015-1016, the peak power deficit and energy deficit in India was 3.2% and 2.1% respectively. This clearly shows how important a role RE plays in India's strategic perspective

Additionally, there has been extensive pressure on India to contribute in the green energy sector. India is endowed abundantly with clean energy sources. It has a high potential to generate RE from sources like wind and solar in particular, other than bio-mass and small hydro. The Government of India's focus on RE includes grid-connected and off-grid energy systems. India has declared an aim to have an installed non-hydro RE capacity of 175GW by 2022 (of which solar PV is 100 GW). To mitigate the carbon intensity of India, adopting to RE with low marginal cost compared to fossil fuels would be the ultimate solution as the power sector contributes to half of the country's carbon emissions. In this aspect, development, and deployment of solar energy technology to attain the grid power parity by 2022, the Government of India approved the "Jawaharlal Nehru National Solar Mission" (JNNSM) which was later named as National Solar Mission (NSM) [55].

The annual global solar radiation in India varies from 1600 to 2,200 kWh/m^2 which is equivalent to 6,000 million GWh energy per year [56]. The radiation levels are distinct for different parts of the country as shown in Figure 2.11 and exploiting such available natural resources in an efficient way is the key answer to the above issue. Considering that India's contribution to wind energy being significant is the impetus to pursue this project. Government aided RE policies have helped India explore wind energy along with the hub of wind turbine manufacturing industries situated in India including Suzlon, Vestas etc. [57]. Thus, adopting renewable energies as distributed energy sources and connecting them to the grid contributes to the prerequisites of the grid development.



(a) (b)

Figure 2.10 a. Energy Requirement Availability in India and (b) Peak Energy Demand and Availability in India[53] (Permission taken on 5.1.17)

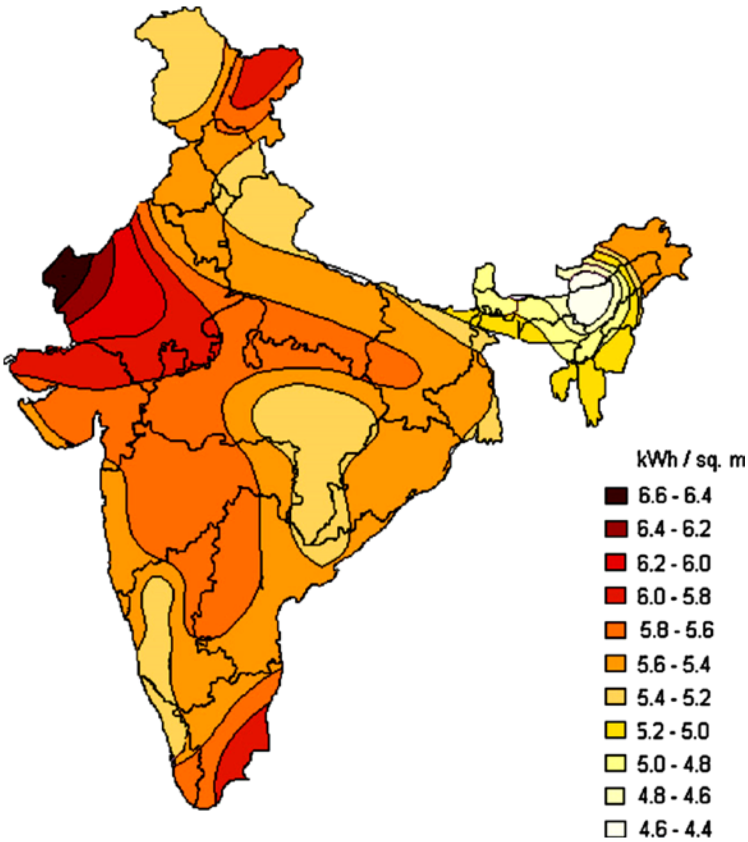


Figure 2.11 Solar Radiation in INDIA [56]

2.8 Renewable Energy integration for a micro-grid

The rapidly increasing energy demand and environmental degradation followed by the increasing use of conventional energy sources have sent an alarming signal globally to explore the benefits of alternate energy sources for energy production. The system cost and easy availability of conventional energy sources have provided a bigger challenge in sizing and optimizing the HRES for micro-grid applications. Although a wide spectrum of studies has been conducted to optimally size the HRES for the desired location to provide better reliability and energy benefits. Designing and optimising a micro-grid and analysing their economic and environmental impacts are considered as a core objective of this research from Australian and Indian perspective.

Similar studies have been conducted using Solar cells or PV, wind turbines, fuel cells (used either for energy conversion or as a storage unit) for different locations like islands in Dongfushan Island, farthest eastern inhabited island in China which relies on diesel generation to meet the energy demand. Integrating RES to improve energy reliance has been proposed for this island due to the unavailability of to meet the island's energy demand have been proposed in [11]. A case study has been conducted for integrating HRES considering PV arrays, wind turbines, and battery storage option to meet the electrical load demand at Catalina Island in California [58]. Similarly another study indicates the efficient utilisation HRES to improve energy reliability in un-electrified seven villages in the Almora district of Uttarakhand state, India [30]. Designing an off-grid energy system by integrating PV and biomass for a house in a remote village has been proved as a viable option in [59] . Stand –alone HRES has proved to be economical viable option compared to grid connected system for a cattle farm in Spain has been studied in [44].

For a large hotel located in Queensland, Australia, RES connected to the grid has proved an economical and environmentally reliable option as compared to the grid-alone system in [47]. For a specific location in Ontario, Canada , integration of solar and wind energies for distributed generation considering a storage option has proved to be a viable option in [60]. A 'Green building' has been studied by integrating HRES with and without energy storage options to meet thermal and electrical demand of the building along with suppling the energy to pump water in [61]. Integrating PV-Wind-Diesel hybrid system has proved to be economically and environmentally viable option by improving the RE penetration has been studied in [62]. Optimum sized HRES along with storage system for a grid connected micro-grid system located in Ontario, Canada has been studied. The grid-connected micro-grid unit was designed for minimum life-time cost resulting in creating positive economic impact has been observed in [63].Using Berkeley Lab's Distributed Energy Resources Customer Adoption Model (DER-CAM) incorporating HRES and CHP technology for a hypothetical commercial building like a hotel in San Francisco has been proposed in [64]. This model has been proved to achieve economic and environmental reliance of the system.

To design and optimise any micro-grid it is significant to understand and study the load requirement of the desired location. This crucial step in the design of a micro-grid should not terminate in underestimating or overestimating the consumption, either of which could result in unmet load or oversized setup respectively. Various methods have been used to optimize a micro-grid including genetic algorithm and swarm optimisation techniques, however many software has been used in such studies widely viz. MATLAB, Simulink, HOMER, iHOGA, RETScreen etc.

Given arbitrary behaviors of renewable energy sources, their energy prediction has always been challenging and hence unit sizing and optimization method study would help to downsize the system cost and improve system reliability. Although oversizing the system components may make the system economically bulky, but, under sizing them would lead to unmet load. Hence an optimum resource management is a pivotal strategy to have a reasonable trade-off between them [65].

2.9 Performance Indicators

There are several performance indicators being used to comply with unit sizing of RE and they are described as follows.

2.9.1 Power Reliability Analysis

- Loss of Power Supply Probability (LPSP)

Electrical load demand should be met by the renewable energy systems due to their stochastic behaviors. LPSP is the method helps to choose a reliable system. LPSP is defined as the ratio of the total shortfall in energy to the demand in load during a specified period. LPSP is defined in equation (2.1).

$$LPSP = \frac{\sum_{t=1}^{T}(Energy\ shortfall\ )}{Load\ Demand} \tag{2.1}$$

- State of Charge of Battery (SOC)

For a stand-alone system, the state of charge of the batteries determine the energy stored and is represented by (2.2):

$$\mathrm{SOC}(\tau + 1) = \mathrm{SOC}\ (\tau).\alpha + \mathrm{i_{bat}}(\tau).\Delta\tau.\eta(\mathrm{i_{bat}}(\tau)) \tag{2.2}$$

where,

α = self-discharging rate of the battery bank,

$i_{bat}(\tau)$ = battery's charging current,

$\Delta\tau$ = sampling period and

$\eta\ (i_{bat}\ (\tau))$ = charging current efficiency.

The reliance on the energy storage for a distributed generation depends on the SOC of the battery used [66].

- Level of Autonomy (LOA)

LOA determines the supply energy from the storage system like battery to supply energy to the load for a definite period of time. It calculated as one minus the fraction between the total numbers of hours during which loss of load (LOL) occurs to the total operating hours, and is given as:

$$LOA = 1 - \frac{T_L}{T_{total}} \tag{2.3}$$

Where,

T_L = entire loss of load hours and

T_{total} = over-all operating hours of the system considered

- Expected Energy Not Supplied (EENS)

When the available energy is less than the expected load, then there is expected energy that has not been supplied by the system, this is a probabilistic reliability index defined as:

$$EENS\ (L, P_h) = \begin{cases} L > P_{h\,max}\ L - \int_{P_{h\,min}}^{P_{h\,max}} P_h \,.\, f_{ph}\,(P_h) dP_h \\ P_{h\,min} \leq P_{h,max} \int_{P_{h\,min}}^{L} (L - P_h) dP_h \\ L < P_{h\,min} \qquad 0 \end{cases} \tag{2.4}$$

where,

L = expected load

P = power generated by hybrid systems

$P_{h,max}$, and $P_{h,min}$ = maximum and minimum energy generation from a HES

f_{ph}(Ph) = the probability density function representing the power output of the hybrid system considered [67].

2.9.2 Economic Criteria

- Levelised Cost of Energy (LCOE) or Cost of Energy (COE)

LCOE is the arithmetic mean (average) of the cost (including all the annual costs) of energy per kWh that causes a break-even investment. For a hybrid energy system design, this is an economic assessment merit and can be calculated as

$$LCOE = \frac{TAC}{E_t} \tag{2.5}$$

Where,

TAC = overall annualized cost and

E_t = total energy annually.

The TAC is the sum of the initial Capital Cost, present replacement cost and capital recovery factor (CRF) of the HES considered where capital recovery factor is defined as shown in (2-6):

$$CRF = \frac{i(1-i)^n}{(1-i)^n - 1} \tag{2.6}$$

where,

i = interest rate/discount rate and

n = lifetime of the HES.

- Net Present Cost (NPC)

NPC is the total net present value of the component subtracted by the (income) profit it incurs for the complete lifetime of the project.

$$\text{Net Present Cost} = \sum_{t=0}^{t=n} \text{Total present cost} - \text{Profit incurred} \tag{2.7}$$

- Annualised Cost of the System (ACS)

The annualised cost of the system calculated by summating the Capital Cost, replacement cost and maintenance cost given by (2-8):

$$ACS = C_{cap} + C_{rep} + C_{main} \tag{2.8}$$

- Internal Rate of Return (IRR)

Internal Rate of Return is rate of the profit that a system offers during its years of operation. It is equivalent to the return on investment (ROI) or the rate of return time adjusted over the time of its operation. It is calculated by determining the discount rate when the net present value of the project is nullified [9].

- Payback Period (PBP)

Payback period is the time duration in which initial cash outflow of an investment is expected to be recovered from the cash inflows through the investment, it can be calculated as [7]:

$$PBP = \frac{Initial\ investement}{Cash\ inflow\ per\ period} \tag{2.9}$$

2.10 Optimum Sizing Methodologies

Based on the above criteria for unit sizing there are different optimisation techniques are used for sizing and optimizing the hybrid energy system [7, 67]. The commonly used methodologies for optimum sizing of renewable energy systems are as shown in Figure 2.12.

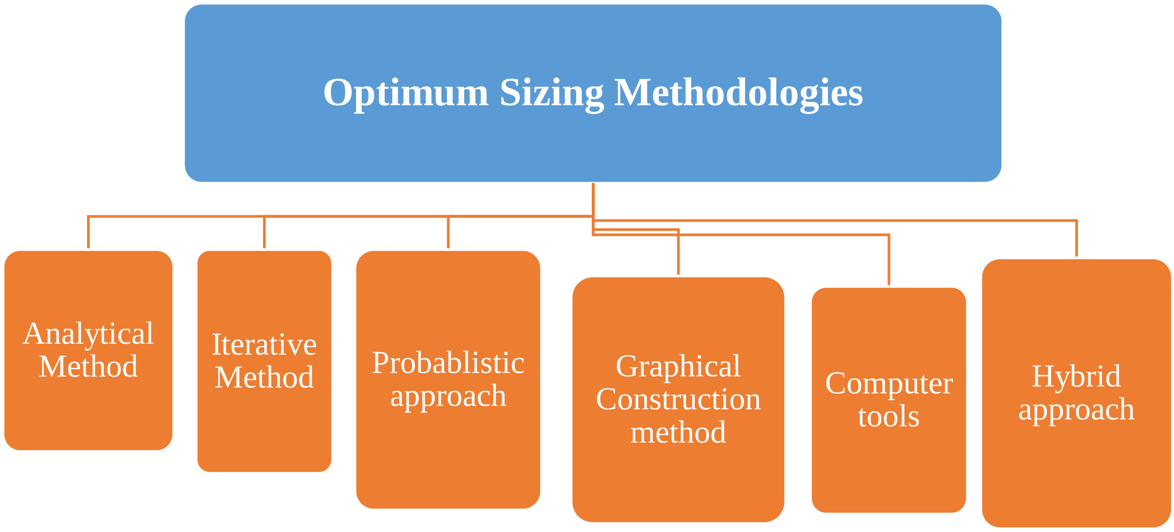


Figure 2.12 Optimum Sizing Methodologies

i. Analytical Method

In this method, the computational models define the hybrid energy system's size as a feasibility function. For definite sizes of such hybrid system, their performance is evaluated. The above-defined performance index can be assessed for any hybrid system design. However, minimum of 1-year weather data is required for such assessments are observed in the literature [67]. Ebbw Vale district in Wales was studied for integrating RE as an energy source using Analytical method for optimal sizing of the system. This method resulted in reduced emissions optimal sizing and a reasonably economical system compared to optimal sizing using Genetic Algorithm method [68].

ii. Iterative Method

In the iterative method, analysis of the hybrid energy performance by a repetitive process stops when the ultimate configuration is reached. In this method, LPSP and least value of LCE or NPC is widely studied using linear programming or by varying the linear parameters the least cost of the system is attained. However, it is noted that certain parameters cannot be optimised, such as, the size and orientation of PV modules, the height and swept area of the wind [7].

An iterative method has been used to optimally size a reliable renewable energy system configuration by minimizing the total life-cycle cost for a rural community [69]. This method includes Artificial Neural network (ANN), Genetic Algorithm (GA) and Fuzzy logic (FL). Artificial Intelligence is an expansive word coined to represent the methodology that portrays human thought. The widely studied techniques are GA, FL etc.

- *Genetic Algorithm*

GA as the name suggests, is based on the evolutionary principle of natural genetics, it is an advanced search and optimisation technique. When compared with traditional optimisation methods, GA is very robust technique especially when optimal solutions are needed in multimodal and multi-objective optimisation problems. Since the base of GA is genetics, the operators used are also named accordingly: selection, crossover, mutation. These operators are used to mimic the process of natural evolution.

The first step in a GA based analysis is to determine if the chosen system configuration, is functional and can be considered as a solution. This is termed as the chromosome. If it passes the test, further tests are carried out to see if this is the best option; if yes then this chromosome is the optimal solution. After the selection process is completed, crossover and mutation operation are conducted on the optimal solution in order to determine the convergence [70]. The flowchart for the iterative procedure using GA is shown in Figure 2.13 [71].

- ***Fuzzy Logic***

Fuzzy logic is a concept used in the definition of decision making, it is used in situations where it is critical to have the exact answer and not a rough answer. The principle is based on the fact of True or False and the use of facts in between them. Fuzzy logic is not meant to replace conventional control methods but can be used to simplify the implementations of the systems and also on dealing with nonlinear functions where complexity is not really well known [72].

- ***Artificial Neural Networks***

Artificial Neural Networks (ANN) is one of the methods of achieving an outcome through Artificial Intelligence (AI). Self-described in the name, ANN is a way of interpreting data like the human brain can. In ANN the problem solving is not the normal way of giving an input and getting an output. It involves presenting a large amount of data and using that data to learn to identify patterns so that future solving of problems can be efficiently done. ANN would also be capable of handling large datasets thus producing answers that would help a designer do their tasks [73].

iii. Probabilistic Approach

In the probabilistic approach, a stochastic behavior of the system is included. To illustrate, solar radiation or wind energy is considered for a hybrid energy system design. Although this is a very simplistic approach as it does not require the application of time series data and not taken into consideration is the dynamic performance variation of the system. Some of the probabilistic approaches consider Particle Swarm Optimisation techniques (PSO) shown in Figure 2.14 and Monte Carlo methods shown in Figure 2.15 are widely studied in this aspect. PSO algorithm results in faster simulations compared to any other methods including GA [74].

Monte Carlo method has been used as a probabilistic model to evaluate the NPC of RE projects under different support mechanism scenarios such as investment incentive, RECs, CERs and FiT due to their uncertainties [71, 75].

iv. Graphical Approach

In this technique to optimize the hybrid renewable system, graphical construction method is used. One of the used cases is analysis using long-term wind speed and solar radiation data. However, in this type of approach to design renewable energy systems significant aspects like the slope of the PV module, wind installation height will be overlooked [7].

v. Computer Tools

There are many commercially available computer tools or software that use the above-addressed techniques [76]. One of most commonly used tools is Hybrid Optimisation Model for Electric Renewables (HOMER). This is very adept at modelling hybrid power system behavior considering the total lifecycle cost of the system. This software gives the ability to the user to compare the technical and economic merits of the optimum configurations obtained. The other famous software that are used in the literature are HYBRID2, HOGA, RETScreen etc.

vi. Hybrid Approach

Considering the heuristic behaviors of renewable energy sources, designing them for diverse objectives is a holy grail. The combination of above-discussed methods using their conflicting objectives has been used in several studies [77, 78]. To illustrate them, there is always compromise between the system cost and obnoxious gas emissions. The above-discussed methods (except the computer tools) have conflicting results when used simultaneously as each of them have a definite objective in sizing the system, more often software tools are preferred. However, there have been reviews using the Artificial intelligence techniques being more reliable for multi-objective design along with the above-discussed software [79].

In spite of the aforementioned methodologies available to size the RES there are other different methodologies from the literature available to size the HRES.

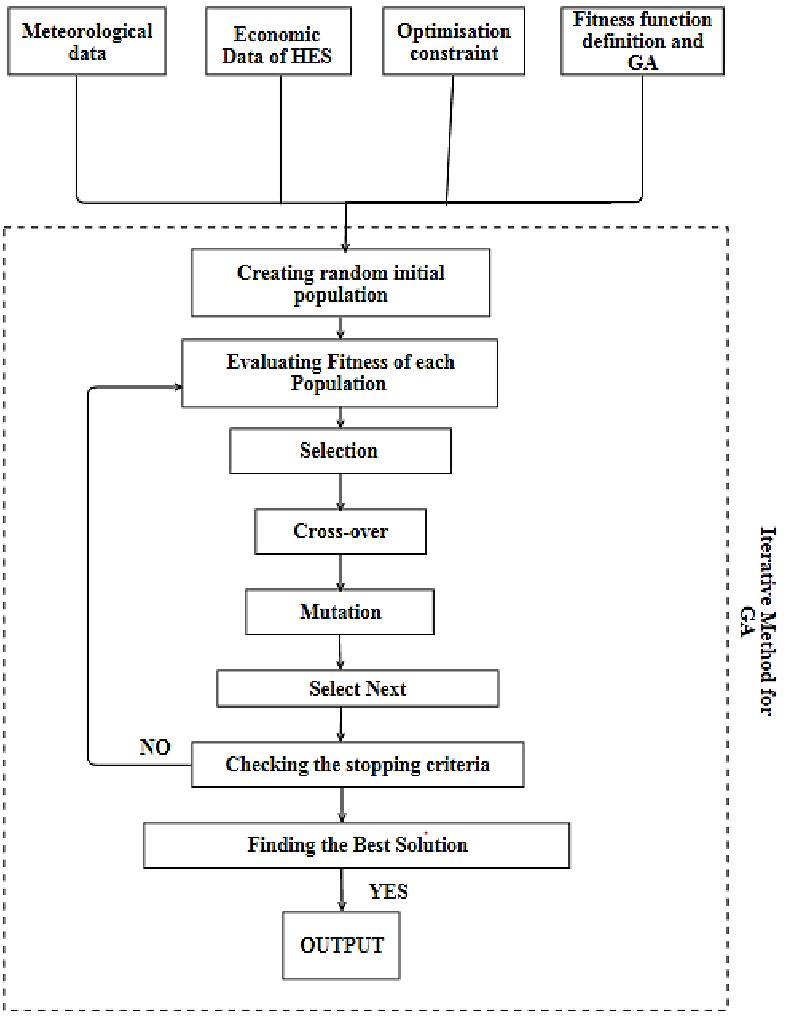


Figure 2.13 Flowchart for GA

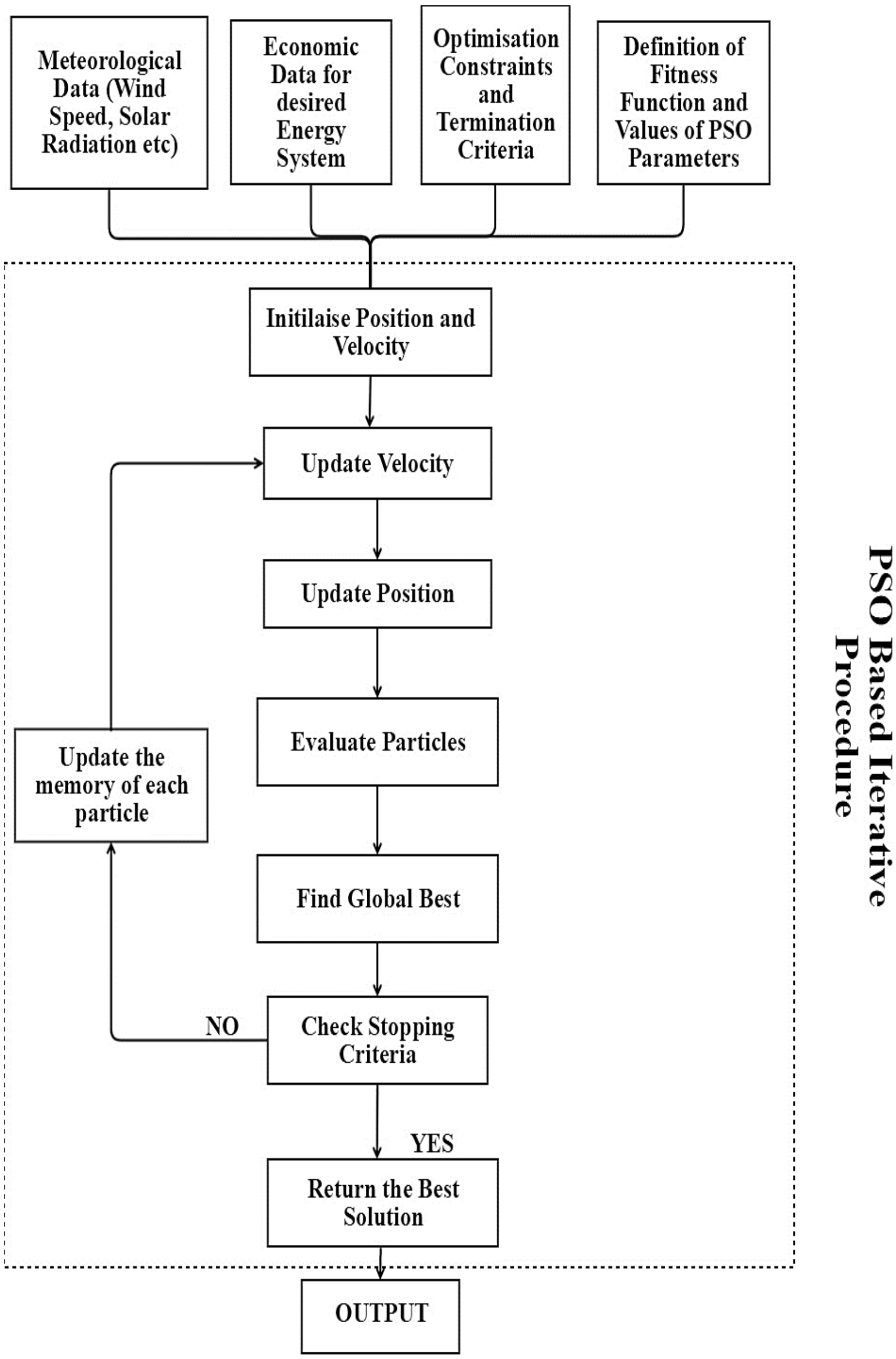


Figure 2.14 PSO flowchart [71].

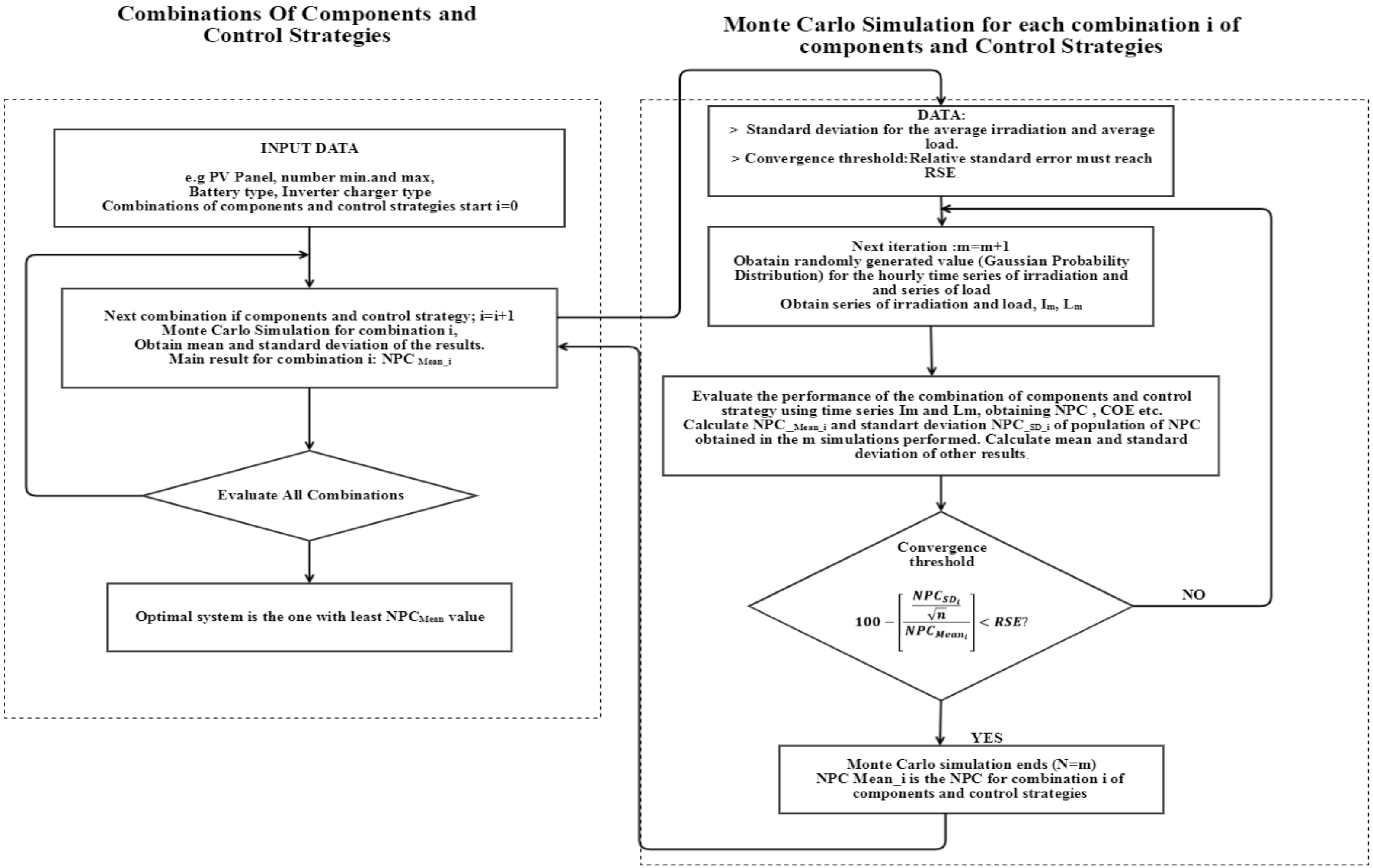


Figure 2.15 Monte Carlo method flowchart [80]

2.11 Shortcomings in the literature survey and contributions from this research work

From the literature survey conducted it was understood that there are many case studies conducted using software packages along with the other aforementioned methods. It was understood that many regions in India, specially the southern part of India has tremendous RE available and has not been explored yet. In this scenario, Aralvaimozhi located in India state Tamil Nadu has been spotted to have abundant source of RE, especially solar and wind energies. This site was chosen to study the RE integration. Similarly, in Australia, Warrnambool was potted to have good source of solar energy than wind energy. A small community in Aralvaimozhi and a university building in Warrnambool was chosen as the best locations to integrate RE in their respective micro-grid. The other advantages to choose these two locations is the ease to procure energy consumption details.

To integrate RE in the micro-grid, most of the studies conducted using HOMER software (See Appendix A-1) assumed the average consumption of a household by vaguely calculating the electrical equipment could be used for a period of time. In this research, the actual energy consumption early bills were procured and analysed for real time scenario. From the literature survey conducted, it was understood that iHOGA software was least explored compared to other methodologies (see Appendix A-2), especially for a battery integrated HRES into a micro-grid iHOGA is least explored. HOMER software is a widely explored software in the literature, however there is no detailed on the result comparison between these two software packages in the literature. Considering these gaps in the literature, this research aims at integrating HRES along with batteries into a micro-grid for a small community in India and university building at Warrnambool Australia. The sizing and optimisation of HRES integration is performed using HOMER and iHOGA and their results will be compared and will provide a reasoning if there are any discrepancies in the results obtained between these software packages. Furthermore, using TBL analysis the results from the perspective of economic, environmental and social factors are discussed for various practical scenarios. Although, the literature survey conducted for HRES integration into a micro-grid considers economic and environmental benefits in the analysis, there has been least focus on social factor. This research contributes to the aforementioned mentioned shortcoming by addressing them.

2.12 Conclusion

RE has been a promising technology to mitigate the GHG emissions and form alternate energy options. A recent energy report confirms that there is still dearth of electricity access and clean cooking facility in the world, this is about 16% and 38% of the global population respectively. The majority of the population lacking these basic access are in rural areas of sub-Saharan Africa and Oceania [81]. Hence there is an insistent need to adopt to RES sooner rather than later. Recent development in technology and the business models built around them are accelerating the access to energy in the developing world possible via Distributed Renewable Energy (DRE) systems. The traditional way of energy access through the ever expanding grid is very much on its way out. This is the top down approach to access energy. In the recent times, the approach to energy access has been the bottom up approach, where by customer demands are driving energy adoption. Some examples of this are off grid units and community scale mini or micro grids. Also enabling the change is the new models of financing access to energy such as Pay-As-You-Go (PAYG), microcredit and micro loans. The companies that specialise in Distributed Energy systems are collectively called Distributed Energy Service Companies (DESCOs). To adopt to the RE from technical and economic context, various methodologies have been showcased to size them and analyze the techno-economic features related to RES adoption. This chapter showcased a global survey on the RE availability, growth and necessary to adopt RES with Australia and India scenario in particular. The reason to size the RES and methodologies involved in sizing the RES. A summary of the different methodologies used in the literature has been showcased in this chapter.

Furthermore, the insight to the modelling of HRES using the software packages like HOMER and iHOGA are presented in detailed in Chapter 3.

Chapter 3

Role of HOMER and iHOGA in HRES Design and Optimisation

3.1 Introduction

3.2 HOMER and iHOGA Software

3.3 Study of HOMER and iHOGA Software

3.4 Conclusion

3.1 Introduction

There are different methodologies to size the RES according to the desired performance indicators. Considering the heuristic behaviors of RE sources, designing them for diverse objectives is a holy grail. The combination of different methods discussed earlier in Section 2.10 of Chapter 2 and their conflicting objectives have been used in several studies. To illustrate them, there is always compromise between the system cost and poisonous gas emissions. These methods discussed have conflicting results when used simultaneously, as each of them have a definite objective in sizing the system, and hence more often software tools are necessary. However, there have been reviews using the Artificial Intelligence techniques being more reliable for multi-objective design along with the earlier packages-discussed software [79]. The design and implementation of RES must consider cost and performance of the energy system considered as mentioned in Chapter 2. The most important aspects of sizing and optimisation according to HOMER and iHOGA software packages are explored in this Chapter. These aspects are further incorporated in the analysis later in the thesis. Several case studies in the literature have been conducted for different locations, including hotel, university, and isolated village etc. using HOMER and iHOGA software packages. While this study though aims at sizing the RES it will contrast the RES's scenario from an Australian and Indian perspectives.

3.2 Working Methodology of HOMER & iHOGA Software

HOMER and iHOGA are the software considered for nonlinear and multi-objective analysis. The advantages of these two software packages is the ability to simulate distinctive, sometimes new technologies of various sizes and system costs, thereby reducing the complexity of decision making.

3.2.1 HOMER

Hybrid Optimisation for Multiple Energy Resources (HOMER) also called the HOMER PRO version is the widely used and considered as a reliable software to perform RES sizing and optimisation. This software aids in performing a pre-feasibility test for different RE configurations of various sizes, while it also performs sensitivity analysis for a set of configurations for the desired energy systems. This software normally used for grid and off-grid applications is developed by National Renewable Energy Laboratory (NREL), USA. The software uses windows platform and programming language C++ [76]. To configure and design a micro-grid, decision making is an important task to be carried out in terms of the size of the components, component design etc. The available RE technology options for a desired location and available energy resources are some of the necessary criteria for decision making. Thus choosing a location to design a micro-grid plays a crucial task. Considering the RES like PV, WT, HFC etc.; cost of these RES; inflation rate at the chosen location, interest rate and other technical characteristics of the chosen components are necessary.

When it comes to decision making, there are many options which depend on technology options and availability of the energy resources. HOMER software consists of optimisation and sensitivity algorithms which makes the option for evaluation easier. The simulation operation results in a definite model configuration whilst the optimisation process decides the best model configuration. The optimal solution simulated by HOMER for a desired configuration for the desired model configuration suggested by HOMER fulfils all the user defined constraints for the smallest NPC value. HOMER also evaluates the system by performing energy balance calculations, rejects the infeasible system designs and displays configurations which can be used to decide which system configurations to use. This method of displaying the results also help in comparing the same to the design [3]. HOMER simulation primarily evaluates the technical feasibility of the system considered to satisfy the electrical and thermal load requirements other than the different user defined constraints. Furthermore, it evaluates the NPC of the system which includes the installation and maintenance costs of the systems. HOMER simulates the RES for 8,760h (corresponding to the number of hours in a year) and tabulates the results. Each set of results includes set of graphs and tables which defines its technical and economic values which help in understanding and analysing their techno-economic behavior. This helps in comparing the results of any RES of desired configurations from the set of results. These results can also be exported and used for later analysis.

HOMER considers deciding on the combination of components for the model, its size and quantity and its dispatch strategies. The optimisation process includes several decision-making variables like [82]:

- Size of PV;

- Number of WTs;
- Number of batteries;
- Size of the converter;
- The existence of the RE including PV, WTs;
- Size of generators and
- The dispatch strategy that determines the operation strategy of the system.

3.2.1.1 Physical Modelling of the Energy Sources

To physically model the energy systems for a given place, certain steps have to be followed, and they are:

a. Input data which are resource available: For simulation and optimisation of HRES using HOMER, six types of data are considered namely: meteorological data, economic data (like inflation rate, discount rate), load profile, characteristic features of the equipment considered and technical data.
b. Meteorological data: HOMER considers discrete energy sources for simulation. The subsequent Section describes the modelling technique that HOMER uses for designing these RES [82, 83].
   - *Solar Resource*: According to the location where the micro-grid must be set up, HOMER extracts the average monthly solar irradiation data from NASA website using the latitude and longitude of the desired location. It also includes the clearness index of the desired location (defined as the ratio of solar radiation incident on the Earth's surface to the solar radiation that hits the top of the atmosphere). The user can also provide the solar radiation data which is synthesized by HOMER to provide the hourly solar energy radiation data for the simulation.
   - *Wind Resource*: HOMER has the flexibility to analyse the user defined wind speed hourly data or it can synthesise the hourly data for an year considering the average wind speed data. It synthesises the data considering the Weibull shape factor, the hour at which the wind speed is at its peak, diurnal pattern strength, autocorrelation factor. Elevation of the desired location above the sea level, the height of the anemometer, hub height are the additional factors considered by HOMER. Using power law or logarithmic law; HOMER calculates the height of the hub when the hub

height and height of the anemometer are different values. The power law assumes an exponential variation of wind speed with height while the logarithmic law assumes that logarithmic variation of wind speed with height. While simulating the data using HOMER, the air density is also included.

- *Hydro resource*: To model a hydro turbine (working of the river flow on the flow of the river with no upstream storage variation), there are two inputs streamflow data (which can be hourly data or HOMER synthesises the data monthly average when provided) from the user and residual flow from which HOMER calculates the available stream flow to the turbine.
- *Biomass resource*: The feedstock fed into the gasifier which is assumed by HOMER produces biogas which in turn is used to generate electricity. One or more generators are used in HOMER for the simulation while these generators work in the same principle as any other normal generator. Depending on the feedstock HOMER decides the working of single or many generators to cater to the electricity demand. The output power of RES are determined considering the monthly average or time series meteorological data.

c. Load profile: Load is a primary criterion to understand what the system configuration must meet. There are three types of load HOMER includes, they are:

- *Primary load* :Electrical demand met by the RES,
- *Deferrable load*: Electric road that has to be met anytime for a given span of time,
- *Thermal load*: Heat demand.

In HOMER, the user defines the primary load in kWh of 8,760h in a year, either by importing the data or HOMER synthesizes a load data when the user specifies the average daily load. The user can define different load for different months of the year or different load profiles for weekdays and weekends. It also considers both A.C. and D.C. loads. There could be energy deficit when the electrical demand exceeds supply, which is termed as Load Unmet by HOMER.

d. Equipment characteristics: The efficient operation of HRES used in the model is determined by the characteristics of every equipment used.

e. Search space: The components used in HRES model could be of different sizes. Homer provides a provision under search space to size the HRES for definite values.

f. Economic (Market) data: The operational cost and maintenance cost (O&M) cost, capital, and replacement cost of the equipment considered are provided by the user. Furthermore, electricity transaction price with the grid (purchase price or selling price), interest rate, inflation rate, lifetime of the project, capital cost, O&M cost, and emissions penalty equipment if any, in the HRES models must be provided by the user. These costs are considered by HOMER to calculate and optimise for the least value of NPC.

g. Technical data: The user must include the dispatch strategy, minimum renewable energy fraction, operation reserve and the minimum renewable energy fraction for the simulation.

h. Assessment Criteria for HOMER: HOMER assess the RES using certain economic criteria and they are as follows [47]:

- *NPC*: NPC is determined on considering the life cycle cost of the system which comprises of the replacement cost, set up cost, O&M costs, fuel costs and salvage value for the project lifetime. The assumption made for the analysis is that, the price of each component would increase at the same rate and considers the interest rate and inflation rate for the calculations.
- *Salvage value:* It is the residual value (or remaining value) of the RES components at the end of the project's lifetime. HOMER deduces that salvage value of every component is directly proportional to its remaining life and thus provides a linear relationship in its depreciation value. Replacement cost decides the salvage value rather than initial Capital Cost as shown in 3.1:

$$S = C_r \frac{t_r}{t_c} \tag{3.1}$$

where,

C_r = Replacement cost of the component

t_r = the remaining lifetime of the project and

t_c = the lifetime of the component.

- *Renewable energy fraction (RF):* It is the share of total electrical energy production derived from RE sources. It is defined as:

$$\text{Renewable energy Fraction} = \frac{\text{Total Renewable energy power production}}{\text{Total Energy Consumed}} \quad (3.2)$$

- *Payback period*: It is the time duration in which initial cash outflow of an investment is expected to be recovered from the cash inflows through the investment, it can be calculated as [7]:

$$\text{Payback Period} = \frac{\text{Initial investment}}{\text{Cash inflow per period}} \quad (3.3)$$

Payback period includes annualized costs which is the sum of maintenance cost and replacement cost for every year until the lifetime of the project for either grid connected or stand-alone micro-grid units.

Figure 3.1 shows the input and output functionalities for performing simulation using HOMER. Load demand, Resources, Component details, Constraints, System control, Emission data are the input data requires for the analysis. Once these details are used, according to the available constraints, HOMER results in a set of outputs which includes Optimal Sizing, NPC, COE, Capital Cost, Capacity Shortage, Excess energy generation, Renewable Energy fraction.

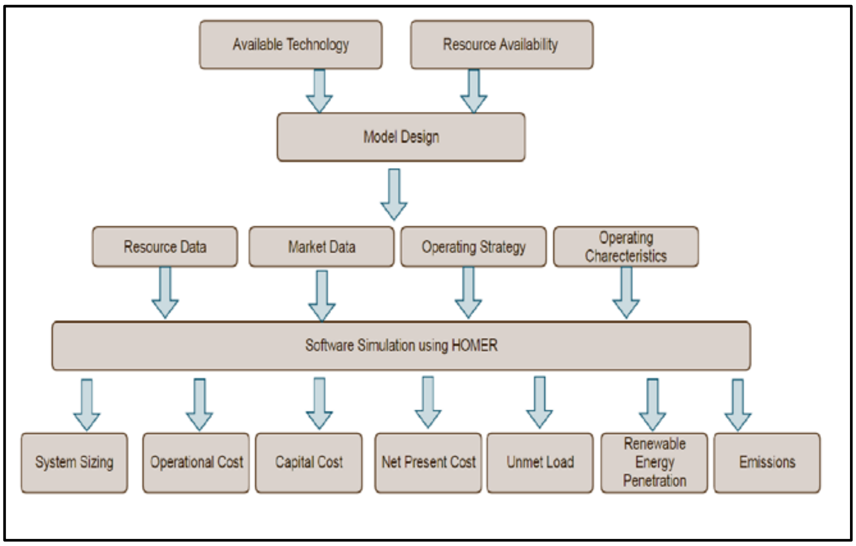


Figure 3.1 Input and output functions for HOMER simulation

3.2.1.2 The algorithm used by HOMER

Figure 3.2 shows the algorithm used by HOMER. The input data, the uncertain parameters, and risk analysis have been explained in detail in previous Section 3.2.1.1. This Section gives an insight into the working of HOMER to provide an optimal solution.

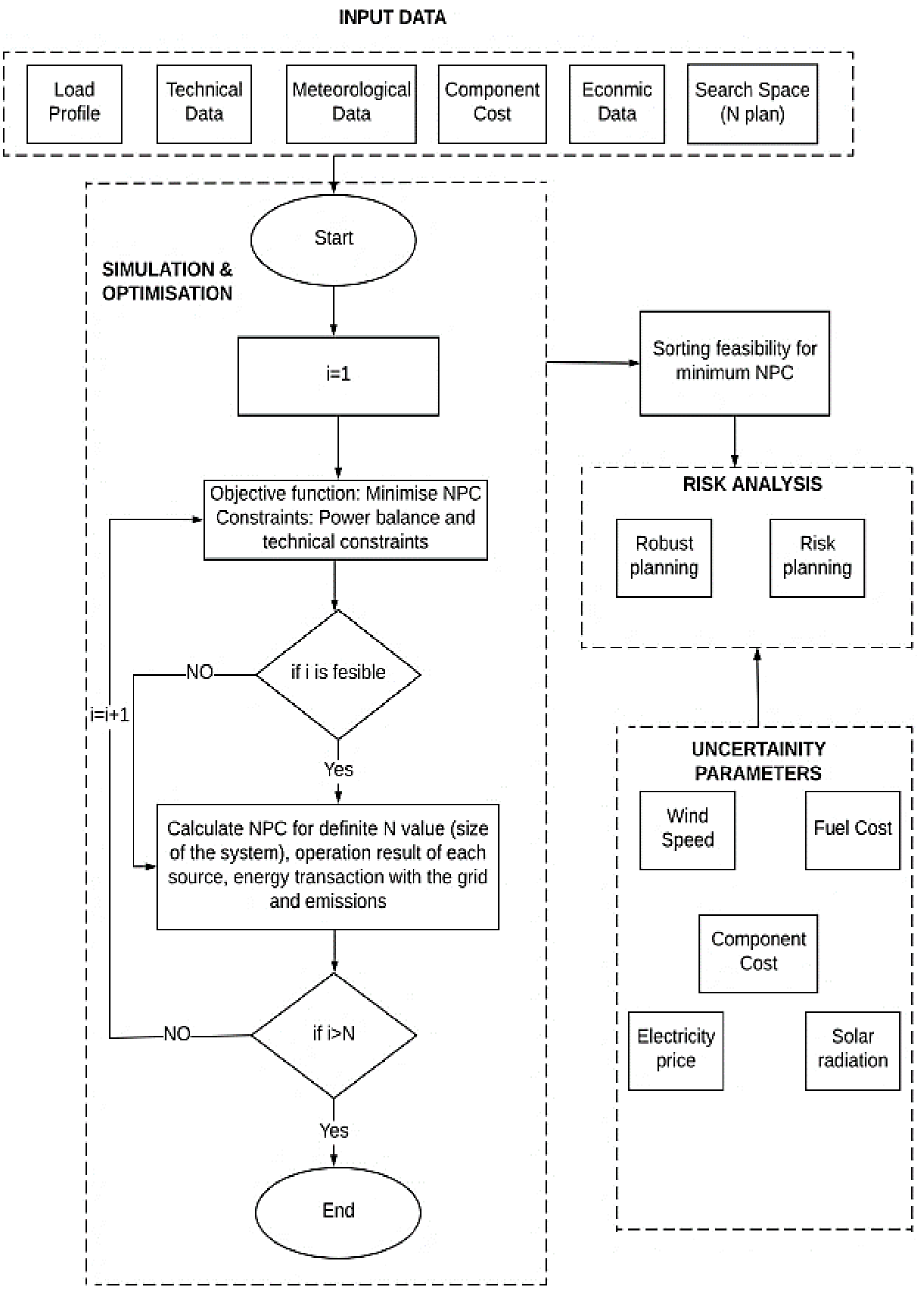


Figure 3.2 Algorithm used by HOMER software [84]

The following steps are followed in HOMER simulation as explained in the algorithm in Figure 3.2:

- Considering user defined input data, uncertainty parameters and risk analysis, for each HRES combinations from search space, perform optimisation and simulation.
- The objective function is to minimise the NPC of the simulated HRES combination. The cost of grid energy purchase, fuel cost, initial cost, O&M costs, salvage cost, revenue (incurred profit) from energy sold to the grid are the factors considered to calculate NPC of the system.
- Considering user defined constraints, e.g: power balance constraint, grid transaction, technical constraints of generators, charging and discharging criteria of battery etc.
- For each of the feasible combination of HRES size, the necessary output is calculated including the NPC, operation results of HRES including the generator, battery, and converter in every time step.
- Also, calculate energy transacted with the grid, and the emissions.
- At the end of each iteration, sort the feasible solutions according to the minimum or least value of NPC.

It should be noted that, a feasibility study is nothing but the study of power balance constraint met for every time step according to the demand. For optimally sizing HRES using HOMER, the uncertain parameters are user defined values e.g.: fuel cost, solar radiation, electricity purchase or selling price, etc. These uncertain parameters are used as sensitive parameters and probability parameters. For each of these uncertain parameters, HOMER simulates and optimises the HRES following the aforementioned procedure and the results having the best solutions are updated in the tabular column [85].

3.2.2 iHOGA

iHOGA, is developed by the Electrical Engineering Department of the University of Zaragoza in Spain. iHOGA is another software tool to study sizing and optimisation of RES connected to the grid or stand-alone systems. Like HOMER, iHOGA can simulate optimum solution using GA. This is done by minimising the energy system cost along the term of the project which would manifest on the NPC. Thus iHOGA, like HOMER, are the so gives a mono-objective solution.

However, iHOGA is flexible to permit multi-objective optimisation also. The multi-objective variables comprise of:

- Minimising NPC.
- Minimising of the unmet load.
- Minimising of CO_2 emissions.
- Maximising Human Development Index (HDI) and job creation.

The user can select any of the aforementioned multi-objective variables can be selected accordingly. Multiple feasible solutions are resulted when the multi-objective optimisation is chosen. This is due to the detrimental behaviour of each objective function to provide a feasible optimum solution. The software can simulate systems of any size ranging from Wh to MWh [86].

iHOGA is based on the C++ programming language used to size the HRES including HFC for the energy generation up to MWh of energy consumption. The software fundamentally considers the sizing of HRES and optimisation for a definite control strategy resulting in the systems with least value of NPC. This predominantly implies, that iHOGA provides mono-objective optimisation (minimizing the NPC), however, it has the flexibility of performing Multi-Objective optimisation for a given situation.

3.2.2.1 The algorithm used by iHOGA

iHOGA is a program that uses GA to determine the optimal sizing of desired energy system including diesel generator and HFC. This software also can size the energy system model for both grid connected and isolated systems. It has built-in PV panel, wind turbine, and battery models, however, the user can define these models for any desired energy systems like HOMER.

iHOGA employs two GAs, one provides the optimum configuration of energy system considered, called the main algorithm; while the secondary algorithm considers the control strategies for the above combination of the system resulting from the main algorithm. The characteristics and methodology of the primary and secondary algorithm are as follows:

- *Primary /Main algorithm:*

  The main algorithm produces the optimal system configurations on minimizing the total system costs for a given lifetime of the project. A mono-objective optimisation minimises the NPC of the system for a given lifetime whilst for multi-objective optimisation, minimising NPCs, CO_2 emissions, unmet load or any other parameter can be considered as objectives. The main algorithm scrutinizes 11 genes, which are all integers, and they are:

a. The number of PV in parallel and its type;
b. The number of WT in parallel and its type;
c. Type of Fuel Cell and the electrolyser;
d. Number of Batteries in parallel connection and its type;
e. Type of A.C. Generator; and
f. Type of Inverter

Each of the integers is assigned a definite code for the simulation. The inverter used in the analysis can be optimised or can be a specific value (its power rated should be higher than the A.C. load power). The variables such as a rectifier, battery charge regulator will be optimised with respect to their control variables or with respect to one another.

- *Secondary Algorithm:*

The user must define the number of system parameters of the system when GA is chosen as an option number-2 for simulation method. To optimise the physical system components, iHOGA must be provided with populations, number of generations and breeding and mutation rates and how uniform the rate of mutation should be, by the user.

For uniform mutation, randomly selected are values for the variables. To perform non-uniform mutation, the values are selected at random as well, but the randomness is such that the random value will be very close to the original value. The solutions computed would be an illustrative of a larger dataset. By means of GA, an optimum solution is produced more effectively. Though, using higher values will give more accurate results, but will increase processing time rather significantly. To avoid this, balance is needed between accuracy and execution time.

For uniform mutation, randomly selected are values for the variables. To perform non uniform mutation, the values are selected at random as well, but the randomness is such that the random value will be very close to the original value. The solutions computed is more representative of a larger data set. Using genetic algorithm helps reach an optimum solution more effectively. However, using higher values gives more accurate results, but increases processing time rather significantly. To avoid this, balance is needed between accuracy and execution time.

For large differences between minimum and maximum values for PV Panels, WTs and batteries are in parallel. There will be many combinations of these constituents for creating the PV system. For the system which has the least value of the constituents, it could create problems while having to cater for the energy demand unless there are any backup sources available such as fuel cells or diesel generators.

The user has the flexibility to choose the optimisation method to be either GA or Evaluate All Combination. If GA is chosen as to be the optimisation method, then the user must define the GA parameters like the number of generations, Percentage of Cross over and uniformity in mutation etc. as shown in the Figure 3.3.

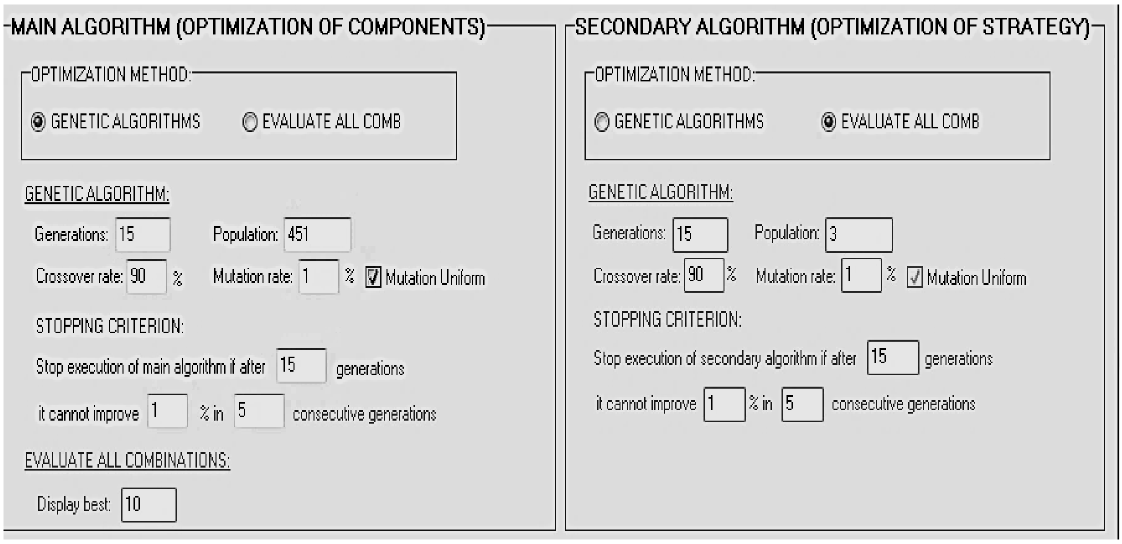


Figure 3.3 The input parameters for optimisation using Genetic Algorithm

The mutation will be either uniform or non –uniform on random considering the variables. However, it is to be noted that for a non-uniform mutation the probability of the randomness is high and thus ending up in a GA simulated generations. If the evaluation considers GA, then the combination of the components is given by (3.4):

$$C_{main} = \left[\begin{array}{c} (\text{Population}_{main}) + (\text{Generation} - 1) \\ \times\ \text{Population}_{main} * \left(\begin{array}{c} \dfrac{\text{Cross over Rate}_{main}}{100} + \text{Mutation Rate}_{main} \\ \times \dfrac{\text{long}}{100} \times \text{Combination}_{sec} \end{array} \right) \end{array} \right] \tag{3.4}$$

If the user choose all combination then:

$$C_{main} = \text{No of PV} \times (1 + \text{No of Max PV in parallel} - \text{No of PV in Parallel}) \times \text{No of WT} * (1 + \text{No of Max WT} - \text{No of Min WT} * C_{Sec} \quad (3.5)$$

If the specified generation has been met, the simulation comes to a stop, with the set of results having least value of NPC.

As discussed earlier, the secondary algorithm takes care of the control strategies to optimise shown in Figure 3-4. If the user considers GA as the secondary algorithm, then the above parameter explained for the primary algorithm like number of generations, percentage of Cross-over etc. should be given. The optimisation of the control strategy using secondary algorithm is given by (3.6):

$$C_{Sec} = \text{Population}_{sec} + (\text{Generations}_{sec} - 1) \times \text{Population}_{sec} \times \left(\frac{\text{Cross over rate}_{sec}}{100} + \frac{\text{Mutation}_{sec}}{100} \times \text{long}\right) \quad (3.6)$$

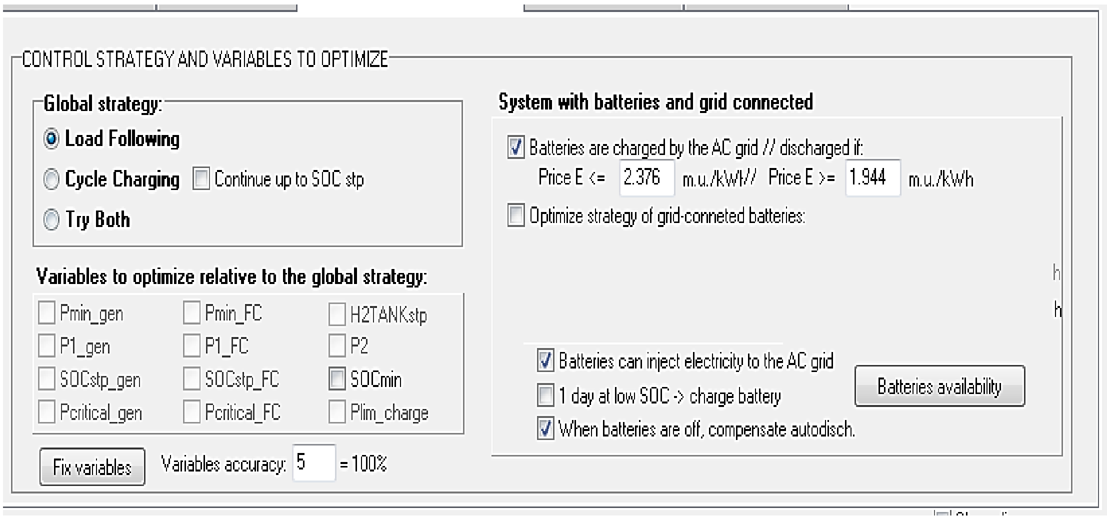


Figure 3.4 Control strategy used by secondary algorithm in iHOGA

As aforementioned, if "evaluate all comb" option is used for either or both main and secondary algorithm, forced optimisation will be applied disregarding the application of GA. For large numbers of variables to optimize, an extremely high value may result. This will render the optimisation process to be unfeasible.

The GA consists of two parts, the Main Algorithm, and the Secondary Algorithm. The aim of the Main Algorithm is to produce the best combination of PV panels connected in parallel, type of generator (PV), type of battery used, number of batteries, any other type of generator (Diesel, wind etc) required to achieve the least cost for an energy delivery system. The aim of the secondary algorithm is to produce the best result for the cost of the system based on a particular control placed and this is done based on each of the elements in the first algorithm. The algorithm used by iHOGA s shown in Figure 3.5.

i. Consider the Main Algorithm to consist of an array of A_k integers. Each of the contents of the array represents the number of constituents of the energy delivery system that are to be optimised.

ii. For each of this array of the Ak integers, the Secondary Algorithm is executed with a random combination of each of the Asec vector elements using a particular control strategy

iii. This results in calculating the NPC for that particular setup.

iv. Once the NPC's are calculated, we perform the crossing and the mutation of the different options.

v. All the NPC's calculated, are sorted to find the best one.

vi. Fitness calculated for the secondary algorithm is represented mathematically as shown in (3-6):

$$\mathrm{Fitness}_{\mathrm{secondary}i} = \frac{(\mathrm{A}_{\mathrm{sec}} + 1) - \mathrm{i}}{\sum_{\mathrm{j}}[(\mathrm{A}_{\mathrm{sec}} + 1) - \mathrm{j}]} \quad \mathrm{j} = 1,2,3, \dots \mathrm{A}_{\mathrm{sec}} \tag{3-1}$$

vii. The fittest vector is the one that has the probability to reproduce themselves by crossing over with the other elements. Crossing over of the vector elements results in a new vector called Descendent. These are evaluated further and they result in replacing the less capable elements with the most capable.

viii. However, for achieving the optimal solution, the solutions have to go through the mutation process by which more changes that are random are introduced by varying the control strategies.

ix. The resultants achieved by the mutation and reproduction make up the elements for the next generation.

x. The mathematical representation of the Fitness of the main algorithm is according to (3.7)

$$\text{Fitness}_{\text{maini}} = \frac{(A_k + 1) - i}{\sum_j [(A_k + 1) - j]}, j = 1,2, \dots A_k \quad (3.7)$$

xi. This process continues until the final criterion (example minimising the NPC , for single objective function) of the number of determined generations are satisfied and that becomes the solution [87].

xii. Jobs created for a given project is the employment created by HRES (example: photovoltaic and wind power by default value used in [88]) is considered per MW is calculated using (3-8) for each of the generated solution.

$$\text{Total jobs created} = \text{Jobs}\left\{\left(PV_{\text{per MW}}\right)\right\} + \text{Jobs}\left\{\left(WT_{\text{per MW}}\right)\right\} + \cdots \quad (3.8)$$

xiii. Human Development Index (HDI) is calculated using (3-9) [89].

$$\text{HDI} = 0.091 \text{ In } \left(E_{pc}\right) + 0.0724 \quad (3.9)$$

where, E_{pc} is the annual per capita electricity consumption

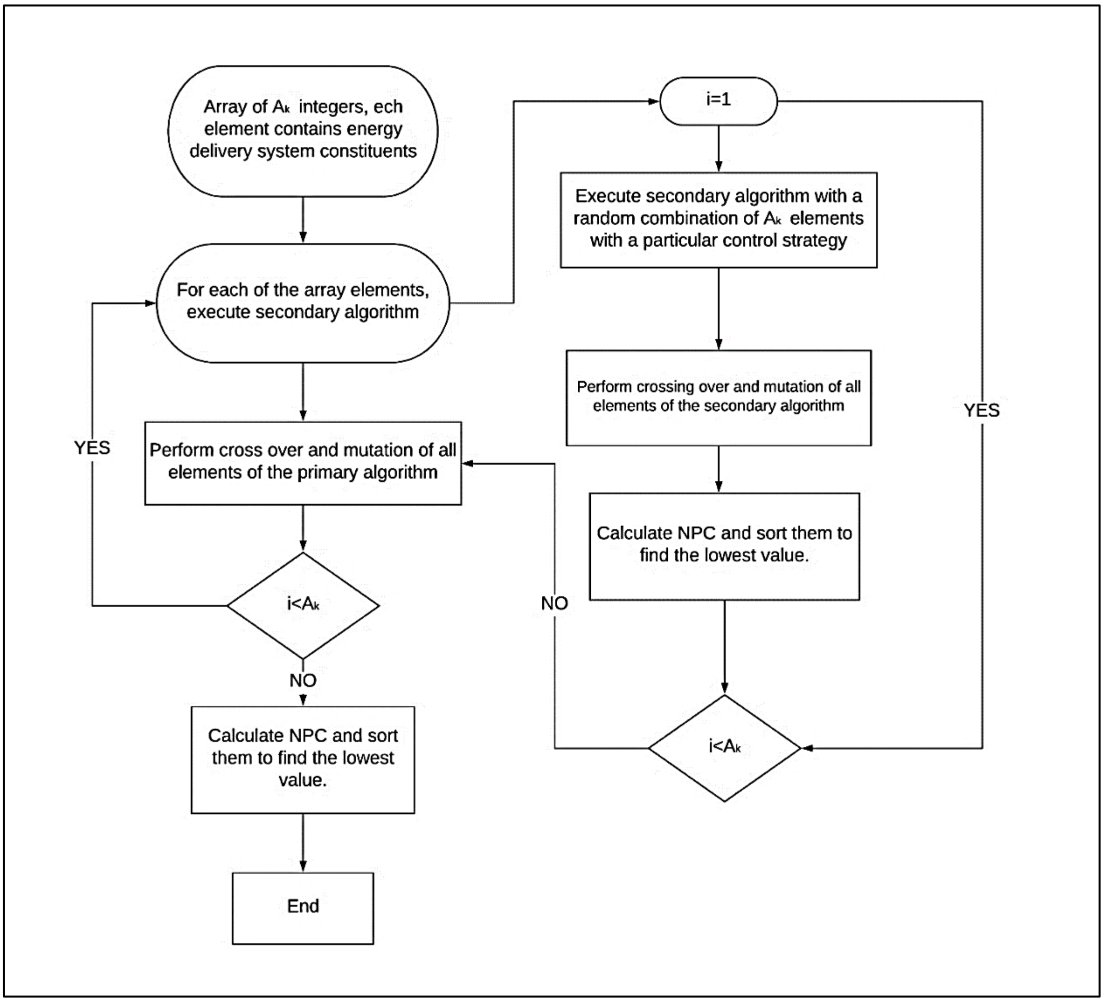


Figure 3.5 Algorithm used by iHOGA

3.2.2.2 Modelling of Hybrid Energy system using iHOGA

Mathematical modelling of the components are considered to design HES by iHOGA [90]. For example:

a) PV Generator – PV cell is the fundamental unit of PV system, which can convert photons from sun to electrical energy. When these cells are connected in series or parallel, forming a solar module, resulting in PV or solar array. The solar irradiation and ambient temperature decide the energy generation using PV. iHOGA can be used to model PV system with or without a tracking system. PV system neglecting tracking system, battery voltage influences the PV generation output given by:

$$V_{bus\ DC} = V_{npanels} \times N_{panels\_series} \tag{3.10}$$

where,

$V_{bus\ DC}$ = D.C. bus voltage,

V_n = Nominal voltage of PV panel,

N_{panel_series} = Number of panels connected in series.

The PV output power is independent of ambient temperature, it is given by:

$$P = \frac{I_{sc} \times S_i \times V_{n\_panel} \times N_{panels\_series} \times N_{panels_{parallel}}}{\text{Loss Factor}} \tag{3.11}$$

where,

I_{sc} =the short-circuit current,

S_i = the global solar radiation on the PV.

On considering the effect of ambient temperature and Maximum Power Point Tracker (MPPT) tracker is given by:

$$P = \frac{P_n \times S_i \times \left(\frac{1 + C_t}{100 \times T_c - 25}\right) \times N_{panels\_series} \times N_{panels_{parallel}}}{\text{Safety Factor}} \tag{3.12}$$

$$T_c = T_{amb} + S_i \times \frac{(TONC - 20)}{800} \tag{3.13}$$

where,

P_n = Nominal power of PV panel

T_{amb} = Ambient temperature

T_c = Internal cell temperature.

For a small PV system when connected to battery storage, number of panels in series is calculated by (3.14):

$$N_{panels\_s} = \frac{V_{busDC}}{V_{n\_panel}} \quad (3.14)$$

For number of panels when connected in series to produce high power, the equation is given by (3.15):

$$N_{panels\_s} = \frac{V_{busDC}}{V_{max\_panel}} \quad (3.15)$$

where,

V_{max_panel} = the voltage of the maximum power of the PV panels in (3.15).

$$N_{panels\_p} < \text{Peak power of generator} * \frac{N_{panels\_s}}{V_{n\_p}} \quad (3.16)$$

However, a disadvantage with iHOGA software is its inability to optimise the RES in series combination. For optimal sizing, the fixed variables are determined by the nominal voltage of PV panels and batteries and the D.C. bust voltage [91].

b) Wind Turbine

Power generated from a wind turbine is given by:

$$P_{WT} = \frac{C_p * \rho * A * V_w^3}{2} \quad (3.17)$$

where,

C_p= Power coefficient, V_w is the wind speed,

A = Area swept by the rotor

ρ = Air density.

The value for aerodynamic torque τ_w is given by:

$$\tau_w = \frac{P_w}{R_w} \quad (3.18)$$

where,

P_w = Power extracted from the wind

R_w = Turbine rotor speed.

c) Battery System

A storage system is mostly considered in designing hybrid energy system to produce uninterrupted power. On the basis of daily energy (E_{daily}) consumption of the desired location, storage battery systems are usually designed. Any interruption in the power supply due to the energy resources used, number of autonomous days (AD) are considered during the system design. The battery storage capacity calculated using:

$$C_{batt} = \frac{(E_{daily} \times AD)}{(\eta_{inverer} \times \eta_{battery} \times DOD)} \tag{3.19}$$

where

DOD = Depth of Discharge of the battery (allowable value)

$\eta_{inverte}$r = Bidirectional inverter efficiency

$\eta_{battery}$ = Battery efficiency.

d) Charge Regulator

Controlling the charge flow between load, battery and RES (like PV, WT) is the performed by the charge regulator. This device not only aids in the protection of RES from overcharging and swift discharging, it also helps in efficient utilisation of these energy sources.

e) Bi-directional Converter

The bi-directional converter is used when the A.C. and D.C. loads are considered in the system. The maximum value of the load (peak load) decides the converter rating. The usually available bi-directional converters will normally include the PV battery charge controller.

Along with the aforementioned hybrid energy systems, iHOGA also includes modules for HFC and diesel generator. These modules are considered beyond the scope of the current study; hence they are not included in this Section 3.2.2, while only the HRES design for PV, WT along with battery for a micro-grid model is focussed here. iHOGA also provides an option for systems to connect to the grid. The software also provides an advanced setting for the purchase or selling of deficit or excess energy respectively which provides a financial analysis considering feed-in-tariffs.

3.3 Utilisation of HOMER and iHOGA in Case Studies

3.3.1 Utilisation of HOMER in Case Studies

HOMER has been widely used for the study of DER to introduce RES in it. The widely studied RES are solar and wind energy either connected to the grid or stand-alone (connected to the storage unit) mode. The economic analysis have been made using HOMER in all the studies for different locations in different regions. It is commonly observed that, for places which lack grids, for example, Island, isolated village etc, the stand-alone RES options are explored. It is observed that to optimally size the RES, a realistic system can be considered to optimise using HOMER. It can include the stochastic behaviour of the renewable energies and variation in the load every hour in a year which makes HOMER a unique technique for optimisation. This software has been appearing consistently in the literature proving it to be the reliable software for optimisation study [76]. It can be used for both A.C. and D.C. loads, and the can be modelled for different energy source. However it comes with an inbuilt database which makes the modelling of the energy sources easier. HOMER produces the best feasible solution for different combination of energy resources and sort it out according to the cost effectiveness.

The Appendix A-1 provides a synopsis of studies conducted using HOMER software since the year 2000.

3.3.2 Utilisation of iHOGA in Case Studies

There have been many references to iHOGA as one of the software used for optimally sizing the hybrid energy systems, though not many studies have been conducted using this software. Appendix A-2 provides a list of case study conducted using iHOGA software.

3.4 Conclusion

There are many ways to optimally design and size RE systems for different locations in order to analyse the available energy resources and daily consumption data. Study suggests the optimal designing of RE is meant to be more reliable using the software. Nonetheless, there are many studies on HOMER software which is considered more reliable by many energy providers in Australia. Not many other software packages have been explored other than HOMER. The current study aims at exploring iHOGA software other than HOMER is to understand the sizing of RES. As discussed earlier, the objective of both the software analysis is to reduce the NPC of the system considered. However, the analysis made by HOMER is an analytical method of evaluating all the combinations while that of iHOGA is using a GA along with evaluating all the combinations methods.

Both the software includes preliminary steps involved in simulation and they are as follows:

- Choosing the desired location to introduce hybrid energy systems
- Understanding the load requirements
- Analysing the Market data
- Ascertain the renewable energy behavior
- Designing of the best-suited energy system for the requirement
- Simulating using the software

The steps for simulations will be explained briefly in Chapters 4 and 5 as an application of these software packages.

Chapter 4

Renewable Energy Policies Assessment

4.1 Introduction

The drive for RE and its major share in the energy mix is related to the energy market and policies. These energy policies also result in industrial development. As already known, RE technologies are too expensive to compete with the conventional sources which are very well established in the energy market for a long time in most of the countries in the world. Despite the hurdles that RE technologies are experiencing, there has equally been a greater advancement in their adoptability in the energy market for a long time. This is due to its technological advancement and energy policies put forward by the governments of the respective countries to reach their RETs. This chapter gives an insight into the RETs of a developing country like India and developed country like Australia. It also illuminates how the two countries are dealing with their energy policies, the path they take to reach their energy targets [92].

RE sources have been a beneficial energy option mainly in developing countries. However, these technologies are difficult to afford in such countries. Focus on the energy policies would make the RES more competitive with respect to the available conventional energy sources and make it more affordable to people in a country like India. Thus, these energy policies would not only have a substantial impact on the industrial growth but also provide support to countries in combating climate change resulting in meeting their respective energy targets.

4.2 Renewable Energy Policy

The definition of RE policy is: "*The strategy in which the government addresses the issues of energy development and the energy industry development to sustain growth which includes energy production, distribution, and consumption. Attributes of these include legislation, international treaties, and investment incentives. The strategy will play a vital role to reduce the impacts of global warming and any crisis in the availability of energy* [93]. The primary motive of energy policies are to decide not only the energy security, costs of RES and their environmental impacts, but also the wide employment opportunities and energy-related business opportunities from other countries. The new energy investment in clean energy in the last decade illustrates a dip in the investment in solar and wind energies, while this dip is more prominent in the year 2016 compared to year 2015. Clean energy, however, has a downfall of 18% in 2016 compared to 2015 as shown in Figure 4.1 [94].

According to the Bloomberg report – ‘*Policy support for renewables remains fickle. A less friendly turn by the new UK government after the May 2015 election has been one example, and another may be the US Supreme Court’s decision in February 2016 to allow all legal objections to the Environmental Protection Agency’s Clean Power Plan to be heard before it can be implemented. It is also possible that the recent big fall in coal, oil and gas prices may tempt some developing countries to keep relying on the fossil-fuel capacity for longer*’.

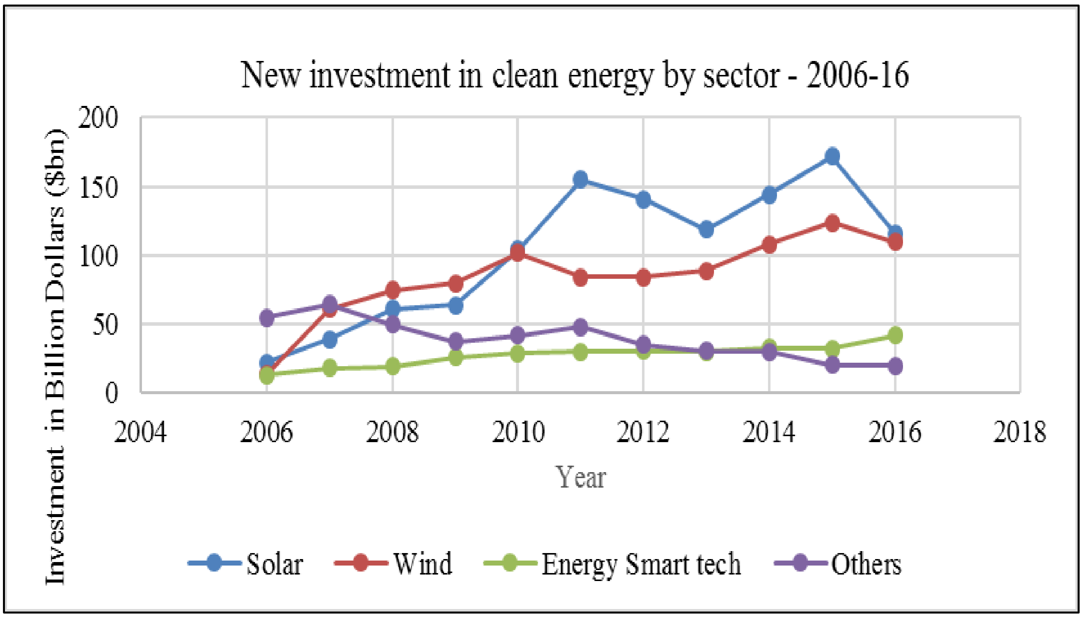


Figure 4.1 Investments in billion Dollars in new investment made in the Clean energy sector from 2006-2016

This suggests that the energy policies, decided by the respective governments, have a major impact on the global renewable investment energy market and countries’ development [95].

4.3 India’s Renewable Energy Scenario: An Overview

“India’s forecast is more optimistic as it moves to address the financial health of its utilities and to tackle grid-integration issues. By 2022, India is expected to more than double its current renewable electricity capacity. For the first time, this growth over the forecast period is higher than the European Union. Solar PV and wind together represent 90% of India’s capacity growth as auctions yielded some of the world’s lowest prices for both technologies. In some Indian states, these recent contract prices are comparable to coal tariffs. India’s accelerated case indicates that renewable capacity expansion could be boosted by almost a third, providing that existing grid integration and infrastructure challenges are addressed, policy and regulatory uncertainties are reduced, and costs

continue to fall. This deployment path could put India's growth on par with the United States, thus becoming the joint second-largest growth market after China. - (IEA: RENEWABLES 2017- Analysis and Forecasts to 2022).

In 2015, India announced the RET, increasing about five times the installed capacity of RE to 175GW by 2022 compared to 34GW in 2015. With such an assertive target from the Government of India in this scenario, there is a notable impact on its energy policies and regulations to integrate RE in the Indian energy mix. India has a peak electricity demand of about 150GW while the total installed capacity is 270GW, making it one of the world's largest electricity transmitter and distributor. State governments in India own about half of the installed capacity while one third is owned by the central government Co-operations and the remaining owned by the private sector.

To encourage the development of RE in India, the government launched a commission for Additional Sources of energy in Department of Science and Technology in 1981. In 1982, an autonomous department of Non-Conventional Energy systems was started which later in 1992 became the Ministry of Non-Conventional Energy sources (MNES). In 1987, to finance RE projects, the Indian Renewable Energy Development Agency (IREDA) was established. In October 2006, MNES was renamed as Ministry of New and Renewable Energies (MNRE). MNRE is the important entity for the RE development of the country due to its vigorous demonstration in incentive schemes and an extensive support of research and development [96]. India's development in the RE sector is backed up by the intense energy policies shown in Figure 4.2.

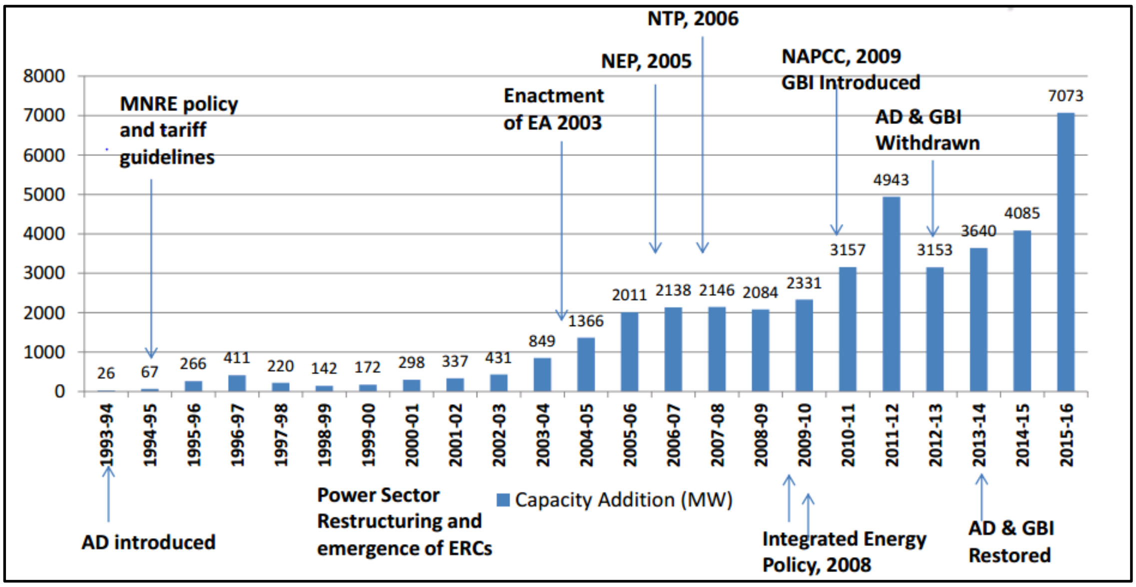


Figure 4.2 India's energy policies over the years until 2016 [97]

4.4 Renewable Energy Policies and action plan to assist Renewable Energy adoption in India

In the last decade, the Indian Government aided by MNRE has introduced several RE policies and they are listed in Table 4.1 [98].

Table 4.1 Renewable Energy Policies of India

Act	Year	Objectives/Achievements
Electricity Act (EA)	2003	• Develop national policies for the optimal utilization of RE. • Promote RE through grid connections and grid sale. • Minimum percentage of RE was fixed by SERCs under Renewable Purchase Obligation (RPO)
National Electricity Policy (NEP)	2005	• Encourage private participation and thus reducing the Capital Cost due to competition. • Promote RE by setting up fixed tariffs by SERCs
National Tariff Policy (NTP)	2006	• Minimum procurement percentage to be set by April 1, 2006. • SERC to determine and setup a preferential tariff to enable RET's to compete. • Enable distribution licensee to procure RE through competitive bidding • Mandate a minimum purchase of Solar Specific Renewables through RP) starting from a minimum of 0.25% 2012-13 to 3% by 2022. This was amended in 2016 to be 8% by 2022.
National Action Plan on Climate Change		One of the eight-core "National Missions" running through to 2017 was to set RPO to be set at 5% of total grids purchase, increasing by 1% each year for next 10 years.

4.4.1 Renewable Energy Certificates (RECs)

It is known that nature has unevenly spread her RE sources in India. In addition to this, the levelised costs of clean energy are becoming more expensive than the environmentally unfriendly fossil fuels. This has implications for the finances of power distributors. These distributors minimise their RE power purchase beyond the State level regulatory authority fixed RPO. To make this more compatible, Renewable Energy Certificates (RECs) were introduced. These certificates also motivate states, having greater potential to harness more renewable energies for energy generation. Supplementing this cause, RECs also help to create a national level market for these generators and assist their financial burden and provide them with the opportunities and more RE investments. A regulation will be declared by the Central Electricity Regulatory Commission (CERC) on RECs on fulfilling its mandate to promote RE and its use in the electricity market.

Thus, RECs act as an instrument in promoting both RE in the country and RPO. From the perspective of the RE generators, energy can be sold in two ways:

a) To sell the energy at preferential tariff rates;
b) To sell the electricity generated and other environmental credit related to the RE generations.

There are two classifications of energy certificates available namely: an eligible entity can procure the certificates on the energy produced based on solar energy solely and on non-solar RE (energy through other forms ex: wind). These certificates are eligible only for RE generation up to 1MWh (1000 units) fed into the grid.

The government provides further subsidies to promote RE in the form of fiscal incentives, which include:

- Accelerated depreciation;
- Generation based incentives;
- Capital subsidies for off-grid systems;
- Support for research & development;
- Income tax holiday and
- Concessions on excise and customs duties.

India is a country bestowed with high wind resources, and the country is equally harnessing wind energy by being the fourth largest country to have wind power installed capacity, after China, USA and Germany, of about 27,441MW (as on 2016). The Government of India has introduced major policies on wind energy, they are:

- Income Tax Holiday $80/ 1Ampere for 10 years.
- 100% exemption on excise duty.
- Concessions can be availed on customs import duty in relation to the import of specified parts and components.
- Special Additional Duty (SAD) can be exempted from in certain parts and components of wind turbines.
- FiTs fixed by the state regulators.

- Generation based incentives at INR0.50/unit and above FiT, the ceiling of INR10 million/MW.
- Accelerated Depreciation at 80%.
- States with potential wind energy providing promotional tariff for wind power projects to promote RE through the wind as shown in Table 4.2.
- States also provide concessional wheeling, banking, Electricity Duty and Cross Subsidy Surcharge.

Table 4.2 India's Wind Power Project State wise Power Tariff in INR/kWh

State	Power Tariff (INR/kWh)
Kerala	4.77
Gujarat	4.15
Madhya Pradesh	4.78
Karnataka	4.50
Rajasthan	5.76 & 6.04
Maharashtra	3.82-5.56
Tamil Nadu	4.16
Andhra Pradesh & Telangana	4.84

4.4.2 National Solar Mission (NSM)

In June 2008 the Government of India initiated National Action Plan on Climate Change (NAPCC) policy which proposed an investment on R&D and infrastructure to make solar energy a major part of its energy mix. In 2009, NSM as JNNSM was launched and it became one of the eight National missions under NAPCC. The main ambition of this mission is to generate power through the solar energy of 20,000MW by 2022. In addition to this, NSM also aims at cost rebates through solar power generation by focusing on [99].

a) Long-term energy policies,
b) Disposal of large-scale goals,
c) In-house production of raw materials and components and
d) Channelizing on R&D

NSM includes a set of targets divided into three phases, however, the deployment targets can be made flexible with the timeline based on its achievement. However, the target of reaching 20,000MW was escalated five times to 100,000MW by 2022 by the current Prime Minister. This target includes 40GW rooftop PV through large and medium scale grid connected solar power projects which would lead to India becoming one of the largest clean energy producers in the world. A set of targets have been illustrated in the Table 4.3 [100].

Table 4.3 India's target for NSM

Segment	**Targets**		
	Phase 1 (2010-2013)	Phase 2 (2013-2017)	Phase 3 (2017-2022)
Solar Collector (CSP)	7 million m^2	15 million m^2	20 million m^2
Utility power grid including Rooftop	1000MW to 2000 MW	4000MW to 10,000 MW	20000 MW
Off-grid solar Application	200 MW	1000 MW	2000 MW

4.4.3 Policies and Framework to Assist NSM Target

Though the existing Electricity Act 2003 concentrates RE, the magnitude of NSM demands stringent amendments. Nevertheless, The National Tariff Policy 2006 focuses on the fixed percentage of energy purchase per the available RE. A mandatory solar purchase with the help of REC obligates to 0.25% in phase 1- 3% by 2022 by the states. To cut the average cost of solar power and aid investments in achieving the mission's goal, the CERC has issued guidelines for fixing FiTs which would be monitored and reassessed. To promote the NSM at its incubation level, the Ministry of Power, the NTPC, and the Central Electricity Authority, simplifies the selling off the solar power generated, thereby minimising the financial burden on the Government.

This mission includes the promotion of rooftop PV, and small solar power plants, connected to the Low Tension (LT)/11 KV grid. In this regard, it is proposed that the distribution utility will pay FiTs as determined by the State Electricity Regulatory Commission for the metered electricity generated from rooftop solar or ground mounted installation. Under NSM, Generation Based Incentive will be paid to the utility, which is the difference between the solar tariff determined by the CERC for the concerned solar generation technology and a base price of INR5.50/kWh with 3% annual increments. For the development of solar parks, the central government grants fiscal incentives and rebates on customs duties and excise duties concessions on specific capital equipment, certain materials, and components. This mission also prioritizes India to be the indigenous manufacturer on a global scale. The available manufacturing facility in India is about 700MW which is very low compared to its mission's target; complementing this fact, India lacks the manufacturing facilities for solar thermal power plants. These are some of the hurdles India must surpass to achieve its goal. It also emphasizes the energy efficiency 5-star rating of the equipments. To finance these facilities, the Government has introduced Special Incentive Packages (SIPs) for both solar panels and CSP manufacturing companies. This has become the key to attracting about 15 manufacturing companies to aim for 8-10 GW solar power by 2022. NTPC has a wholly owned subsidiary company engaged in the business of trading of Power – NTPC Vidyut Vyapar Nigam Ltd. List of States which have announced Solar Policy and have encouraged setting up of solar projects is shown in Table 4.4. However, it can observed that some States have not taken action to meet RPO [101].

4.4.4 Tracking the Mission's Successive Progress

To monitor the NSM's progress and improvements, certain strategies have been undertaken by MNRE which are as follows:

i. Reviewing the mission's progress MNRE would conduct quarterly meetings.
ii. Conducting monthly meetings to record the utilization of funds, progress on the projects of funds utilized, progress made on on-going projects, hourly/monthly output from systems etc.
iii. Monitoring the growth of independent Monitoring and Verification (M&V) Systems.
iv. Intensifying IT systems which reports the progress of M&V system status

MNRE considers certain indicators to measure the mission's success, which includes: grid connected RE's share in the energy mix; the deployment of off-grid (decentralised) systems with respect to their targets; implementation of RES in isolated/rural/ industrial areas to where conventional energy is used; and improvement in the quality of RES and monitor the consumer's satisfaction in deployment of RES.

Table 4.4 India's State Solar Programs

Sl No	State	Solar Program
1	Gujrat	• Announced – 968.5 MW, • Commissioned – 857.9 MW
2	Karnataka	• Commissioned – 24 MW, Approved Plan for 200 MW • Project allotted – 70 MW, Min. tariff – INR7.94/Unit 10 MW Commissioned on 05 Jun 13 • LOI Issued-130 MW
3	Andhra Pradesh	• Tendered - 1000 MW • The bid received for 400 MW for tariff INR6.49/- • PPA signing is under process
4	Punjab	• Tendered for 300 MW out of which capacity of 250 MW under allotment
5	Tamil Nadu	• Announced – 3000 MW, • Tendered 1000 MW out of which LOI for 701 MW issued, • Commissioned – 17.105 MW
6	Uttar Pradesh	• Aims at the capacity of 500 MW till March 2017 • 130 MW allotted. • A JVC is proposed between UPNEDA and NHPC Ltd. initially for 50 MW and the total target is 100 MW.
7	Odisha	• Allocated 50 MW in two phases of 25 MW each • Awarded -25 MW, Minimum Tariff – INR7/Unit
8	Rajasthan	• Tendered – 200 MW (100 MW PV + 100 MW ST), 75 MW PV allotted
9	Maharashtra.	• Commissioned– 125 MW under State initiative and 35 MW under REC scheme
10	Bihar	• 50 MW allotted and 100 MW tendered.
11	Chhattisgarh	• Aims at the capacity of 500 to 1000 MW till March 2017 • As per the policy SPDs are registering and till now the response of total capacity of 500 MW received. 7 MW commissioned, 50 MW in the pipeline.
12	Madhya Pradesh	• Awarded 200 MW 15 9 Madhya Pradesh • Awarded 200 MW • MinimumTariff-INR7.90/Unit • Commissioned-122.315 MW

While the Government of India has taken ample measures and strategies in making this mission successful and entitling India to lead in global RE, there exist certain barriers which the country must surpass. Though there has been a monetary support for the development of RE in the country through ongoing policies and budgetary support, there is a lack of RE deployment that is especially for off-grid systems. This includes the disparity in the accessibility of decentralised RES to Capital Costs, adoption, and technological advancement. The system lacks technology innovations and strategies for RES implementation.

4.5 Australia's Renewable Energy Scenario Overview

Australia is bestowed with a rich amount of renewable energies like solar, wind and bioenergy sources. Other than renewable energies, Australia is the biggest exporter of uranium and coal. With coal being the major share of the energy mix makes the island one of the largest carbon emission country globally. In 2010, Australia dominated in exporting Natural Gas. To mitigate the emissions and assist in keeping the global temperature rise to under 2^0C, Australia has signed an international agreement at the 2015 UN climate negotiations in Paris. Since then RE has played a crucial role in mitigation of Australia's GHG emissions. The recent RET put forth by the government includes a RE of 20% by 2020.

Australia is facing many issues in the energy sector. The oil plants and coal plants have hit their maximum lifespan and are now shutting down. Recent shutdowns include Hazelwood power station in early 2017, supplementing the fact that the fragile electricity grid has resulted in chaos and statewide blackouts. A major incident occurred on 28th September 2016 due to South Australia (SA) experiencing an isolation from the main electricity grid, with more blackouts than in the last 50 years. This major natural disaster caused about $300 million loss in the state. Though SA was endowed with renewable energies, integrating these into the grids made it vulnerable. Poor energy policies and the nation's politics have put Australia under a huge energy crisis, lack of Carbon tax has led to bulkier electricity bills due to energy deficits.

Wind and solar do not have the same qualities as other power from coal and hydropower. These systems are very sensitive systems. Australia grid is one of the biggest. Its 20th-century grid is now facing 21st-century problem. Grid stretches almost 5,000km end to end from Port Douglas in North to Hobart to Port Lincoln in West. Old coal power station is hitting their end of life, renewables will have to fill in the need for energy.

The 2030 Emission target has set 26-28% emission by 2030 and by 2050, zero net emissions [102]. Technology will be the key; however, the Government is focussed on RE and energy security with zero emissions. Australia Gas and Light Company (AGL), the country's largest energy generators has decided to be out of coal utilisation by 2050 regardless of carbon pricing. Gas is seen as the bridge to the future between coal and renewables. Australian gas is sometimes cheaper in Japan than Australia this is due to the catastrophic failure of the National Energy Market (NEM) and energy policy. Reklan solar coupled solar battery and grid is the first project of this kind in Queensland. Baseload power generator and generation where demand is needed. Solar is intermittent and having battery matched will be the best. Installation like this will be the solution. Large-scale wind, solar and hydro farms with batteries can give power all through the day [103].

4.6 Renewable Energy Policies in Australia

4.6.1 Renewable Energy Target

Mandatory Renewable Energy Target (MNRET) existed until 2001 to incorporate a minimum of 2% of RE into electricity production of Australia. This was later renamed as RET. This target was later increased up to 20% of total energy production through RE in 2009. In January 2011, the RET was further subdivided into:

- *Large Scale Renewable Energy Target* – This scheme concentrated on large scale project assistance such as, setting up large solar and wind farms by providing financial incentives. This would eventually contribute towards Australia's 2020 RET. One of the other remits to this scheme was to provide energy certificates depending on the size of RE installation. The certificates thus procured could be used to trade in the RE being sold to the grid. This could also include the energy transactions between the entities who are legally bound for RET. Clean energy regulator would then receive these certificates.
- *Small Scale Renewable Energy Scheme* – Similar to the Large Scale Renewable Energy Target, this scheme focussed on providing financial assistance towards the installation of RES for small businesses and individuals. The certificates issued towards these individuals and small businesses works similar to that of the Large Scale Renewable Energy Target.

4.6.2 Clean Energy Innovation Fund

In 2017, the Australian Prime minister and Environment Minister have sanctioned $100 million annually for a decade by forming of Clean Energy Innovation Fund (CEIF). Clean Energy Finance Corporation (CEFC) and the Australian Renewable Energy Agency (ARENA) administer the CEIF by initiating loans to business and supporting the development of emerging technologies. In cooperation with Australia's Paris commitment in investing on new energy technology, CEIF's would be on par with the same interest.

4.6.3 Aiding the Solar Boom

Australia is the country with the highest per capita rate of household solar installation in the world, yet it uses fossil fuels as the main energy source. Since 2015, the main concern of Australia is that it has never been in the top 10 countries in solar and large-scale wind energy adoption. To address these issues Australia's CEFC and ARENA in their two funding programs, have targeted additional 300MW large-scale projects. In 2016, the government of Australia put forth its interest in funding for solar panels with battery storage in Australian communities for the support and deployment of battery storage technology.

4.6.4 Low Emission Technology

Australia has aimed at the largest challenge when compared to major developed countries, which is emission reduction: to mitigate emissions below 52% per capita emissions compared to 2005 which was 26-28% and about 67% in emission intensity. A roadmap to this low emission is to target new innovations and invest in low emission science and technology. To achieve large-scale development, CSIRO, along with other energy experts, industries and stakeholders merge with international partners to attain better prospects. This would give a better opportunity for Australian businesses to be represented in the global market thus creating new jobs [104, 105].

4.6.5 State Renewable Energy Target

In order to achieve Australia's RET, the state governments have announced their individual RE targets. South Australia in 2014, has set a target of producing 50% electricity from RE, their current contribution is 40%. Recently, the South Australian

Government has aimed to attract $10 billion investment in RE by 2025. A RE plan for in 2011, South Australia introduced an RE plan to position the state as the best place to do business for RE. This plan included:

- Introducing legislation to grant access to energy developers to use government owned farmland
- To introduce a model of community-owned solar and to support the design and implementation of it.
- Limiting the carbon emissions for new generation of electricity.
- Supporting the building of solar power concentrators for hearing and electricity use in Port Augusta.

ACT in 2014, announced its own RET of having 50% of its energy production through RE by 2020. To get to this target, the ACT has announced a RE strategy called Action Plan (AP2), which monitors the state's RET and emissions. This plan highlights the state's expansion of around 72 MW of small and medium scale solar PV and 690 MW of large-scale RE and by the end of 2020.

NSW has introduced Renewable Energy Action Plan which aims to assist the uptake of RE. To do this, the plan includes 24 actions and 3 goals. These goals consist of:

- Attract RE investment.
- Build support among the community to increase RE adoption.
- Attract people and companies with expertise in RE and growing the expertise.

Governments of ACT and NSW have partnered with the Regional Development Australia agency and 20 large scale industries to introduce South East Region of Renewable Energy Excellence (SERREE) to help increase and improve the financial investment in RE.

The State of Victoria in 2016 has also committed to production of electricity from RE to reach 25% by 2020 and 40% by 2025. Victoria is in a unique position as it has an abundance of both wind and solar energy resources, although, this is in danger of not being exploited to its fullest extent due to weak and misguided energy polices which make it hard to invest in RE. Some of these are as below.

- Prohibited areas for wind generation.
- Allowing landowners, the final say in allowing whether WTs to be located.

Queensland has also announced that it would want to see the share of RE in total energy output reach 50% by 2030 and has also committed to having up to 1 million home rooftops to have solar installed. Queensland has also introduced a strategy named PowerQ which aims to reduce the emissions from its electricity sector between 2016 and 2026.

Tasmania already has the largest renewable energy mix in the total electricity production with wind and hydro contributing near 93% of the total electricity production. Prior to the 2014 election there was a plan to introduce the effort towards 100% RE, but this plan has since been abandoned.

Northern Territory (NT), has an abundance of solar energy, but does not have any RET or any plans to reduce emissions RE. It also lacks a climate change policy [107].

4.6.6 Renewable Energy Power Percentage (RPP)

Renewable Energy Power Percentage relates to the RE in accordance with large-scale generation certificates in par with total estimated electricity consumption during a certain period of time. RPP was 12.75% in 2016.

The RPP is the liability rate under the large-scale RET. The RPP is the predetermined annual target set to achieve the large-scale RET of 33,000GWh by 2020 as defined in Section 40 of the *Renewable Energy (Electricity) Act 2000.*

Every year, liable entities acquired large-scale RET liability by purchasing large-scale generation certificates. If the entity does not meet the necessary obligations, the entity may have to pay a large-scale generation shortfall charge. The number of such certificates, which an entity should surrender each year, would be a proportion of the amount of electricity acquired in that year. The amount to be surrendered would be determined by multiplying the RPP by the liable entity purchases minus any exemption certificates each year.

Calculation of the RRP considers the following points:

- Amount of renewable electricity required for the year;
- The total amount of electricity that will be acquired during the year;
- Whether there was more or less supply of renewable electricity under the scheme in previous years; and
- Any of the exemptions to be claimed for the year.

Renewable Energy (Electricity) Act 2000 was amended in June 2015 to allow complete exemptions from liability for Emissions-Intensive Trade-Exposed (EITE) activities. As a result of this, the Clean Energy Regulator amended the partial certificates issued for 2015 to be a full exemption. Calculations of the 2016 RPP and Small-scale Technology Percentage (STP) have been completed by taking into account the full impact of increases in 2015 exemptions due to the move from partial to full.

4.6.7 Renewable Energy Certificates (RECs)

Until January 2011, Renewable Energy Certificates were mere commodities, but were then segregated into small-scale technology certificates (STCs) and large-scale generation certificates (LGCs).

- STCs: STCs are entitled to small-scale generation including solar water heaters, air source heat pumps and small generation units (small-scale solar panels, wind, and hydro-electricity systems. One STC is equivalent to 1MWh of electricity generated by a small renewable generation unit or 1MWh of equivalent electricity generated that is driven by solar water heaters or air source heat pumps. Depending on the status of REC market these LGCs are priced accordingly.
- LGCs: LGCs are like STCs but the generation capacity entitled to them is much larger. RE power stations should be accredited to gain LGCs which are based on the generation capacity that they produce and it considers wind and solar farms, and hydroelectric projects of larger size. One LGC is equivalent to renewable electricity generated by the aforementioned power station baseline. The LGCs thus obtained can be used as a currency to transfer or exchange with individual or business entities. Clean Energy Regulators obtains the sold certificates from the energy retailers to whom LGCs are being given [106, 107].

4.6.8 Feed-in-Tariffs (FiTs)

If energy from wind or solar is fed to the electricity grid, some amount of profit is created as revenue, this is called FiTs. The energy retailers or the government commonly sets the FiTs. This not only aids in easy RE adoption, it also minimises the IRR of the project. FiTs also help in scheduling the energy consumption according to the available RE source. However, it could also help in reducing the energy consumption. FiTs helps in minimising the vulnerability of electric grid. FiTs help in minimising the grid's vulnerability to natural hazards through decentralisation of electricity generation. The other advantage of FiTs is the diversification of the energy generation thus reducing the risk management of the energy source.

The procedure to obtain the benefits of FiTs, certain procedures are to be followed by the owners of the small business entities, they are as follows.

- Installation of suitable RES.
- Submission of application to get qualified for FiTs.
- Signing of the contract to feed the electricity generated to the grid.

Once the contract has been signed, which is mostly a fixed term, the validity of it is until the owners exist in their respective properties as on the contract application. FiTs are directly related to the price of the RES. In the last decade, it is observed that the price of RES (PV in particular) has reduced considerably. This has made PV more affordable in reaching the rooftops of several households. This resulted in state government slashing of FiTs to less than 10c/kWh. Table 4.5 elucidates the PV installations in different Australian states.

Table 4.5 PV installations in different states in Australia [108]

State/Territory	**MW**	**Installations**
Northern Territory	50	6,253
Queensland	1602	485,794
Victoria	968	294,815
South Australia	690	200,213
Australian Capital Territory	77	17,085
Western Australia	645	211,091
New South Wales	1314	343,930
Tasmania	98	27,836
TOTAL	5444	1,587,017

- Reports suggests that Queensland and SA are contending to reach the top position with their PV rooftop installations reaching 30%. This is due to the abundant solar energy these two states are capable of harnessing. More than 20 projects have been signed of 1gW and more capacity of PV installations whilst total large-scale project of 3.7GW capacity are in the pitch [108].

- State like ACT used reverse auction method to fix the FiTs, where the entity who bids for the lowest price are chosen. This reverse auction approach invites large number of investors to bid.
- 3968 PV units producing 10MW power at Morphet Vale in SA have been installed. SA's RE production reached a whopping 100%, which exceeded the total demand on a given working day. This has further cemented SA's status as the leading RE producing state. The minimum FiT in SA for small-scale PV systems is 6c/kWh.
- 4185 solar PV systems producing close to 10 MW have been installed at a home in Hoppers Crossing, Victoria. Although, coal is the major source of energy in Victoria, the state's RET is driving the RE Adoption. The minimum FiT in Victoria for small-scale PV systems was 5c/kWh until January 2017 when it was increased it to 11.3c/kWh from July 2017.
- In Queensland, the FiT concept is absent; instead, the houses that have adopted grid connected RET receive a definite rate which is decided by the energy retailer. However, FiTs exists in regional areas. In Tasmania, FiT is fixed to 5.6c/kWh for the households having the size less than 10kW of RE. In Northern Territory, which has abundant solar energy, the FiT is also called the energy buy-back rate, which is fixed by the energy retailer. Sometimes the rate may escalate to 25c/kWh (according to Jacana Energy 2014 and Solar Market 2014).

4.7 Renewable Energy Policies in Developed Countries

RE policies in developed countries exhibit a clear picture of their commitments, ideas and their achievements. Hence it is necessary to briefly understand these policies of these countries which could help in improving RE adoption for countries like Australia and India.

4.7.1 Denmark

A country like Denmark is aiming for 100% energy from renewables by 2050. This target has created a benchmark for other countries in terms of RE development. To minimise its dependency on fossil fuels, Denmark has structured a determined and steady set of policies which are persistent and actively backed up by its technical and industrial innovation and developments. In 2014, about 40 % of the Danish electricity consumption was wind power based, while it would increase to 50% by 2020. Denmark energy policy is sustained and functional as a result of the1973 oil crisis [109]. The fact that small country like Denmark has the least emissions globally and contributes to one of the highest RE adoptions is the effect of energy efficiency and the general public support for the energy sector transition. Energy policies are well rooted in Danish citizens, who are involved in campaigns to increase RE adoptions. Some of the regulatory policies in Denmark are as shown in Appendix B-1 [110].

4.7.2 Germany

Germany, being a part of EU, has an abundant supply of RE. Like Denmark, Germany is aiming at adopting RE and mitigating GHG emissions. In this aspect, Germany has targeted an 18% of the share of energy generated from renewable sources by 2020. Some of the elements of RE policy framework to assist Germany to reach its target are illustrated in Appendix B-2.

4.7.3 United States of America (USA)

The United States (US) is one of the global leaders in RE. It has the best potential in wind, solar, geothermal, hydro, and biomass resources globally in addition to the innovation trend, perineal financial support and being abreast of the technological development. A recent study by The National Renewable Energy Laboratory's (NREL), Renewable Electricity Futures Study (RE Futures) suggests that from the currently available energy technology combined with additional sophisticated equipment can result in the U.S reaching 80% of energy supply by 2050 [111]. The table below highlights elements of RE policy framework in the US as shown in Appendix B-3.

4.8 A Case study of FiTs from an Australian perspective

Australia as a developed country is attempting to reach its RET. With the exception of NT, rest of the Australian states are striving to meet the respective RET. The energy policies introduced by the Government of Australia has focused on encouraging RE adoption, this includes FiTs. The case study conducted in this section emphasises the impact of FiTs for Australian scenario. It details the impact on economics of the consumers in RE adoption for a grid connected HRES. Sizing the HRES for a university building is considered and the effect of FiTs has been examined. Scrutinising the advantages and disadvantages, suggestions for the improvement of FiTs for Australian scenario are discussed.

By modelling the HRES for a university micro-grid by analysing the electricity bills for three years of the university, the advantages of RE adoption through FiTs are examined. Assuming the university building to be located at all the chosen locations in Australia, the effect of FiTs on the economics of HRES is scrutinised. HOMER PRO software was chosen to size the HRES for the RE adoption and the economic analysis was conducted. NPC and LCOE of the system was considered as the performance indicators. The definition of these indicators have been explained in detail in Section 2.8.2.

In all the states of Australia, FiTs are provided for PV and WT systems. Thus, micro-grid is designed at chosen locations for HRES connected to the grid and these HRES are optimally sized using HOMER software. Collecting the electricity price from Australian Energy Market Operator (AEMO) database for the chosen location, this study has been conducted [114].

4.8.1 An Australian Case study to understand the advantages of FiT using HOMER

HOMER, also referred as HOMER PRO is explained in detail Chapter 3. This software is extensively used and considered reliable for optimally sizing HRES. Feasibility test and sensitivity analysis can be performed using this software for a desired HRES configuration. The crucial step of decision making for a set of input criteria depends on the RE source availability for a desired location. Thus, choosing a location for micro-grid setup is an utmost task of importance. Different RES like PV, WT, HFC etc. are considered along with system costs, inflation rate, resource availability and other technical factors are considered.

4.8.2 Input Factors for the Analysis

This case study was conducted using HOMER PRO by utilising the university's electricity bills and the analysis of the energy consumption data was conducted. However, the electricity price varies from state to state and thus, the average electricity price for a year (2015-2016) was considered from AEMO and is as shown in Table 4.6. The other inputs which are discount rate and inflation rate were 5.32% and 2.1% respectively for 20 years [112].

Table 4.6 Average Electricity Price in 2015-2016 state-wise [113]

Year	QLD	VIC	NSW	TAS	SA
2000-2001	41.33	44.57	37.69		56.39
2001-2002	35.34	30.97	34.76		31.61
2002-2003	37.79	27.56	32.91		30.11
2003-2004	28.18	25.38	32.37		34.86
2004-2005	28.96	27.62	39.33	190.38	36.07
2005-2006	28.12	32.47	37.24	56.76	37.76
2006-2007	52.14	54.80	58.72	49.56	51.61
2007-2008	52.34	46.79	41.66	54.68	73.50
2008-2009	34.00	41.82	38.85	58.48	50.98
2009-2010	33.30	36.28	44.19	29.37	55.31
2010-2011	30.97	27.09	36.74	29.45	32.58
2011-2012	29.07	27.28	29.67	32.58	30.28
2012-2013	67.02	57.44	55.10	48.30	69.75
2013-2014	58.42	51.49	52.26	41.98	61.71
2014-2015	52.52	30.35	35.17	37.16	39.29
2015-2016	58.78	43.95	49.36	104.27	58.28

For this case study, locations from five states were considered and thy are, Cleve, South Australia (SA), Minimbah, New South Wales (NSW), Warrnambool, Victoria, Stony Head, Tasmania and Nindaroo, Queensland. Shown in Figure 4-3 are the chosen locations. The places chosen were not the state capitals and there have not been many RE from these locations. WA is not been considered due to the lack of availability of electricity pricing data. For FiTs analysis, WA and NT have not been explored due to the restriction imposed on PV based off-grid to not use isolated power generation.

The monthly average solar radiation, clearness index and wind speed of the chosen locations are shown in Figures 4.4 and 4.5 while the annual average solar radiation and wind speed of the chosen locations are shown in Figure 4.6. The variations of the solar radiation, wind speed and clearness index are summarised in Table 4.7.

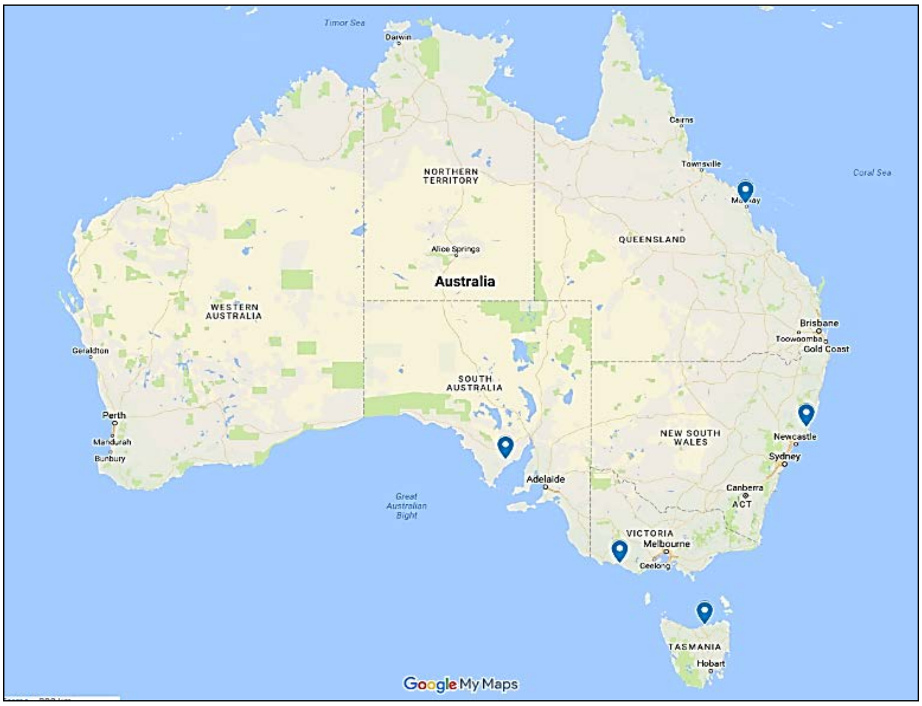


Figure 4.3 Locations considered for the study in five states of Australia

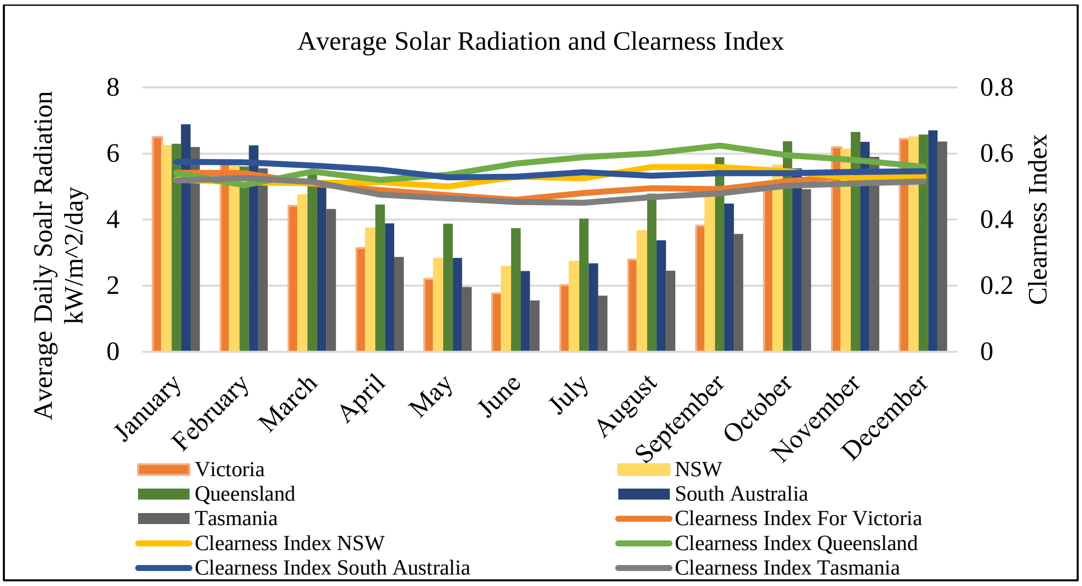


Figure 4.4 Average solar radiation and Clearness Index for the study case

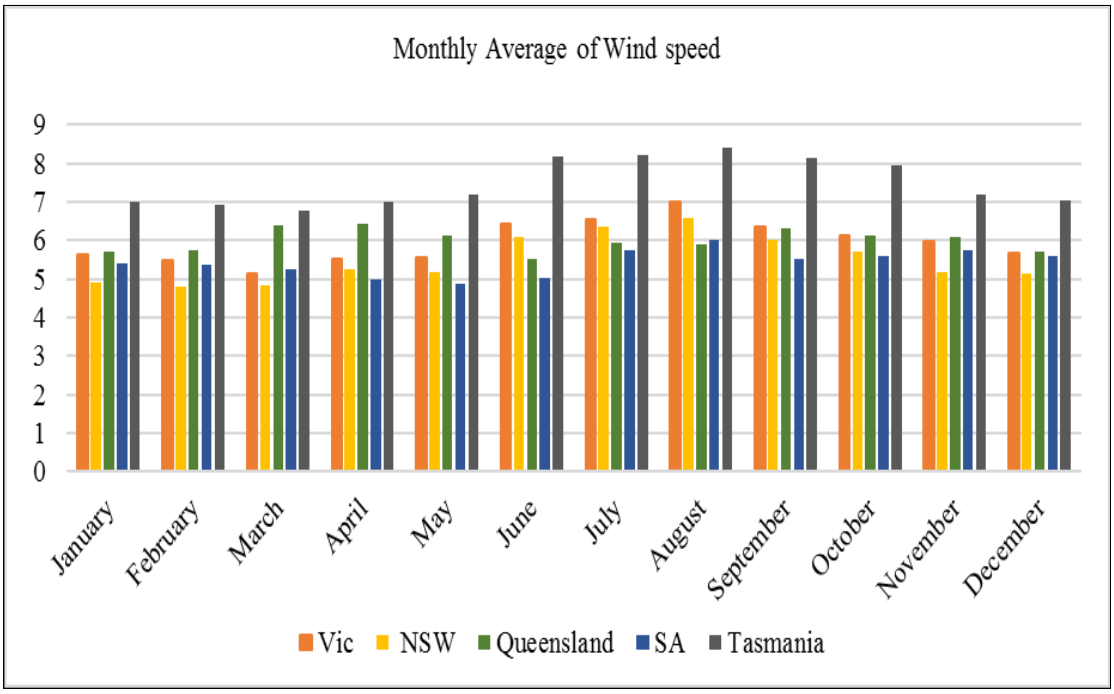


Figure 4.5 Monthly average Wind speed in the desired locations in Australia

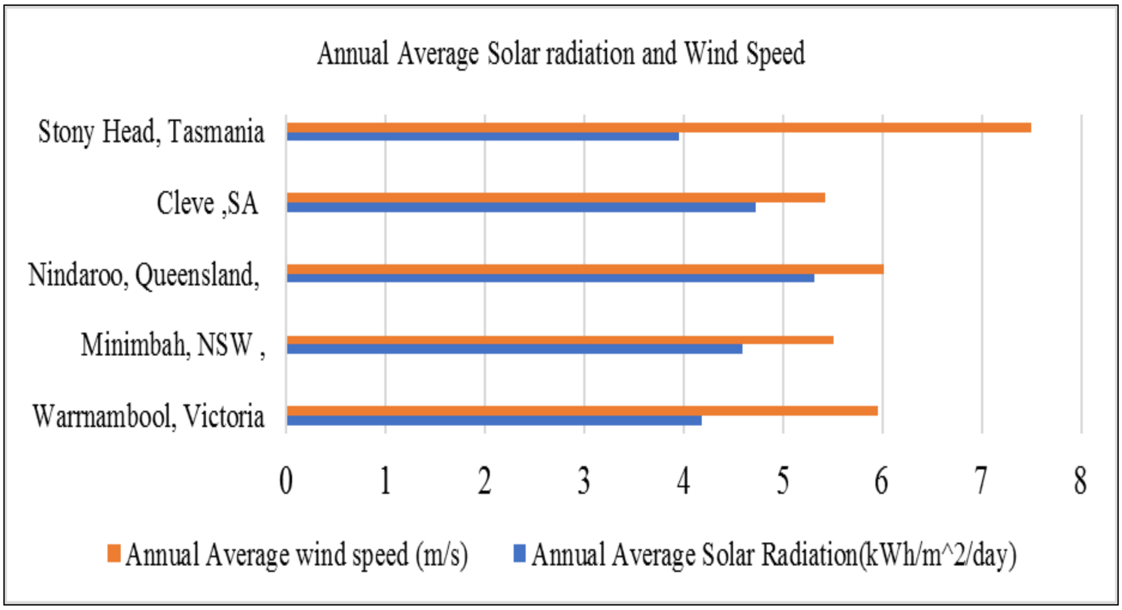


Figure 4.6 Annual average solar radiation and Wind speed at the desired locations

As shown in the schematic diagram in Figure 4.7, PV and wind turbine were considered as RES, since these locations had a consistently good solar radiation and wind speed. In order to explore the benefits of FiTs, grid was considered in this model. To match the energy demand of the university in a day, 7000kWh battery was considered. To understand the sizing of HRES for different solar and wind energy availabilities, the size of these HRES were fixed, as illustrated in Table 4.8.

Table 4.7 Summary of solar radiation, clearness index and wind speed at the chosen locations

Location	Monthly Average Solar Radiation in kWh/m^2/day		Clearness index		Wind speed (m/s)		Annual Average Solar Radiation kWh/m^2/day	Annual Average Wind speed (m/s)
	Minimum (month)	Maximum (month)	Minimum (month)	Maximum (month)	Minimum (month)	Maximum (month)		
Warrnambool, Vic	1.77 (June)	6.5 (January)	0.46 (June)	0.542 (January)	7 (August)	5.6 (March)	4.18	5.96
Minimbah, NSW	2.57 (June)	6.49 (December)	0.5 (May)	0.559 (August and September)	4.82 (February)	6.6 (August)	4.59	5.51
Nindaroo, Queensland	7.74 (June)	6.65 (November)	0.53 (April)	0.624 (September)	5.53 (May)	6.45 (April)	5.32	6.01
Stony Head, Tasmania	1.55 (June)	6.36 (December)	0.451 (July)	0.526 (December)	8.42 (August)	6.76 (March)	3.95	7.5
Cleve, SA	2.44 (June)	6.89 (January)	0.528 (May)	0.575 (January)	4.88 (May)	6.02 (August)	4.72	5.43

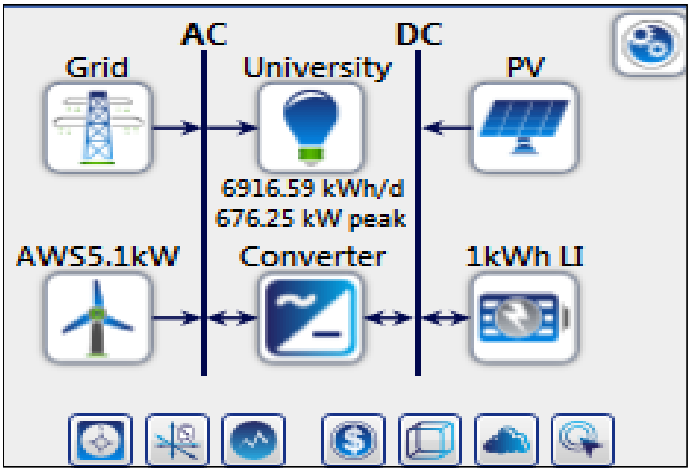


Figure 4.7 Schematic diagram of HRES considered

Table 4.8The size of HRES considered for the study

Components	Capital	Replacement	Operation & Maintenance	Size Constraint
PV (kW)	680	680	10	7000
AWS5.1kW	35,000	35,000	3500	0-1
System Converter (kW)	240	240	0	1000
1kWh Li-Ion Battery	50	50	10	7000

Considering only PV and wind as sources of energies, the analysis was conducted for the following cases.

- FiTs provided by the respective states
- FiTs made equivalent to power tariff for the respective state.

4.8.3 Results and Discussions

COE for all the locations was assessed to study the advantages of FiTs provided by the Australian government. The economic analysis of RES (both inclusive and exclusive of WT) are represented as Case 1 and Case 2 respectively is shown in Table 4.9.The regular FiTs provided by the energy retailers, and FiTs equivalent to the grid energy purchase price were considered for the analysis. The performance indicators were NPC, RE fraction, COE as economic criteria. When the results between Cases 1 and 2 were compared for all the chosen state, it is observed that micro-grid with two RES provided larger values of NPC, COE and RE penetration. There was a significant difference in the NPC, COE and RE penetration values even though their difference is not much.

This study also confirms the nearly 15-20% difference in NPC, COE and RE penetration when the FiTs and grid energy pricing was made equal. The values of COE, NPC decreases significantly whilst there was an increase in RE penetration. When the government set FiT was considered, Tasmania had the least value of FiT of A$[1]0.089 while the SA had the highest FiT of A$0.163. Considering Cases 1 and 2 for SA, the COE was smaller values of A$0.008 and A$0.0088 respectively. NPC of SA being the smallest of A$853,721 and A$943,652 for Cases 1 and 2 as compared to other Australian states.

When RE penetration also referred as RE fraction was considered, Tasmania has the maximum value of 75.5% and 75.7% for Cases1and 2 respectively as compared to SA having 60.5% for both the Cases. When the FiT between NSW, Victoria and Queensland were observed, NSW and Queensland have the FiTs of A$0.111 and A$0.106 respectively whilst Victoria had the highest tariff of A$0.113.

Considering COE, NPC and RE penetration for all the Australian states, NPC and COE for Victoria had the least value while the RE penetration (being smaller value compared Queensland and NSW) for both the cases was about 56%. The NPC and COE was with A$0.0359 and 3.82M respectively for Case-1 while it was A$0.0367 and 3.91M for Case-2 respectively. These numbers indicate that smaller value of RE penetration resulted in smaller COE and NPC for Victoria, NSW and Queensland scenarios. This is attributed to the fact of RE availability in NSW and Queensland is greater than the Victoria state.

A remarkable improvement in the results obtained for COE, NPC and RE penetration for all the states (other than Tasmania) were observed when the grid price was made equivalent to FiTs. At least 15% increase in RE penetration was observed in all the other stets (except Tasmania)

RE penetration for Tasmania when the grid price was made equivalent to FiTs is the least as the difference between grid price and FiT is about A$0.11/kWh. An increase in RE fraction in other states were: 15.5% for Queensland, NSW surged to 18.3% while Victoria's RE penetration increases to a maximum value of 18.3%. NSW and Victoria states had the Re penetration very similar, as the respective state government fixed FiTs and the electricity purchase price form the grid were comparable values. Similar relationship was observed for NPC, COE and RE penetration between Queensland and

[1] A$= Australian Dollar

SA. The results implicate that, for smaller values of FiT, the COE is smaller when state set FiTs were made equivalent to the grid electricity price.

Table 4.9 The economic analysis of the HRES considered in the desired locations in Australia

	FiTs (A$/kWh)	**COE (A$)**		**NPC (A$)**		**Renewable energy Fraction (%)**	
		Case-1	Case-2	Case-1	Case-2	Case-1	Case-2
Warrnambool, Victoria	0.113	0.0359	0.0367	3.82M	3.91M	55.9	56
	0.044	0.0969	0.0980	7.55M	7.64M	76.4	76.5
Minimbah, NSW	0.111	0.0364	0.0372	7.35M	7.44M	59	59.1
	0.049	0.0915	0.0926	3.92M	4.01M	77.3	77.4
Cleve, SA	0.163	0.00792	0.00874	853,721	943,652	60.5	60.5
	0.058	0.089	0.0901	7.16M	7.25M	77.6	77.7
Nindaroo, Queensland,	0.106	0.0382	0.039	4.2M	4.29M	63.1	63.1
	0.058	0.0854	0.0864	7.03M	7.12M	78.5	78.6
Stony Head, Tasmania	0.089	0.101	0.102	7.78M	7.86M	75.5	75.7
	0.20	0.0282	0.0273	2.65M	2.67M	57.5	53.4

4.8.4 Suggestions for FiTs Adoption

The FiTs are bifurcated into two types, they are as follows:

- Net FiT: It is the price paid for purchasing the excess or unused electricity to the RE based electricity producer.
- Gross FiT: Electricity is bought from the RE producer for a suitable price and subsequently for the personal use, generator buy the required electricity from the grid back.

FiTs have several disadvantages, although they aid in RE adoption by creating revenue to the RE producers.

- FiTs are specific to certain type of RE generation (i.e. it is fixed only for energy generation by certain type of RE sources).
- It is limited to certain locations (i.e FiTs exists for certain type RE production in different states). For example, FiTs is available for energy produced from PV and occasionally from WT in Victoria.
- FiTs is unobtainable for energy produced from the other RE sources. This leads to lesser exploitation of other RE sources in a particular location, thus makes it challenging to reach RET.
- There is dissimilarity in the Government set FiT and the retailers provided FiTs. During study conducted, the electricity retailers were approached for different states.
- It was noted that, although some of the state governments set FiTs for energy produced by both PV and WT, the retailers provided FiTs only for electricity generated from PV alone. This also restricts the RE exploitation.
- Due to the timely update of the FiT prices by the respective government has led lack of updated information reaching RE adopters.

Considering the aforementioned disadvantages of FiTs, some suggestions and recommendations are provided, they are as follows:

- Timely upgradations of the FiTs information is necessary from the concerned government organisations. If the FiTs set by the government is a very low price, it could result in difficulty in RE adoption.
- Any disagreement between the government set FiTs and FiTs set by the retailers could lead to confusions amongst the RES installers or energy consumers. Consequently, it could lead the consumers choose the existing energy from the grid and demeaning RE adoption which further regress the country’s RE growth .
- Setting up FiTs according to the available RE for a given location can be another option considered for Re development. For example, when solar energy adoption in considered, those states that have abundant solar energy can fix FiTs for accordingly.
- Providing competitive FiT pricing could lead to easier RE adoption.

- Offering FiTs pricing equivalent to grid electricity purchase price could lead to further growth in RE adoption.
- Monitoring and timely upgradation of the FiTs b according to the available energy source for a location by the respective government is necessary to break the stereotypical energy consumption. This could also assist in easier RE adoption for the energy consumers.

4.8.5 Conclusion from the Case study

There are two commonly used methods suggested in the literatures for RE adoption, grid connected RES and stand – alone type. A stand-alone system could cause oversized RES which could thus result in an expensive RES otherwise an under-sized RES which could not meet the necessary load demand, thus limiting RE usage. Thus, including a set of energy storage system like batteries can provide an optimum solution for the aforementioned problems. Necessary rebates and competitive FiTs pricing could provide better initiative for RE adoption. It is observed that there is a dearth in citizen's participation for RE adoption in Australia when compared to other developing countries. For example, in Denmark there have been several instances of citizens participation in RE adoption [114], whilst no such claims have ever been made by Australia. Thus, while Australia is striving to reach its RET, it is compulsory to constantly focus FiTs to reach Australia's RET.

In spite of Australia's abundance availability of RE, it still relies on coal for the main source of energy. This case study conducted outlines the drive towards RE adoption by focusing on improving the micro-grid by integrating HRES for a university building. This study confirms there is a mismatch in the FiTs by the Australian Government in comparison with the FiTs set by the retailers for RE adoption. Five prominent locations in Australian states where RE was least explores was chosen to study the FiT options. A striking balance is necessary between the FiTs set by the government and the availability of RE sources. Australia has the ability to be one of the forerunners in RE exploration if it focuses on the improvement on the shortfall for RET. Nonetheless, if Australia offers better discounts or rebates on RES, easy sanction of loan with smaller rate of interests apart from the boosting the emission trading scheme, it can reach its RET within the postulated time frame.

4.9 Conclusion

There are set of understandings that are being imparted from the energy policies of these aforementioned countries. Respective Governments set a target for the two decades and assist to achieve its target by introducing policies. These policies along with financial support and innovations from the technologies make it an achievable target. These policies need constant timely monitoring and change according to the countries' achievement and progress. The lessons that India and Australia could learn from each other is that though insightful in comparing their RETs and policies, both countries have different energy distribution and transmission methods. Australia's energy sectors have been privatized to give the private parties a better competing platform to prove themselves better than the rest. Each of the energy retailers has a set of goals to meet in RE deployment to make Australia achieve its target. Australia lacks consistent monitoring of RE progress and there is a wide impact of adopting certain RE technologies like wind energy in places like Victoria which has abundant wind resources. There is a lack of technological innovations as Australia lack production center for any of the RE equipment's as they are mostly imported.

On the other hand, India is certainly lacking many aspects. The disagreement between the state and central policies to assist RET is the biggest barrier. Many states do not meet the timeline of progress which makes it hard for a country like India to execute its targets. Though India initiated 'Make in India' campaign, it lacks the status monitoring and execution strategies. Nonetheless, India has claimed to have met 100% electricity reachable to its people, the resource to reach this is mainly through fossil fuels.

Both Australia and India have set of RETs, the people of both the countries are either deliberately not adopting the technology or lack the knowledge for adopting them. This gap impact on RE uptake even though the policies aimed at developing these technologies compare to a country like Denmark's, where the citizens are involved in promoting RE technology. Corruption at all levels and economic instability form a major hurdle for a country like India which is a home for many wind energy companies like Suzlon, Vestas etc. Population takes the major share in India's priority list. However, with many such barriers, India is on a mission to produce its share of renewables. Recently in March 2018, India surpassed its hurdles to progress in RE by contributing 100% RE solely by solar energy from one of its Union Territories, Diu (Diu of the Diu and Daman). A total of

13MW solar power with 3MW generated from the solar rooftops and 10 MW from the solar plants. This is said to have brought financial benefits due to solar energy adoption by 12% [115]. Meanwhile, in Australia, the FiTs having the least rates makes RE less adoptable for grid connected systems. However, the cost of good batteries makes it a tough task to adopt RE technology to the normal civilian. With constant monitoring and changes in RE policies and keeping the knowledge abreast of these technologies by the citizens of the countries and educating them could be a few major factors enabling the countries like India and Australia to be considered consider to successfully achieve their RETs.

Chapter 5

Simulation and Analysis of HRES for sizing and optimisation using HOMER and iHOGA

5.1 Introduction

Following the discussion in Chapter 4 related to energy policies and RE policies of India and Australia, this chapter will discuss the optimum sizing of RES for specific locations as case studies. It also discusses the financial viability of implementing the same, taking into account the country's economic status which reflects in the inflation rate. The software analysis conducted here are for two different locations, India and Australia. From the literature survey, it is understood that optimally sizing the RES is best done by software than any other methods discussed in Chapter 2. However, HOMER is one of the software packages predominantly used for sizing RES. It is noted that not much study has been done to date using the iHOGA software. HOMER has been updated with newer versions like iHOGA. HOMER is more user-friendly than any available software for sizing or optimisation which could be the reason researchers and installers choose it. Unlike HOMER, iHOGA software comes with a trial version with fewer features for sizing RES. Optimisation tool needs to be purchased for the analysis which is expensive than HOMER, this could be one of the demerits of iHOGA which makes the software less explored.

5.2 Data Collection for Aralvaimozhi and Warrnambool, case studies

Preliminary studies were conducted to understand the feasibility to integrate RE into a micro-grid. The following procedures were used:

i. Choose a location to integrate RES.

   Two locations were chosen, in India and in Australia, one is a developing country while the other is a developed country. Both the countries have a common target, which is to meet their respective RET. The target of both the countries have been dealt with earlier in Chapter 4. Both countries are novices in the case of accessing RES to its respective household or community. There are immense applications of the adoption of RES on a business scale or a large scale, however, both the countries are yet to explore accessing RES to a small household or community. However, Australia has taken many measures to enable RES to meet the household or community needs. But, India is yet to do so.

Since both the countries need to adopt RES to meet their RET, the current study has been undertaken to study the feasibility of RES implementation at a community level. A small community of about 70 households in Aralvaimozhi, India was chosen, while a university building at Warrnambool was chosen for the Australian scenario. A detailed understanding of energy consumption analysis is required. Literature suggests that a minimum of 1 year of energy consumption is the necessary criteria to understand the energy consumption trend and this would successfully assist in sizing the RES. The location of the case study area, Aralvaimozhi, India and Warrnambool, Australia are shown in Figures 5.1 and 5.2 respectively.

Figure 5.1 Location of Aralvaimozhi, India

Figure 5.2 Location of Warrnambool, Australia

ii. Load Analysis

❖ Aralvaimozhi, India

To understand the load for integrating RE at Aralvaimozhi, the energy consumption for 70 houses for approximately 2 years was studied. See Appendix C-1 for the details of the energy consumption of individual houses from September 2014 to July 2016.

Average energy consumption is 183.403kWh/day for 70 houses, which is about 2.62kWh/day/house. The average energy consumption trend is used from HOMER software for 70 houses on a typical day as shown in Figure 5.3. The nature of energy consumption trend for a house was taken from HOMER as it was not possible to get the hourly consumption data from India. The snapshot of the electricity consumption bill procured is shown in Figure 5.4.

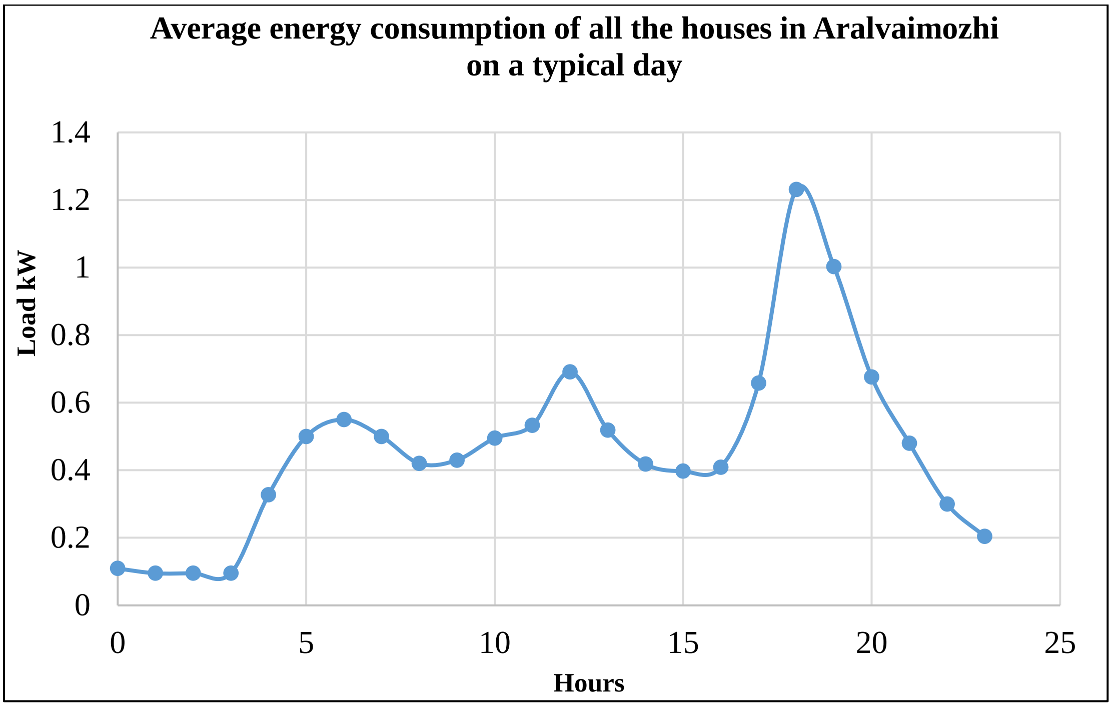


Figure 5.3 Average Energy Consumption of all houses in Aralvaimozhi, India

- Warrnambool, Australia

A university building has been selected to understand the energy consumption data. The name of the university has not been disclosed due to privacy concern. The average daily electricity consumption of the university 7,781.73kWh/day is shown in Figure 5-5.

The energy consumption detail of the university were collected from March 2014 to February 2016 (adds up to 731 days inclusive of 1 March 2014 to 29 February 2016) is shown in Appendix C-2. The Energy consumption of the university on a typical day is illustrated in Table 5.1

iii. Accessing RES

India and Australia have a common energy generation mix structure. i.e., both the countries depend on coal as a main source of supply. Though the presence of this dirty fuel in the energy mix is an economically viable option, it has a serious impact on country's GHG emissions. To include RE as part of the energy mix, it is significant to analyze the availability of energy sources and the viability in adopting them. It is understood that most of the places in India has tropical climate, hence adopting solar energy is understood to be a feasible option. Aralvaimozhi has been spotted by the State Government of Tamil Nadu as a promising place for wind energy utilization. Considering the fact of abundant solar energy radiation availability, a system considering solar panels and the wind turbine is considered along with a definite size of the battery whilst being connected to the A.C. grid. The annual average solar radiation and wind energy for Aralvaimozhi and Warrnambool are shown in Table 5.2 and Table 5.3 respectively.

8/29/2016 SERVICE DETAILS

Back | **ACCOUNT SUMMARY** | Home

CONSUMER NAME: [redacted] **CONSUMER NUMBER:** [redacted]

REGION	07-Tirunelveli	PHASE	1	SLAB RATE
CIRCLE	474-Kanyakumari	LOAD	.54 KW	
SECTION	133-ARALVAIMOZHI	TARIFF	LA1A	
DISTRIBUTION	002-ARALVAIMOZHI - D	METER NUMBER	[redacted]	
SERVICE NUMBER	[redacted]	ACCD* AS ON Date/ SD Available for Refund or Adj.(Rs.)	1272 / NIL	
ADDRESS	[redacted]	MCD AS ON Date/ MCD Available for Refund or Adj.(Rs.),	700 / 0	
SERVICE STATUS	LIVE	SERVICE CATEGORY	OTHERS	

From Unit	To Unit	Rate (Rs.)	Max. Unit
1	100	1	100
1	200	1.5	200
1	200	2	500
201	500	3	500
1	200	3.5	9999999
201	500	4.6	9999999
501	Above	6.6	9999999

Min.Chrg: 0 *Fixd.Cost:* 50
BPSC:* 0 *Welding.Chrg:* 0%
E.Tax: 0 % (CC + DPF + WD+RDFC)

DUES TO BE PAID IS "NIL"

CLICK HERE TO PAY ADVANCE *

Monthly Consumption Charge Collection Details

Assessment Date	Assessment Entry Date	Reading	Consumed Unit	CC Charges* (Rs.)	Other charges ETAX (Rs.)	WD (Rs.)	EDC (Rs.)	DPF (Rs.)	FC (Rs.)	Total (Rs.)	Assessed Amount (Rs.)	Advance Amount (Rs.)	Adjustment Amount (Rs.)	Total Bill Amount (Rs.)	Due Date For payment	Amount Paid	Receipt No	Payment Date	Pending Amt To be Paid
07/07/2016	14/07/2016	8890	230	336	0	0	0	0	30	30	366	0	0	366	27/07/2016	366	TIK133AR2S1068	14/07/2016	(
04/05/2016	04/05/2016	8660	160	240	0	0	0	0	20	20	260	0	0	260	24/05/2016	260	TIK133IA1S429	14/05/2016	(
09/03/2016	09/03/2016	8500	150	225	0	0	0	0	20	20	245	0	0	245	29/03/2016	245	TIK133AR2S1315	14/03/2016	(
09/01/2016	09/01/2016	8350	160	240	0	0	0	0	20	20	260	0	0	260	28/01/2016	260	TIK133AR2S1072	12/01/2016	(
05/11/2015	05/11/2015	8190	160	240	0	0	0	0	20	20	260	0	0	260	24/11/2015	260	TIK133AR2S933	09/11/2015	(
07/09/2015	07/09/2015	8030	180	270	0	0	0	0	20	20	290	0	0	290	26/09/2015	290	TIK133AR2S1615	14/09/2015	(
08/07/2015	09/07/2015	7850	140	210	0	0	0	0	20	20	230	0	0	230	27/07/2015	230	TIK133AR2S1262	13/07/2015	(
10/05/2015	13/05/2015	7710	180	270	0	0	0	0	20	20	290	0	0	290	29/05/2015	290	TIK133AR1S1166	15/05/2015	(
09/03/2015	09/03/2015	7530	130	195	0	0	0	0	20	20	215	0	0	215	28/03/2015	215	TIK133AR2S765	11/03/2015	(
06/01/2015	06/01/2015	7400	130	195	0	0	0	0	20	20	215	0	0	215	27/01/2015	215	TIK133AR2S606	07/01/2015	(
06/11/2014	07/11/2014	7270	150	225	0	0	0	0	20	20	245	0	0	245	25/11/2014	245	TIK133IA1S584	07/11/2014	(
07/09/2014	08/09/2014	7120	150	225	0	0	0	0	20	20	245	0	0	245	26/09/2014	245	TIK133IA1S1104	16/09/2014	(

Miscellaneous Collection Details

Slip No / Cheque No	Slip Date / Cheque Date	Cheque Dishonour Date	Account Description	Amount	Due Date	Collection Date	Receipt No	Instal Amt / Cheque Amt/ Pending Amt	Total Installments	Installment Status
1330315141	23-03-2015		61964-Name Transfer Fees(61909c)	200	06-04-2015	23-03-2015	TIK133AR2S2278			
1330315141	23-03-2015		48100-Cc Deposit	200	06-04-2015	23-03-2015	TIK133AR2S2278			

Legend

ACCD	Additional Current Consumption Deposit	BPSC	Belated Payment Surcharge
CC Charges	Current Consumption Charges	PMC	Previous Month Consumption
WD	Welding Charges	EDC	Excess Demand Charges
DPF	Disincentive for Power factor	FC	Fixed costs
RDFC	Fixed Charges to the extent of Recorded demand		

** "The Consumers may opt for payment of Electricity Charges in advance. Interest at the rate of 6% p.a is credited to such amount, held for full month(more than 30days) as advance.The amount paid as advance towards Electricity charges(Current Consumption Charges) can be adjusted only against future CC bills."*

VIEW ANOTHER

Figure 5.4 Snapshot of the Electricity bill of a consumer in Aralvaimozhi, India

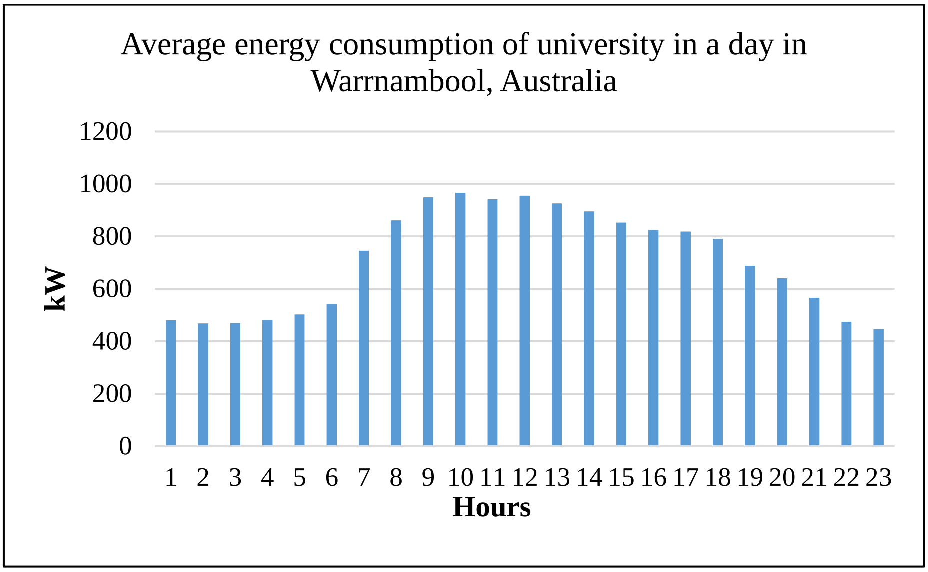


Figure 5.5 Average energy consumption in a day in the university in Warrnambool, Australia

Table 5.1 Energy Consumption of the university on a typical day

Hours	***Energy consumption in kWh***
0	480.42
1	467.97
2	469.07
3	481.74
4	502.96
5	543.25
6	745.85
7	861.75
8	948.52
9	966.59
10	941.4
11	955.23
12	926.19
13	895.22
14	852.98
15	824.02
16	819.09
17	790.96
18	688.09
19	640.67
20	565.35
21	473.85
22	446.73
23	480.42

Table 5.2 Annual Average Solar energy and Wind energy available in Aralvaimozhi, India

	Clearness Index	Daily solar Radiation (kWh/m^2/day)	Wind speed m/s
January	0.576	5.246	7.03
February	0.613	5.967	4.69
March	0.603	6.217	4.27
April	0.537	5.632	4.5
May	0.485	4.998	8.79
June	0.424	4.291	9.27
July	0.438	4.456	10.97
August	0.443	4.588	10.15
September	0.501	5.156	8.46
October	0.488	4.8	6.01
November	0.494	4.545	5
December	0.534	4.74	6.79

Table 5.3 Annual Average Solar energy and Wind energy available in Warrnambool, Australia.

Month	**Clearness Index**	**Daily solar Radiation (kWh/m^2/day)**	**Wind speed m/s**
January	0.542	6.5	5.65
February	0.542	5.78	5.49
March	0.513	4.42	5.16
April	0.495	3.14	5.51
May	0.478	2.2	5.55
June	0.461	1.77	6.44
July	0.478	2.02	6.54
August	0.49	2.79	7
September	0.487	3.82	6.35
October	0.512	5.14	6.15
November	0.531	6.19	5.97
December	0.522	6.44	5.68

For Aralvaimozhi and Warrnambool, the incident average annual solar energy radiation was taken from the NASA surface meteorology website based on the latitude and longitude of the location. The clearness index was also considered in the study. Clearness index is defined as the fraction of the solar radiation that reaches earth's surface after it passes through the top of the Earth's atmosphere. The wind velocity at Aralvaimozhi was noted from a wind site near the town [2]. The wind speed and the average solar radiation at Aralvaimozhi are 7.16m/s and 5.05kWh/m^2/day respectively. The average solar radiation in Warrnambool 4.16kWh/m^2/day and annual average wind velocity 5.96m/s.

iv. Validation of the software models

The software models that ware already published was considered for validation. Upon considering the model of "The Application of Homer Optimization Software to Investigate the Prospects of Hybrid Renewable Energy System in Rural Communities of Sokoto in Nigeria" and " Design and Optimization of Hybrid PV-Wind Renewable Energy System" the validation of the model using HOMER and iHOGA software packages was done [90, 116].

5.3 Software simulation: Aralvaimozhi Case study

5.3.1 HOMER and iHOGA software simulation for Aralvaimozhi, India

HOMER and iHOGA software were used to optimally size the RES for Aralvaimozhi. As aforementioned, Aralvaimozhi has abundant solar and wind energies. These two energies are exploited by sizing the RES for a community in Aralvaimozhi and their costs are analyzed. The HRES are considered as the source for a small community of approximately 70 houses at Aralvaimozhi.

5.3.1.1 Resource Availability in Aralvaimozhi

Aralvaimozhi has an average temperature of 26.3^{0}C. It has a tropical climate with solar energy at peak during the summer season (Feb-May) and least during June-July. The annual average solar radiation is about 4.92kWh/m^2/day as shown in Figure 5.6 [117]. The wind speed at Aralvaimozhi was measured from the nearest site and annual average of the wind speed was measured to be 7.16m/s as shown in Figure 5.7 [2].

The HRES included in the simulation considers a flat plate generic PV, Wind Turbine UE1500 which is modeled from the specifications provided by the wind turbine manufacturing company [118] along with a Trojan Battery.

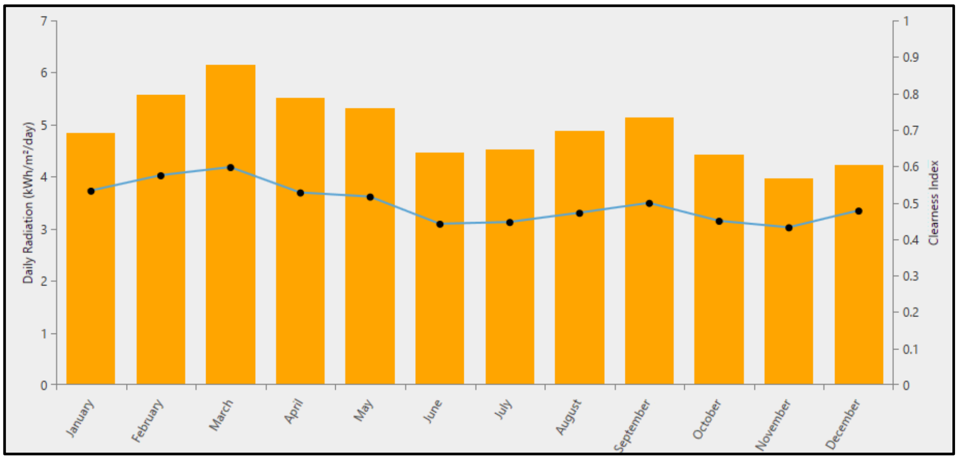


Figure 5.6 Annual average solar radiation in Aralvaimozhi, India

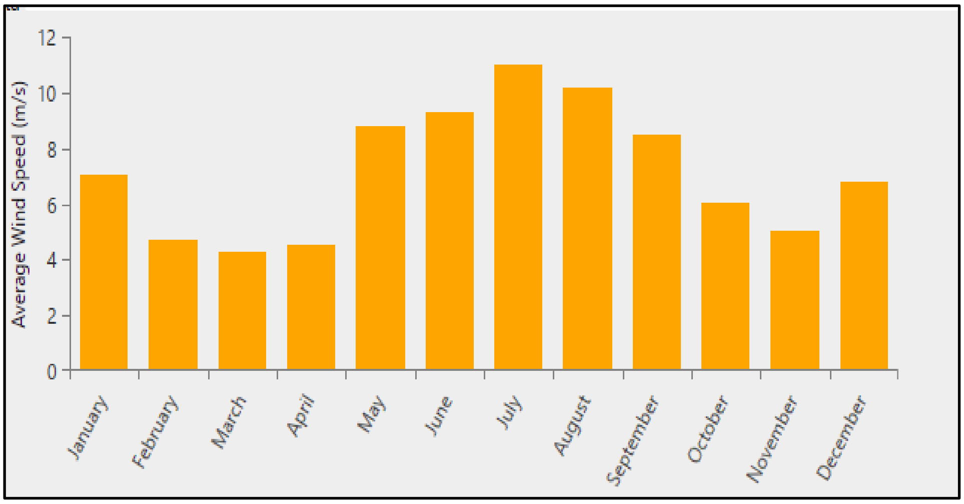


Figure 5.7 Annual average of the wind speed measure near Aralvaimozhi, India

5.3.1.2 System Description and Sensitivity Variables used for Aralvaimozhi

The sensitive variables that influence the economics of HRES are considered to perform the financial analysis. For example, the inflation rate dropped to a record low of 2.99% in April 2017 in India. Demonetization was one of the other reasons for this fall in the inflation rate. Hence, the inflation rate of 7.13%, as the average from 2012 until 2017, has been considered in the calculation. The interest rate provided by a nationalized bank was considered and minimum RE penetration have also been used as sensitive variables to size the HRES of the system. This means, HRES sized should at least meet the load demand by contributing this amount of RE penetration. The real-time price of the individual components was provided by the RE installer/distributor and these prices were included in the analysis. The prices quoted by the installers were the market prices including the tax and considering the discounts if any, form the Government. However, it should be noted that these prices though were individual prices in the energy market, there could be a further reduction in price if any RES were to be installed in the real-world for a larger HRES setup. The cost of the HRES used in the analysis is shown in Table 5.4.

Table 5.4 Inputs used for simulation

Component	Details	Capital Cost (INR)[2]	Operational and maintenance cost (INR/ year)
Wind Turbine (1500W)	UE 1500	3,50,000	40
PV (1kW)	Generic Flat plate	79,600	20
Converter (1kW)	Generic system converter (bi-directional inverter/converter)	68,500	-
Trojan T-105 (105Ah)	AGM	19,000	50

The HRES setup for Aralvaimozhi community considers PV and WT as HRES. The interest rate was considered to be 15.5%, which is the interest rate from nationalised bank provides and the present inflation rate is 7.13%. The technical characteristics of the components used in the analysis are modelled using both the software packages. They have been discussed in Appendix C-3 and the Power curve of the WT is provided in Appendix C-4.

5.3.2 Simulation for Aralvaimozhi using HOMER Software: A Case study

The HRES is designed for a community in Aralvaimozhi, India is shown in Figure 5.8. HOMER evaluates all the possible combinations and sizes the RES according to the constraints defined by the user.

[2] INR=Indian Rupee
1A$= 50INR

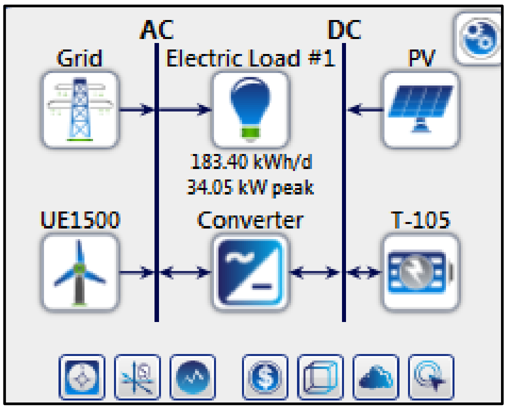
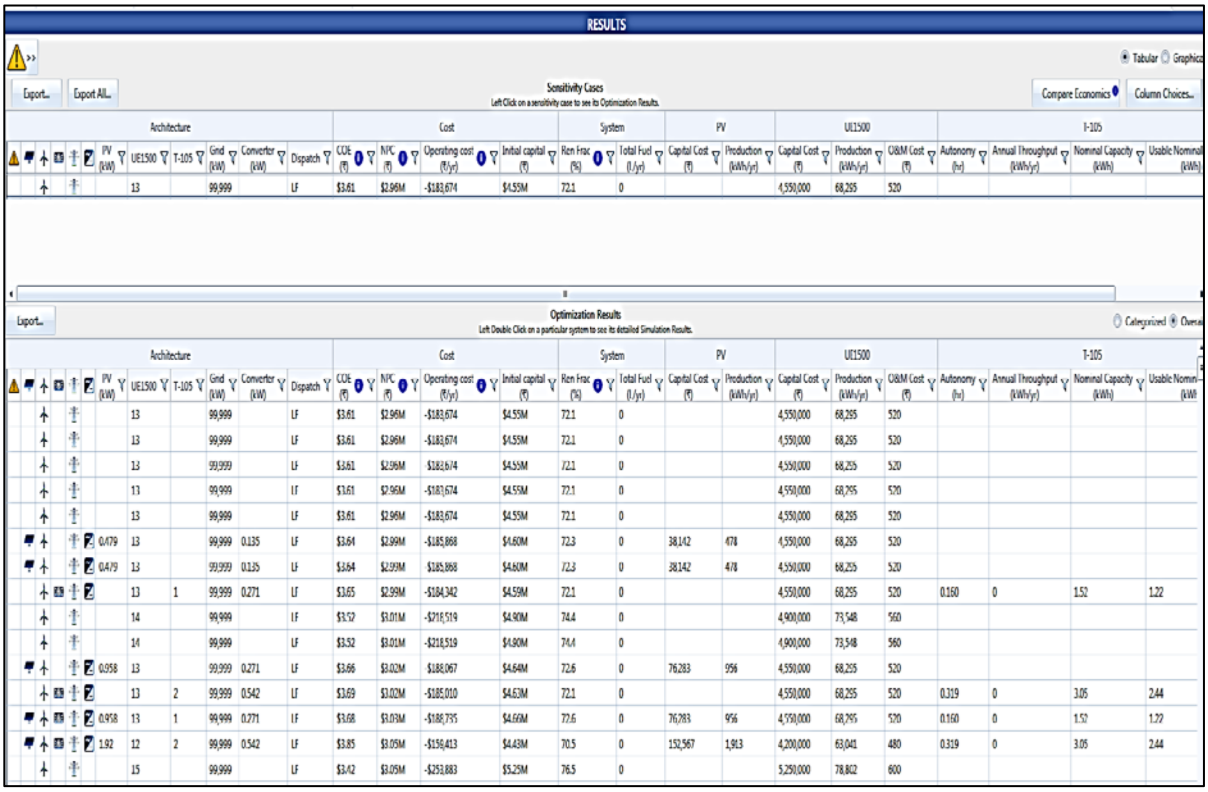


Figure 5.8 Schematic of the HRES used for HOMER Software Analysis

HOMER after evaluating all the combinations of HRES, sizes the HRES according to the constraints and displays set of results according to the least value of NPC. Calculations were made considering the rate of interest rate provided by the Indian nationalized bank [119] and the inflation rate of India [120].

For the HOMER simulation, the size of the system components was scaled according to the specific constraints and the results were tabulated according to the least value of NPC as shown in the snapshot in the Figure 5.9. The results of all the possible combination of HRES is evaluated by HOMER for Aralvaimozhi is provided in Table 5.5.



PV (kW)	UE1500	T-105	Grid (kW)	Converter (kW)	Dispatch	COE (₹)	NPC (₹)	Operating cost (₹/yr)	Initial capital (₹)	Ren Frac (%)	Total Fuel (L/yr)	PV Capital Cost (₹)	PV Production (kWh/yr)	UE1500 Capital Cost (₹)	UE1500 Production (kWh/yr)	UE1500 O&M Cost (₹)	T-105 Autonomy (hr)	T-105 Annual Throughput (kWh/yr)	T-105 Nominal Capacity (kWh)	T-105 Usable Nominal (kWh)
	13		99,999		LF	$3.61	$2.96M	-$183,674	$4.55M	72.1	0			4,550,000	68,295	520				

PV (kW)	UE1500	T-105	Grid (kW)	Converter (kW)	Dispatch	COE (₹)	NPC (₹)	Operating cost (₹/yr)	Initial capital (₹)	Ren Frac (%)	Total Fuel (L/yr)	PV Capital Cost (₹)	PV Production (kWh/yr)	UE1500 Capital Cost (₹)	UE1500 Production (kWh/yr)	UE1500 O&M Cost (₹)	T-105 Autonomy (hr)	T-105 Annual Throughput (kWh/yr)	T-105 Nominal Capacity (kWh)	T-105 Usable Nominal (kWh)
	13		99,999		LF	$3.61	$2.96M	-$183,674	$4.55M	72.1	0			4,550,000	68,295	520				
	13		99,999		LF	$3.61	$2.96M	-$183,674	$4.55M	72.1	0			4,550,000	68,295	520				
	13		99,999		LF	$3.61	$2.96M	-$183,674	$4.55M	72.1	0			4,550,000	68,295	520				
	13		99,999		LF	$3.61	$2.96M	-$183,674	$4.55M	72.1	0			4,550,000	68,295	520				
	13		99,999		LF	$3.61	$2.96M	-$183,674	$4.55M	72.1	0			4,550,000	68,295	520				
0.479	13		99,999	0.135	LF	$3.64	$2.99M	-$185,868	$4.60M	72.3	0	38,142	478	4,550,000	68,295	520				
0.479	13		99,999	0.135	LF	$3.64	$2.99M	-$185,868	$4.60M	72.3	0	38,142	478	4,550,000	68,295	520				
	13	1	99,999	0.271	LF	$3.65	$2.99M	-$184,342	$4.59M	72.1	0			4,550,000	68,295	520	0.160	0	1.52	1.22
	14		99,999		LF	$3.52	$3.01M	-$218,519	$4.90M	74.4	0			4,900,000	73,548	560				
	14		99,999		LF	$3.52	$3.01M	-$218,519	$4.90M	74.4	0			4,900,000	73,548	560				
0.958	13		99,999	0.271	LF	$3.66	$3.02M	-$188,067	$4.64M	72.6	0	76,283	956	4,550,000	68,295	520				
	13	2	99,999	0.542	LF	$3.69	$3.02M	-$185,010	$4.63M	72.1	0			4,550,000	68,295	520	0.319	0	3.05	2.44
0.958	13	1	99,999	0.271	LF	$3.68	$3.03M	-$188,735	$4.66M	72.6	0	76,283	956	4,550,000	68,295	520	0.160	0	1.52	1.22
1.92	12	2	99,999	0.542	LF	$3.85	$3.05M	-$159,413	$4.43M	70.5	0	152,567	1,913	4,200,000	63,041	480	0.319	0	3.05	2.44
	15		99,999		LF	$3.42	$3.05M	-$253,883	$5.25M	76.5	0			5,250,000	78,802	600				

Figure 5.9 Snapshot of the HOMER simulated results

Table 5.5 Optimum Sized HRES models simulated by HOMER Software

Model	PV	WT	Battery	Converter	Grid	COE	NPC	Renewable Energy Fraction
Model-1	1.02	12	-	0.353	999,999	4.31	3.4M	70.1
Model-2	-	13	-	-	999,999	4.21	3.45M	72.1
Model-3	-	13	1	0.0621	999,999	4.23	3.47M	72.1
Model-4	1.88	12	2	0.531	999,999	4.4	3.48M	70.5
Model-5	99.3	-		37.1	999,999	7.34	7.71M	70.1
Model-6	98.9	-	1	37.5	999,999	7.34	7.72M	70.1

The architecture in Table 5.5 showcases the most economically viable model for Aralvaimozhi. Although this model may not include all the components in the system, on evaluation the HRES combinations, the best model chosen by HOMER is as discussed:

- *Model-1*: The best HRES model consists of 1.02kW PV with 12 WT connected to the grid with the system converter of 0.35kW. This hybrid system with 70.1% of RE penetration has the NPC INR3.4M and COE 4.31 INR/kWh. The Initial Capital Cost of the system is INR4.31M with the Capital Cost of the WT is highest of INR4.2M. The operating cost of the system is about -INR1M.The Capital Cost of PV is INR81k and system converter INR24k. The Capital Cost being maximum compared to other costs of the whole system with INR4.3M. However, approximately 24,228kWh of energy is sold to the grid by this HRES. In this HRES, 1.12% of electricity is produced by PV, 69% from WT, and 29.9% from the Grid purchases in a year. However, 24228kWh of energy is sold to the grid thus creating revenue through FiTs.
- *Model-2*: The second optimised HRES combination is WT and grid combination. Considering 13WT with a Load following despatch had a RE penetration of 72.1%. The NPC of the system is INR3.45M with COE INR4.21/kWh. The operating cost of the system is about INR1.2M. The Capital Cost of the total system is INR4.55M with the Capital Cost of WT is the highest of INR 4.5M. In this HRES, 72.1% of electricity is produced by WT and 27.9% of electricity is purchased from the grid. However, 27804kWh/year has been sold to the grid.

- *Model-3*: The third optimised HRES combination is WT and grid combination with a small amount of battery storage included. 13WT with a Load following despatch had 1 T105 battery storage system connected to the grid. The renewable energy penetration of this system is 72.1%. The NPC of the system is INR3.47M with COE INR4.23/kWh. The Capital Cost of the system is INR4.57M with the WT having maximum Capital Cost of INR4.55M. In this HRES, 72.1% of electricity is produced by WT and 27.9% of electricity is purchased from the grid. About 27,804kWh/year has been sold to the grid.
- *Model-4*: The fourth model included PV,WT and battery connected to the grid. This system had a very small PV contribution of 1.88kW with 12 WT and 2 battery system connected to the grid through 0.531kW converter. This HRES contributed 70.5% of renewable energy penetration with NPC INR3.48M and COE of 4.4INR/kWh. The Capital Cost of the system is INR4.42M with the WT contributing the maximum Capital Cost of INR4.2M. This HRES contributes 70.5% renewable energy penetration with 2.04% of electrical energy production from PV, 68.6% from WT and 29.3% from the grid purchase. Nearly 24,497kWh of energy is sold to the grid every year from this HRES.
- *Model-5*: This model consisted of 99.3kW of PV connected to the grid. Though a 37.1kW converter. The COE using this system was 7.34INR/kWh with NPC of INR7.71M. The Capital Cost of this system is INR 10.4M with the Capital Cost of PV being maximum of INR 7.9M and the Capital Cost of the system converter is INR 2.54M. This system has the renewable energy penetration of 70.1%. In a year 73.2% of electricity production is from PV and 26.8% through grid purchase. 54,482kWh of energy is sold to the grid from this system every year.
- *Model-6*: This model consisted of 98.9kW PV connected to the 1 T-105 battery system and to the grid through a system converter of 37.5kW. The COE of this system is 7.34INR/kWh and NPC of INR7.72M. The Capital Cost of the system is INR10.4M, is highest compared to the other five models discussed earlier. PV having the maximum Capital Cost of INR7.87M. In a year, nearly 73.1% of electricity is produced by PV, while 26.9% of electricity is through grid purchase. However, 54,580kWh of energy is sold to the grid from this system.

These aforementioned models are the best six models for the optimised HRES combinations. This concludes the fact that unlike iHOGA which gives the best result for one set of combination (however it has the flexibility to choose the best HRES model with the grid only setup), HOMER can give all the probable combinations of HRES. This leads to the next section which discusses the comparison of iHOGA and HOMER models and this nearly matches the given constraints.

5.3.3 Analysis of the results of HRES sized by HOMER and iHOGA software packages

This section considers the same financial inputs of HRES used discussed in Table 5.4 earlier and HRES technical characteristics of the systems described in Section 5.3.1. The HRES is designed by considering PV, WT and battery with 2.4hours of autonomy and connecting them to the grid. The sensitive variables considered to perform the financial analysis are shown in Table 5.6. The HRES was modeled for the annual capacity shortage of 0%, which means that the total load is either met by the RE, battery or by the A.C. grid and no load is unmet.

The HRES model for simulation includes a generic 1kW PV, UE 1500 WT, converters, Trojan-105 battery which are connected to the grid in the model. The literature survey conducted mostly includes grid connected models (in the absence of storage device) [63] or stand-alone models (mostly batteries used as storage device) [121, 122]. Though this study aims at a grid connected model, it also includes a specific capacity of battery storage to satisfy the load in times of grid failure. The presence of the grid is to create revenue through FiTs. Depending on the availability of the RE, HOMER calculates the best option to charge the battery, either through grid power or through RE, according to the least cost option.

Table 5.6 Sensitive Variables used in simulation

Inflation rate	7.13%
Discount Rate	15.5%
Lifetime of the Project	15 years
Annual Capacity shortage	0%
Minimum Renewable energy fraction	70%
Grid Power Price	2.16INR/kWh
Grid sell back	5.10INR/kWh
Unmet load	0%

The present discount rate of 15.5% and inflation rate of 7.13% is considered for the analysis. Meanwhile, 70% of minimum renewable energy penetration is considered. The average power price that the community pay to purchase electricity from the grid is 2.16INR/kWh. The grid sell back price (FiTs) for the state of 5.10INR/kWh has been considered.

The PV used here is a generic 1kW solar panel with 80% de-rating factor and 25 years lifetime. The UE 1500 WT considered here has a power output of 1500W and lifetime of 25 years. A generic converter is used along with a Trojan battery with nominal voltage of 6V and 254Ah nominal capacity with round trip efficiency of 80%. The initial state of charge of the batteries considered is 100% and the minimum state of charge of the batteries is 20%. The HRES considered for the HOMER and iHOGA software simulations is shown in Figure 5.10. The costs of the HRES included is summarised in the Table 5.7.

A generic 1kW PV is considered with a capital cost of INR79,600. A Unitron energy1.5kW WT with the capital cost INR250k and Trojan 105 batteries of Capital Cost INR19,500 were considered. These costs are the actual market costs provided by the supplier. These systems were modelled according to the aforementioned specifications using HOMER and iHOGA software and the results are analysed.

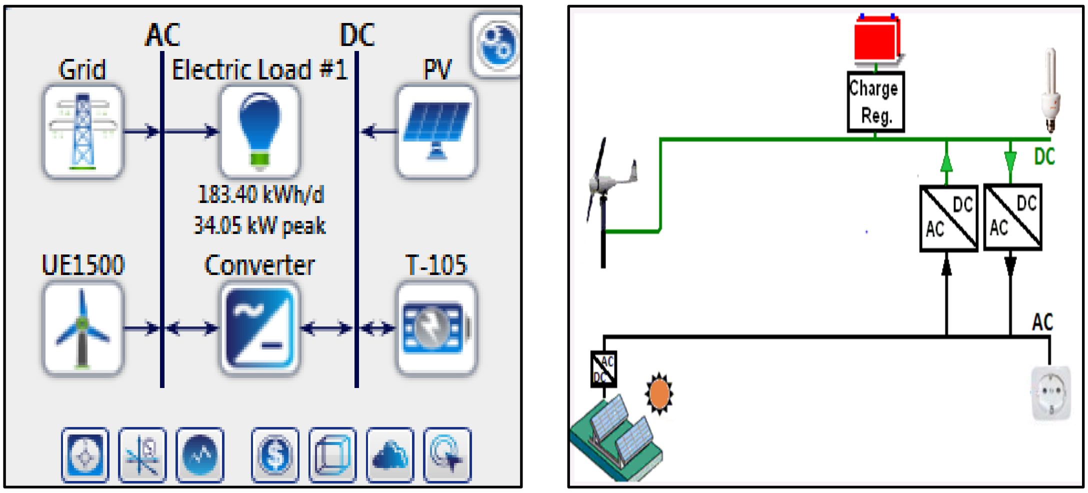


Figure 5.10 The HRES considered for Aralvaimozhi community by HOMER software (left) and iHOGA (right)

Table 5.7 The HRES components, component specifications and market price

Components	Specification		Cost in INR	
Solar Panels (PV)	Nominal Voltage	12V	Capital Cost	79600/year
	Short-circuit Current	8.23A	O&M Cost	100/year
	Nominal power	1000Wp		
	Lifespan	25 years		
UE 1500 Wind Turbine	Height	12m	Capital cost	250,000
	Rated Power	1500W	Replacement cost	250000
	Life Span	20 years	O&M cost	10/year
Trojan-105 Battery	Nominal Capacity	254Ah	Capital cost	19500
	Voltage	6V	O & M cost	20
	SOC	20%	-	-

This section compares the optimised results for Aralvaimozhi using HOMER and iHOGA. Both the software calculates the NPC using the methodology mentioned in Chapter 3 considering the inputs defined by the user for the HRES models and sort the results according to the least value of NPC.

The Primary Algorithm used by iHOGA is GA, while the Secondary Algorithm considered all the combinations of the population resulted from the Primary Algorithm. 70.9% of optimisation evaluating 29,993 cases in 1hr 39 seconds was done by iHOGA. However, HOMER considered all the possible combinations and simulated 1,171 cases out of which 1057 were feasible in less than 5 minutes. In this aspect, HOMER produced 100% possible optimised results while iHOGA considering Primary Algorithm and Secondary Algorithm, simulates results close to the optimised result taking longer time. This long duration in the simulation is also due to the control strategies defined for iHOGA e.g.: the priority to charge the batteries were given to the RE source. If the RE is excess at any instant, it can be sold to the grid.

In the current case study, the control strategy considers prioritizing RE and battery to meet the load. If in any case, RE and battery are not available to meet the load, the grid is flexible to meet the load. Thus, the presence of the grid in the designed micro-grid system is to supply any excess energy to the load, in case of a deficit in RE supply, it also acts as the dumping unit when there is excess RE, thus creating revenue through FiTs. The HRES for HOMER and iHOGA was validated using [90, 116].

5.3.4 HOMER software simulated result analysis

This section comprehends the detailed analysis of the best chosen HOMER software model for a definite case. There are two optimised models from HOMER: Model-1 and Model-2 are the models chosen as the optimised model simulated by HOMER. Model-1 of HOMER has the RE penetration of 71%, Model-2 is the HOMER optimized model with the autonomy of 2.07hr which is comparable to the user set minimum autonomy of 2.4hr. The Model-1 consists a 10.3kW PV, 10 WT and 20 Trojan batteries along with 7.07kW converter. The NPC of this system is INR42Lac with COE 5.6INR/kWh. The HOMER optimised result, Model-2, consists of 15.3kW of PV, 10 WT and 13 Trojan 105 batteries connected to the grid through a converter of 4.33kW. The NPC of this system is INR55.3Lac and COE is 5.27INR/kWh.

a. Result Analysis of Model-I of HOMER software

- ***Techno-Economic Analysis***

The Table 5.8 provides the different types of costs of individual components in the HRES Model-1. It is observed that the capital cost of the system is the highest compared to O&M and salvage cost of INR5.19M. The Capital Cost of the WT being the highest of INR3.5M compared to the Capital Costs of the PV, system converter, and batteries of INR 0.81M, INR0.48M and INR0.39M respectively. The total Capital Cost of the overall system is INR5.19M. When the O&M costs of the PV, WT and batteries are considered, the batteries has the highest cost of INR8,658. It is obvious that the battery life time is less and needs to be timely replaced compared to other componnets. However, the O&M cost of WT is high of INR3,463 compared to PV of O&M cost INR1,780. The O&M of grid is negative due to the reason that the electricity sold to the grid is more than the electricity bought from the grid, thus the O&M cost of the grid is -INR0.41M. The total O&M of the system is -INR0.42M. The salvage value of the components includes the remaining cost of the components at the end of the project's lifetime. The salvage value of the total system is -INR0.5M. Thus, the total cost of the overall system is INR4.25M with the cost of WT to be maximum of INR3.2M.

Figure 5-.11 and Table 5-.9 provides the insight to the energy production of PV and WT in a year and its contribution in electricity production and consumption. The RE production is maximum in the months of July and August, the months correspond to the

wind energy being maximum and thus energy from WT is maximum. In a year, energy from WT production is approximately 52,534kWh with 59.6% of overall energy production compared to PV or grid purchase. Approximately 11.6% of electrical energy is produced from PV which is, 10,254kWh/year. The remaining load is met through grid purchase, this corresponds to 28.8% or 25,430kWh/year. Thus, there is no load that goes unmet from this system. Approximately, 2.12kWh of energy is excess on considering this HRES configuration. Figure 5.12 shows the electricity production of PV, WT, and grid sales. It is observed that, all the energy components meet the load of Aralvaimozhi community. The stochastic behaviour of the RE components are much noticeable from these diagrams. However, it is observed that energy sold to the grid is maximum when the RE output, specially when the wind energy output is maximum. This is noticed in the months between June to September

Table 5.8 Cost analysis of the HOMER optimised model, Model-I

	Capital (INR)	**O&M (INR)**	**Salvage (INR)**	**Total (INR)**
Generic PV (flat plate)	817,815.04	1,779.08	-105,840.50	713,753.62
Grid	0.00	-441,872.57	0.00	-441,872.57
System Converter	484,153.95	0.00	0.00	484,153.95
Trojan T-105	390,000.00	8,658.12	-124,290.42	274,367.70
UE 1500 (1.5kW)Wind Turbine	3,500,000.00	3,463.25	-283,103.26	3,220,359.99
System	5,191,968.99	-427,972.12	-513,234.18	4,250,762.70

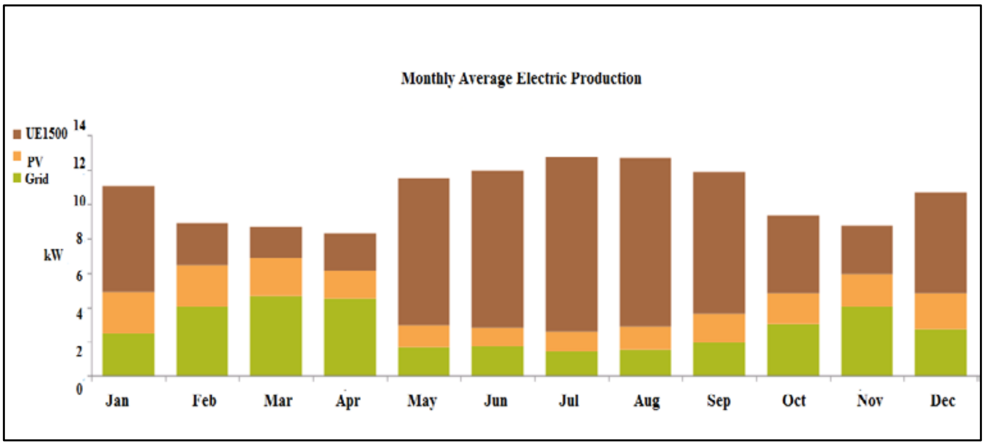


Figure 5.11 Monthly Average Electric Production of the HOMER optimised Model-I

Table 5.9 Details of electricity production and consumption from Model-I

Production			**Consumption**			**Quantity**		
Production	**kWh/yr**	**Percentage**	**Consumption**	**kWh/yr**	**Percentage**	**Quantity**	**kWh/yr**	**Percentage**
Generic PV (flat plate)	10,25 4	11.6	**A.C. Primary Load**	66,941	76.3	**Excess Electricity**	2.12	0.0024
UE 1500 (1.5kW)Wind Turbine	52,53 4	59.6	**D.C. Primary Load**	0	0	**Unmet Electric Load**	0	0
Grid Purchases	25,43 0	28.8	**Grid Sales**	20,763	23.7	**Capacity Shortage**	0	0
Total	88,21 8	100	**Total**	87,704	100			

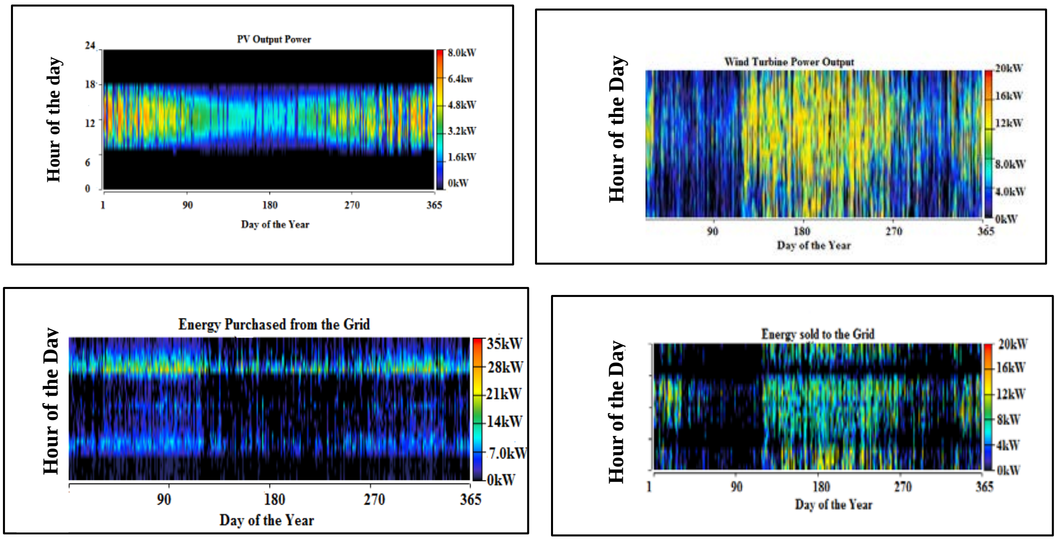


Figure 5.12 Shows the energy output of a PV, WT and Grid sales from HRES of Model-I (top left to bottom anti-clockwise)

Table 5.10 illustrates the monthly grid sales and corresponding energy charge. It can be observed that, 25,430kWh of energy is purchased annually. The grid energy purchase is maximum in the months of March and April, 3,592.66kWh and 3,439.044kWh respectively. Similarly, energy sold to the grid is maximum in the months of July and August with 3,595.4kWh and 3,225.51kWh respectively. It can be noticed that, July and August months correspond to peak wind energy availability in Aralvaimozhi. The energy purchased from the grid due to lack of availability of RE from the HRES is maximum in the months of March and April which are, 3399kWh and 3,267.75kWh respectively.

However, this energy purchase price is compensated by the energy sold to the grid in the rest of the months as shown in the tabular column with negative values. Thus, there is a yearly revenue of INR51,035.63 generated on considering the current HRES

➢ ***Poisonous Gas Emissions from the HRES model***

HOMER software has the facility to provide the detailed values of different gas emissions involved when a HRES is considered. For the current system the poisonous gas emissions are given in Table 5.11.The CO_x is considered as the prime emission factor considered in any energy related equipment. In this HRES, the CO_2 emission is maximum compared to any other gas emissions. The CO_2 emissions from the considered HRES is 16,072kg/year. The SO_x and NOx emissions are 69.7kg/year and 34.1kg/year respectively

Table 5.10 Grid energy sales and grid chargesfrom Model-I

Month	**Energy Purchased (kWh)**	**Energy sold (kWh)**	**Net Purchased (kWh)**	**Peak Demand (kW)**	**Energy Charge (INR)**
January	1867.00437	1970.717841	-103.713472	28.265583	-6,017.93
February	2748.747	384.554508	2364.193	25.732303	3,976.07
March	3592.66	193.644718	3399.018	30.824643	6,772.56
April	3439.044	171.291968	3267.752	27.729522	6,554.75
May	1317.145	2754.548	-1437.4029	26.602065	-11,203.16
June	1311.98	2821.879	-1509.8989	22.987214	-11,557.71
July	1125.257	3595.397	-2470.139	25.533	-15,905.97
August	1191.449	3225.51098	-2034.062	22.326901	-13,876.58
September	1450.319	2564.07411	-1113.754	20.437868	-9,944.09
October	2369.386	971.307	1398.079	25.67554	164.21
November	2959.7	419.512	2540.187	31.973842	4,253.44
December	2057.499	1690.305	367.193	23.515559	-4,251.23
Annual	25430.197	20762.74	4667.453	31.973842	-51,035.63

Table 5.11 Poisonous gas emissions from the HRES considered in Model-I

Poisonous emissions	kg/yr
Carbon Dioxide	16,072
Carbon Monoxide	0
Unburned Hydrocarbons	0
Particulate Matter	0
Sulphur Dioxide	69.7
Nitrogen Oxides	34.1

b. Result Analysis of Model-II of HOMER software

This section discusses the results of Model-II. Model-II has been considered in the discussion due to its results having battery autonomy value 2.07hr, which is close to 2.4hr (user defined battery autonomy value). The RE penetration of this HRES system is just above 70%, which is 72.3%.

- ***Techno-Economic Analysis***

The Table 5.12 provides the different types of Costs of individual components in the HRES Model-2. It is observed that the Capital Cost of the system is the highest compared to operational & maintenance cost and salvage cost of INR5.27M. The Capital Cost of the WT being the highest of IN 3.5M compared to the Capital Costs of the PV, system converter, and batteries of INR1.22M, INR0.29M and INR0.25M respectively.

Table 5.12 Capital Operating Replacement Salvage Costs Total of HOMER optimised model, Model-II

	Capital (INR)	O&M (INR)	Salvage (INR)	Total (INR)
Generic PV (flat plate)	1,220,533.33	2,655.16	-157,959.75	1,065,228.74
Grid	0.00	-507,454.13	0.00	-507,454.13
System Converter	296,833.33	0.00	0.00	296,833.33
Trojan T-105	253,500.00	5,627.78	-80,788.77	178,339.01
UE 1500 (1.5kW)Wind Turbine	3,500,000.00	3,463.25	-283,103.26	3,220,359.99
System	5,270,866.67	-495,707.95	-521,851.78	4,253,306.94

The O&M costs of the PV, WT and batteries are considered, the batteries have the highest cost of INR5,628, it is obvious that the battery life time is less and needs to be timely replaced compared to other componnets. However, the O&M cost of WT is high of about INR 3,463.25 compared to PV of O&M cost INR2,655. The O&M of grid is negative due to the reason that the electricity sold to the grid is more than the electricity bought from the grid, thus the O&M cost of the grid is -INR0.5M. The total O&M of the system is -INR0.495M. The salvage value of the components includes the remaining cost of the components at the end of the project's lifetime. The salvage value of the total system is -INR0.52M. Thus, the total cost of the overall system is INR4.25M with the cost of WT to be maximum of INR 3.2M compared to other components of the system in Model-II.

Figure 5.13 and Table 5.13 provides the insight to the energy production of PV and WT in a year, its contribution in electricity production and consumption. The RE production is maximum in the months between May and August, the months correspond to the wind energy being maximum; and thus energy from WT is maximum. In a year, energy from WT production is approximately 52,534kWh with 56.8% of overall energy production compared to PV or grid purchase. Approximately 16.6% of electrical energy is produced from PV with 15,303kWh/year. The remaining load is met through grid purchase, this corresponds to 26.6% of 24,603kWh/year. Thus, there is no load that goes unmet from this system. Approximately 2,986kWh of energy which is about 3.23% of energy is excess on considering this HRES configuration.

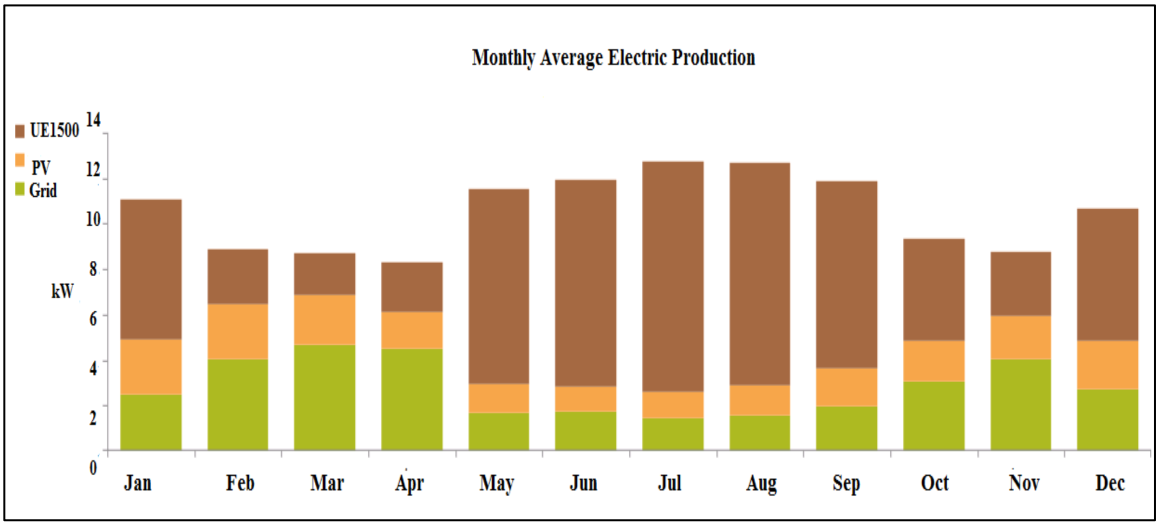


Figure 5.13 Details of electricity production and consumption from Model-I

Figure 5.14 shows the electricity production of PV, WT, and grid sales. We see that all the energy components meet the load of Aralvaimozhi community. The stochastic behaviour of the RE components are much noticeable from these diagrams. However, it is observed that energy sold to the grid is maximum when the RE output, specially when the wind energy output is maximum. This is noticed in the months between May to September.

Table 5.13 Details of electricity production and consumption from Model-II

Production			**Consumption**			**Quantity**		
Production	**kWh/yr**	**Percentage**	**Consumption**	**kWh/yr**	**Percentage**	**Quantity**	**kWh/yr**	**Percentage**
Generic PV (flat plate)	15,303	16.6	**A.C. Primary Load**	66,941	75.4	**Excess Electricity**	2,986	3.23
UE 1500 (1.5kW)Wind Turbine	52,534	56.8	**Grid Sales**	21,898	24.6	**Unmet Electric Load**	0	0
Grid Purchases	24,603	26.6	**Total**	88,839	100	**Capacity Shortage**	0	0
Total	92,440	100						

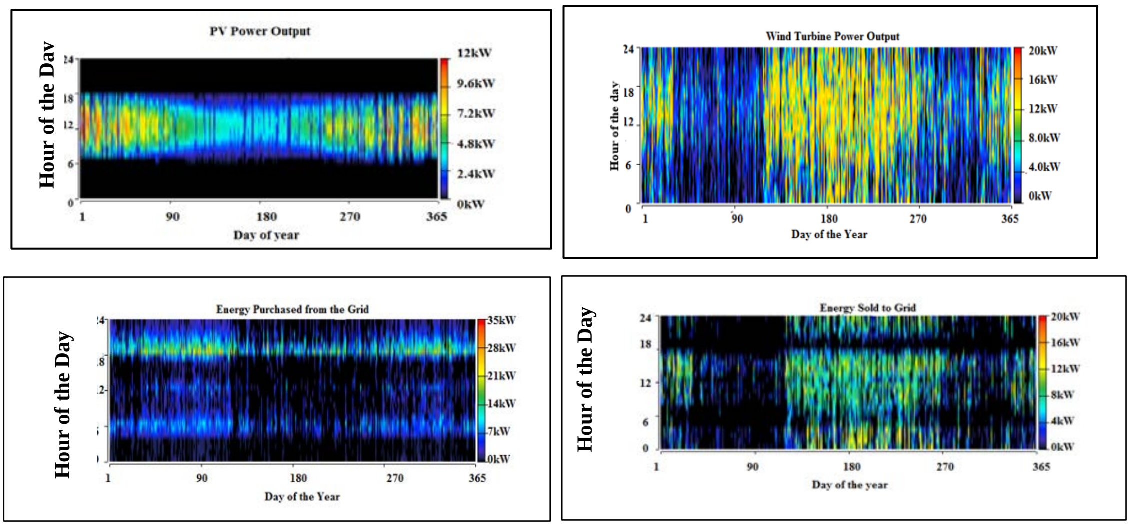


Figure 5.14 Shows the energy output of a PV, WT and Grid sales from HRES of Model-II (top left to bottom anti-clockwise)

Table 5.14 illustrates the monthly grid sales and corresponding energy charge. It can be observed that 24,602.5kWh of energy is purchased annually. The grid energy purchase is maximum in the months of March and April, which is 3,470.26kWh and 3,246.48kWh respectively. Similarly, energy sold to the grid is maximum in the months of July and August with 3,595.4kWh and 3,225.51kWh respectively.

It can be noticed that July and August months correspond to peak wind energy availability in Aralvaimozhi. The energy purchased from the grid due to lack of availability of RE from this HRES is maximum in the months of March and April with 3,807.6kWh and 3,445.25kWh respectively. However, this energy purchased price is compensated by the energy sold to the grid in the rest of the months as shown in the tabular column with negative values. Thus, there is a yearly revenue of generated through FiTs on considering the current HRES.

Table 5.14 Grid energy sales and grid chargesfrom Model-II

Month	Energy Purchased (kWh)	Energy sold (kWh)	Net Purchased (kWh)	Peak Demand (kW)	Energy Charge (INR)
January	1862.579745	1936.634969	-74.055225	28.265583	-5,853.67
February	2709.396103	391.198781	2318.197322	25.732303	3,857.18
March	3470.259862	215.594629	3254.665233	30.824643	6,396.23
April	3246.487407	240.586647	3005.900760	27.729522	5,785.42
May	1256.710002	2975.500183	-1718.790180	26.602065	-12,460.56
June	1259.416975	3017.550400	-1758.133425	22.987214	-12,669.17
July	1074.770059	3807.602749	-2732.832690	25.465261	-17,097.27
August	1148.064334	3445.252837	-2297.188503	22.293872	-15,090.97
September	1396.758434	2699.670674	-1302.912240	20.437868	-10,751.32
October	2259.720187	1046.610131	1213.110056	25.675540	-456.72
November	2906.592122	438.699858	2467.892264	31.973842	4,040.87
December	2011.748000	1682.615578	329.132422	23.515559	-4,310.24
Annual	24602.503231	21897.517437	2704.985794	31.973842	-58,610.21

- ***Poisonous Gas Emissions from the HRES model***

HOMER software has the facility to provide the detailed values of different gas emissions involved when a HRES is considered. For the current system the poisonous gas emissions are given in Table 5.15. The COx is considered as the prime emission factor considered in any energy related equipment. In this HRES, the CO_2 emission is maximum compared to any other gas emissions. The CO_2 emissions from the considered HRES is 15,549kg/year. The SO_x and NO_x emissions are 67.4kg/year and 33kg/year respectively.

Table 5.15 Poisonous gas emissions from the HRES considered.

Poisonous emissions	kg/yr
Carbon Dioxide	15,549
Carbon Monoxide	0
Unburned Hydrocarbons	0
Particulate Matter	0
Sulphur Dioxide	67.4
Nitrogen Oxides	33.0

5.3.5 iHOGA software simulation for Aralvaimozhi Case study

This section introduces the application of iHOGA software for optimally sizing renewable energy system. Unlike HOMER, iHOGA has not been explored much as seen in the literature. The working principle has been already explained in Chapter 3. It is noted that, the same system specifications have been used for iHOGA as used for HOMER in Section 5.4. iHOGA (with additional Pro version) is a software tool to study sizing and optimisation of RES connected to the grid or stand-alone systems. Like HOMER, iHOGA can result in producing an optimum solution by minimizing the cost of the energy systems along the term of the project which would reflect on the NPC. However, iHOGA uses GA technique to find the optimum solution. iHOGA is the software that gives minimising NPC as a mono-objective solution. However, iHOGA is flexible to permit multi-objective optimisation. The multi-objective variables include:

- Minimising NPC.
- Minimising of the unmet load.
- Minimising of CO_2 emissions.
- Maximising Human Development Index (HDI) and job creation.

The aforementioned multi-objective variables can be chosen by the user accordingly. The multi-objective optimisation could result in multiple feasible solutions. This is due to the detrimental behavior of each objective function to provide a feasible optimum solution. The software can simulate systems of any size ranging from Wh to MWh. The optimisation technique used by iHOGA software has already discussed in Chapter 3. The application of this software for the optimisation of HRES for Aralvaimozhi community will be dealt in this section.

Preliminary analysis in Sections 3.1 and 3.2 highlighted Aralvaimozhi's abundant energy resources namely Solar and Wind energy to be exploited for RE option to the community. Figure 5.15 shows the HRES used for RE adoption for Aralvaimozhi community. This includes generic PV, UE1500 Wind turbine, set of Trojan batteries connected to the grid. The details of the components used for the study is provided in Table 5.16. The electricity bill was analyzed to find the average electricity price paid by the community for 1kWh, this was INR2.16/kWh. The feed-in tariff though was not given for TN in any literature, however, it was considered as INR5.1/kWh [123].

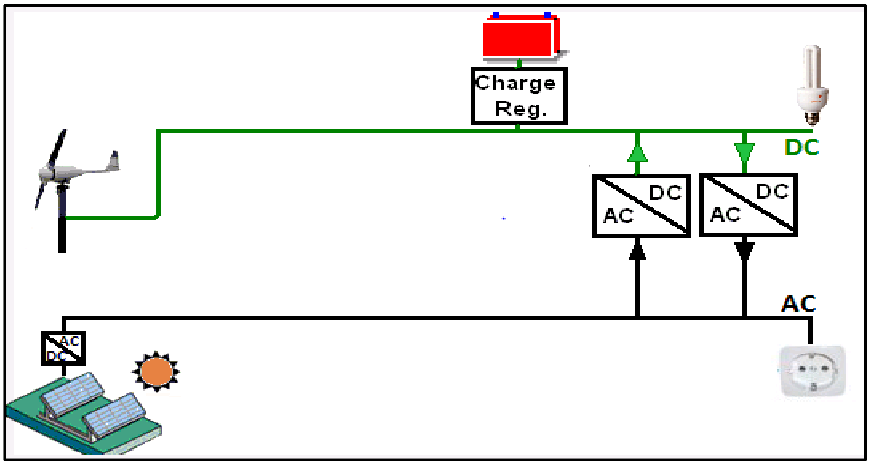


Figure 5.15 The HRES for Aralvaimozhi community, India

Table 5.16 Specifications of HRES components used for analysis

Components	**Specification**		**Cost**	
Solar Panels (PV)	Nominal Voltage	12V	Capital Cost	79600/year
	Shortcut Current	8.23A	O&M Cost	100/year
	Nominal power	1000Wp		
	Life span	25 years		
UE 1500 Wind Turbine	Height	12m	Capital Cost	250,000
	Rated Power	1500W	Replacement cost	250000
	Life Span	20 years	O&M cost	10/year
Converter	Generic system converter (bi-directional inverter/converter)	-	68,500	-
Battery	Nominal Capacity	254Ah	Capital Cost	19000
	Voltage	6V	O & M cost	20
	SOC	20%		

For the control strategy Load following (LF) option was considered, this means the unmet load from the RES will be met by the charged batteries. With one day of minimum autonomy, the HRES was sized for a minimum renewable energy fraction of 65%. Grid system used, would act as an additional support in case the energy to the load is not met by the RES or from the batteries. The grid is also used to dump the excess power after the load is met by the RES.

- ***iHOGA Software Result Analysis***

If the optimistion method considered is the multi-objective optimisation, then in many cases the results thus produced may be mutually counterproductive. Depending on the objectives selected to be optimised, many solutions will be provided by the system. Many of them may offer the least emission and others may provide the least cost or unmet load. The solutions presented will be in a sorted manner with the best ones on top. In contrast to the aforementioned objective, a single objective function has been discussed for various sensitive cases. The study conducted primarily explores the probable variables for Indian scenario, where the optimisation of HRES has been conducted using iHOGA software here.

iHOGA software simulated 15 sets of results. This software performs single objective optimisation considering 15.5% as interest rate and 7.13% inflation rate for a study period of 15 years. iHOGA considered the GA for the main algorithm and evaluating all the combinations of the secondary algorithm with 29,993 cases. For each combination of sensitive cases, iHOGA produced at least 15 results in a tabular column with the last row being the best-optimised result. iHOGA sized the RES with maximum 3 batteries in parallel, maximum 132 PV panels in parallel connection and maximum 20 WT in parallel connection which is shown in Figure 5.16. A generic bi-direction inverter was used for the chosen HRES system

The mono-objective constraint was chosen to minimise the NPC. The analysis was made by evaluating 29993 cases. The control strategy used in the analysis include the minimum SOC of the batteries to be kept as 20%, and any excess of energy from the renewables/batteries can be sold to the grid. Charge battery if the price of electricity from the grid is lower than 2.376INR/kWh while Discharge batteries (load + injecting to the grid) if price Electricity is higher than 1.944 INR/kWh (These prices were +/- 10% of the electricity purchase price from the grid for Aralvaimozhi). The primary algorithm was chosen to be "Evaluating all the combinations" while the secondary algorithm was chosen as GA. A set of 15 results were tabulated with the least values of NPC. The resulting chart of the iHOGA simulation is shown in Figure 5.17.

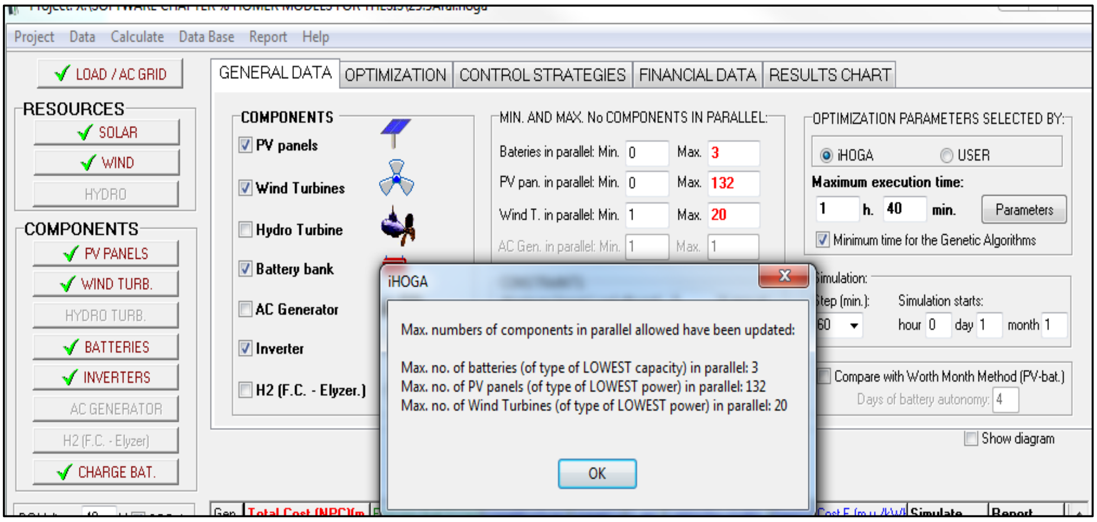
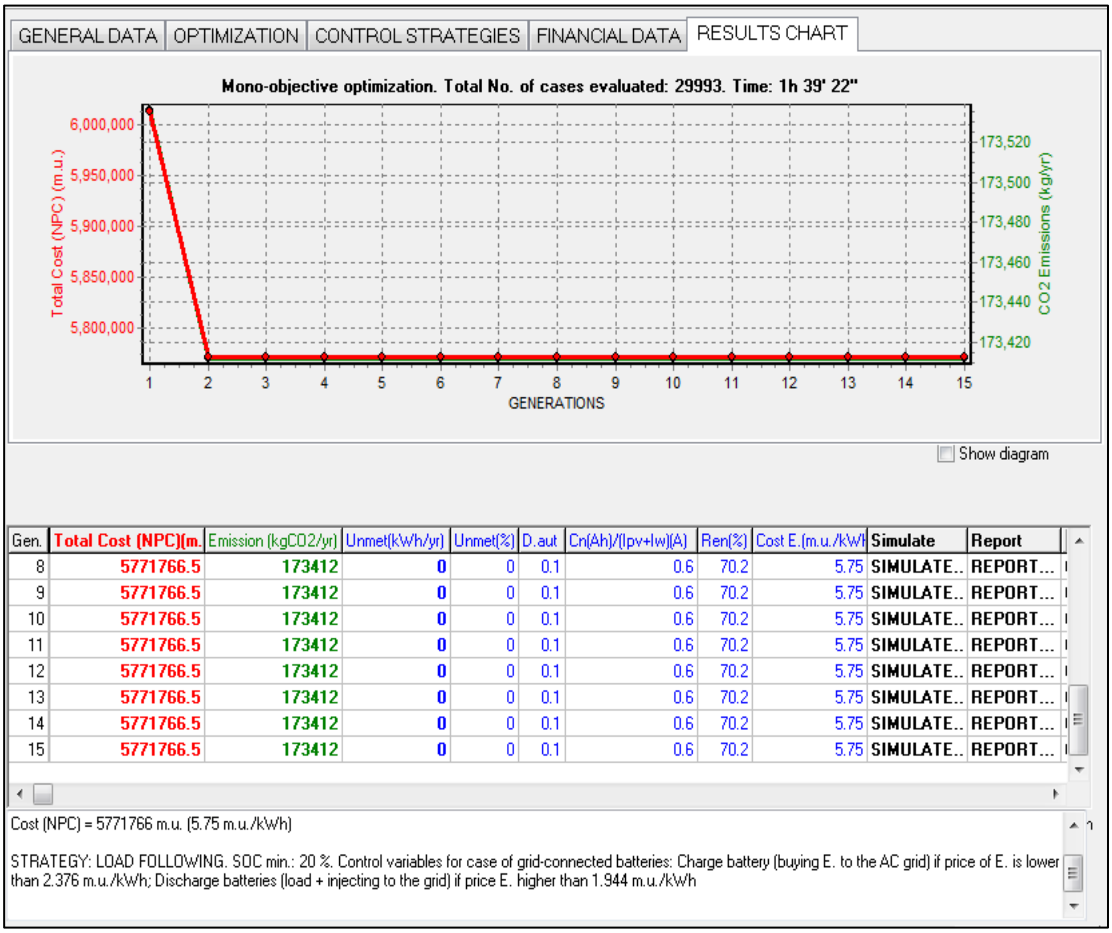


Figure 5.16 Maximum components size chosen by iHOGA for analysis



Gen.	Total Cost (NPC)(m.	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Ah)/(Ipv+Iw)(A)	Ren(%)	Cost E.(m.u./kWh	Simulate	Report
8	5771766.5	173412	0	0	0.1	0.6	70.2	5.75	SIMULATE..	REPORT...
9	5771766.5	173412	0	0	0.1	0.6	70.2	5.75	SIMULATE..	REPORT...
10	5771766.5	173412	0	0	0.1	0.6	70.2	5.75	SIMULATE..	REPORT...
11	5771766.5	173412	0	0	0.1	0.6	70.2	5.75	SIMULATE..	REPORT...
12	5771766.5	173412	0	0	0.1	0.6	70.2	5.75	SIMULATE..	REPORT...
13	5771766.5	173412	0	0	0.1	0.6	70.2	5.75	SIMULATE..	REPORT...
14	5771766.5	173412	0	0	0.1	0.6	70.2	5.75	SIMULATE..	REPORT...
15	5771766.5	173412	0	0	0.1	0.6	70.2	5.75	SIMULATE..	REPORT...

Figure 5.17 Snapshot of the optimum result simulated by iHOGA

The optimally sized HRES using the defined constraints provided by Aralvaimozhi are shown in Figure 5.18. An 18kW PV, 11 UE 1500 WT providing 16.5kW of power. A 10 kW bi-directional inverter and 365.5kWh of batteries with 8 in series and 3 in parallel combinations.

The energy balance of each of the components in a year is shown in the Figure 5.19. In a year 76,668kWh of energy is delivered by PV and 37,400kWh of energy is delivered by the UE 1500 WT turbine. 213kWh/yr of energy is used to charge the batteries while 4kWh/yr is discharged. 27,302kWh/yr of excess energy is sold to the grid by the HRES system and 19,592kWh of energy is purchased to meet the load.

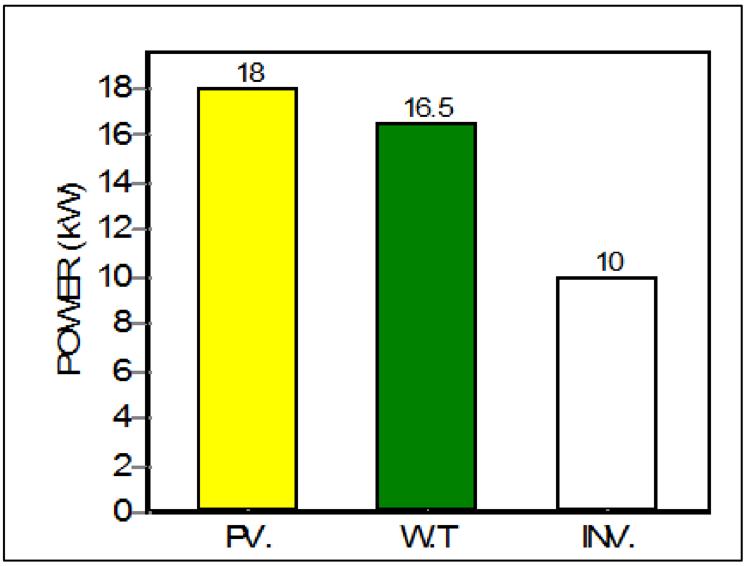


Figure 5.18 Optimum sized HRES for Aralvaimozhi case study simulated by iHOGA

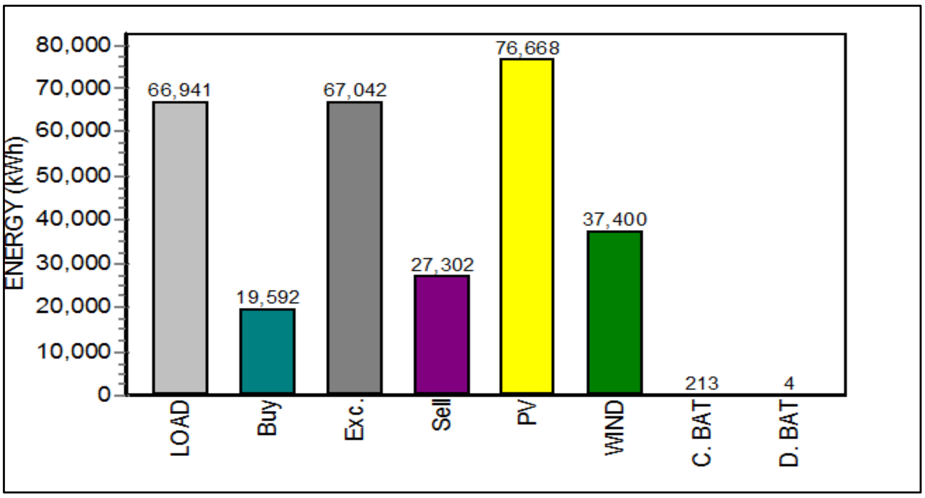


Figure 5.19 Energy generation details by the optimum sized HRES

iHOGA simulated results of all the components in a year is shown in Figure 5.20. It is observed that, most of the micro-grid set up designed for Aralvaimozhi meets total community's load. PV supplies a maximum portion of the energy compared to WT. The batteries charge and discharge efficiently according to the system constraint provided. While a very small amount of energy is bought from the grid in times of lack of RE supply. Nearly 70.2% of energy is met by the chosen RE making the system optimised with least value of NPC. Monthly average output of the optimum HRES model is shown in Figure 5.21. The power output from the HRES showcases the LF strategy set as the input for HRES. At every instant in time, PV or WT meets the load of the system. When the PV or WT output is low, the battery discharges power to meet the load of the community.

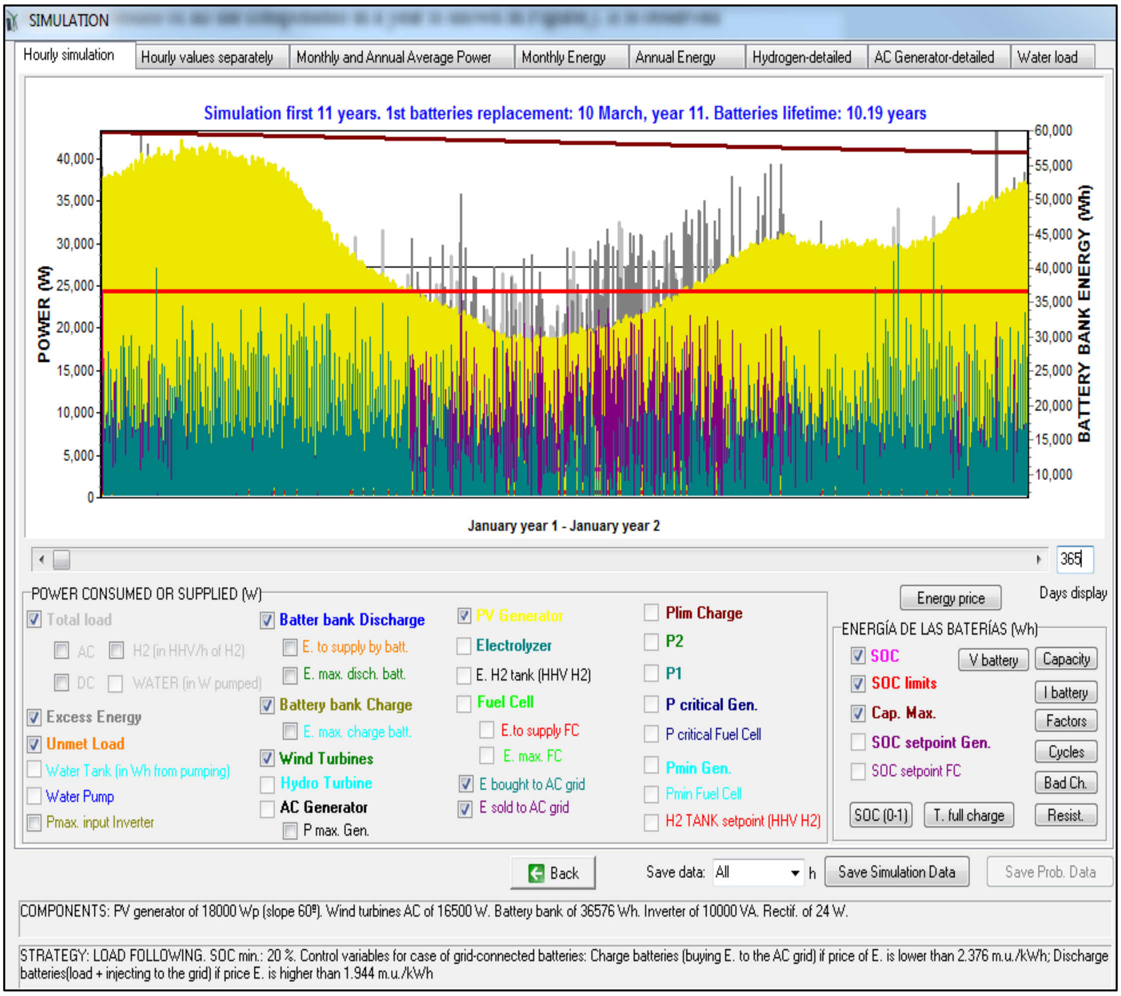


Figure 5.20 Power output of the optimum sized HRES in a year

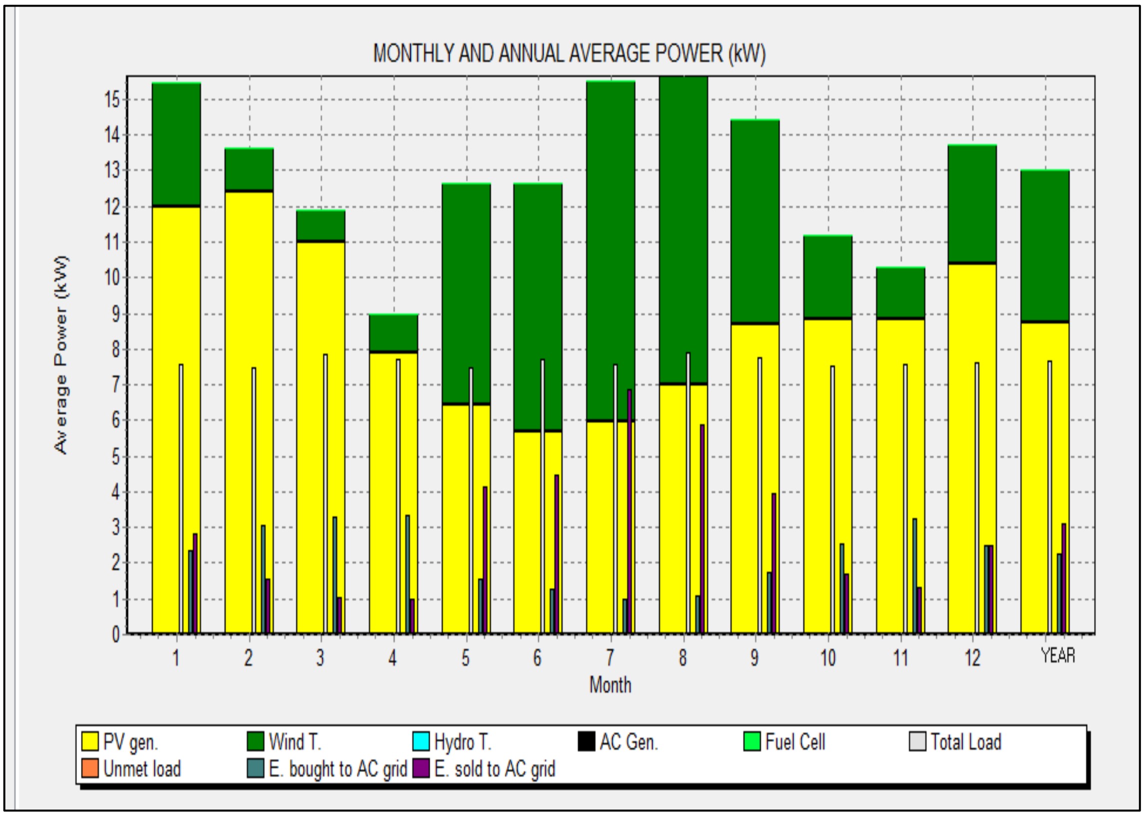


Figure 5.21 Monthly average output of the optimum HRES model

The NPC of the system for the given constraint is discussed in the Figure 5.22. The total NPC of the HRES considered by iHOGA software for Aralvaimozhi community is INR5.77M with the COE of INR5.75/kWh. The total NPC of WT being the highest of INR3.85M. The total NPC of the PV, batteries and inverters are is INR1.43M, INR0.62M and INR0.68M respectively.

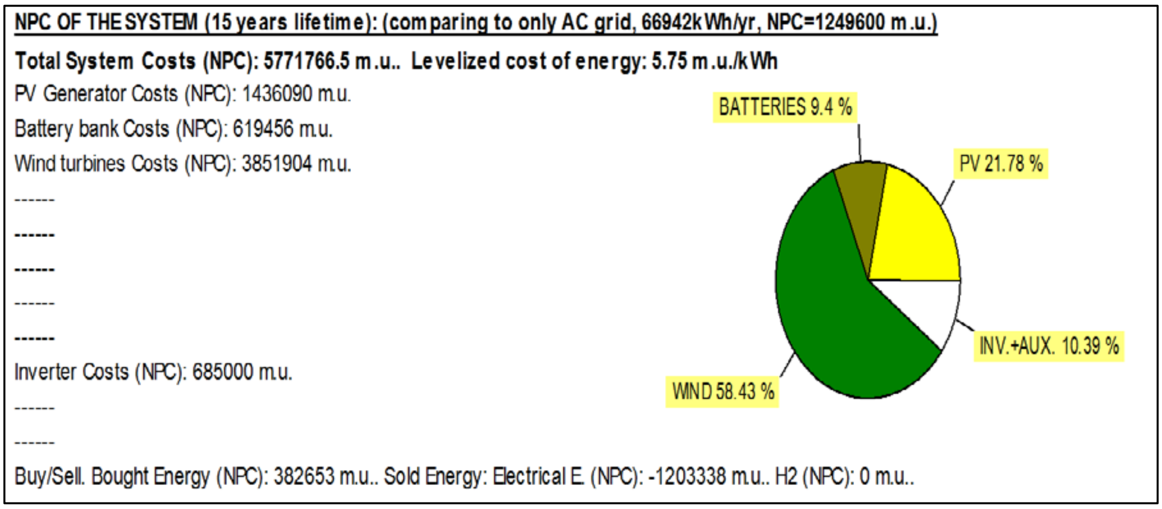


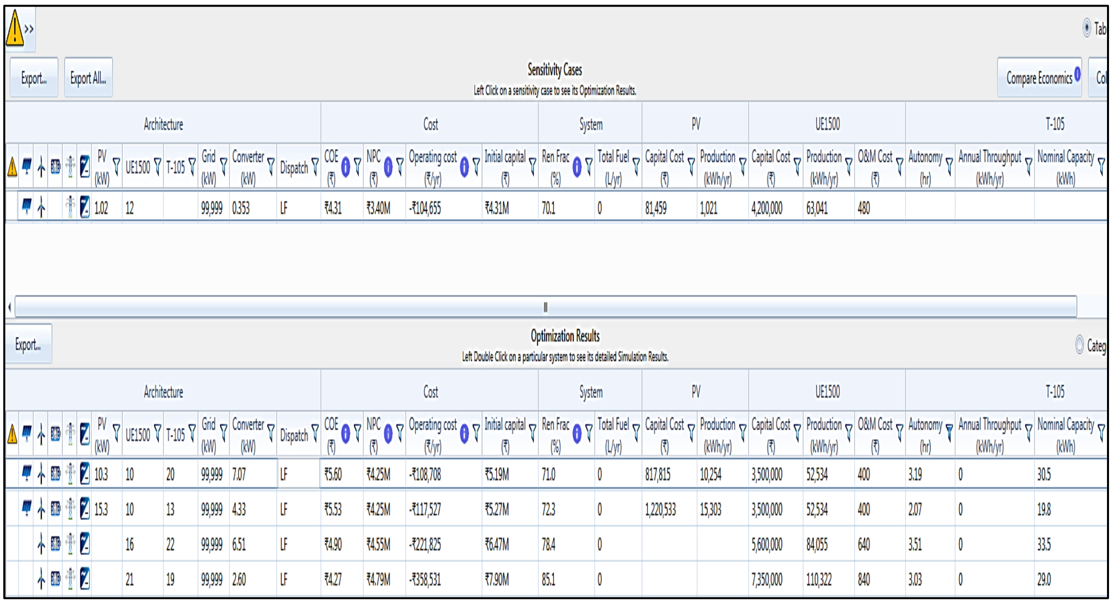
Figure 5.22 NPC details of every components of the optimised HRES

When the individual costs of HRES system is analysed, it is observed that, the Capital Cost of the whole system is INR6.57M, with the Capital Cost of WT to be the highest value of INR3.85M. The Capital Costs of PV, converter and batteries are INR1.43M, INR0.68M and INR0.608M respectively. The O&M costs of the HRES is INR16,017. The total grid sales in 15 years is -INR1.2M. The negative sign indicates that the energy sold to the grid is higher than the energy purchased from the grid.

5.3.6 Result comparison between HRES simulated by HOMER and iHOGA software for Aralvaimozhi

HOMER and iHOGA software packages simulate and produce the results considering the user defined constraints and tabulates the results in according to the least value of NPC. The best HRES with the least value of NPC is on the topmost result (Result 1) in the tabular column according to HOMER, whilst the 15th solution (last solution) is the best solution with the least value of NPC in iHOGA. The snapshot of the tabulated result from HOMER and iHOGA software packages is shown in Figure 5.23.

The size of HRES for Aralvaimozhi by HOMER and iHOGA simulations are almost similar, however, there is a very small discrepancy in their values. This is shown in Table 5-.20. This smaller discrepancy is due to the methodology used by both the software packages to calculate the NPC, the control strategies dealt by iHOGA is more precise compared to HOMER software. There are two models discussed here with the HOMER simulated results, both the models showcase results which are similar to iHOGA optimized results. Model-1 from HOMER was considered due to the RE penetration being close to 70%, while Model-2 was the optimised model by HOMER when the autonomy of battery was close to 2.4hr, the results of all optimised model by HOMER and iHOGA are similar and are highlighted in Table 5.17.



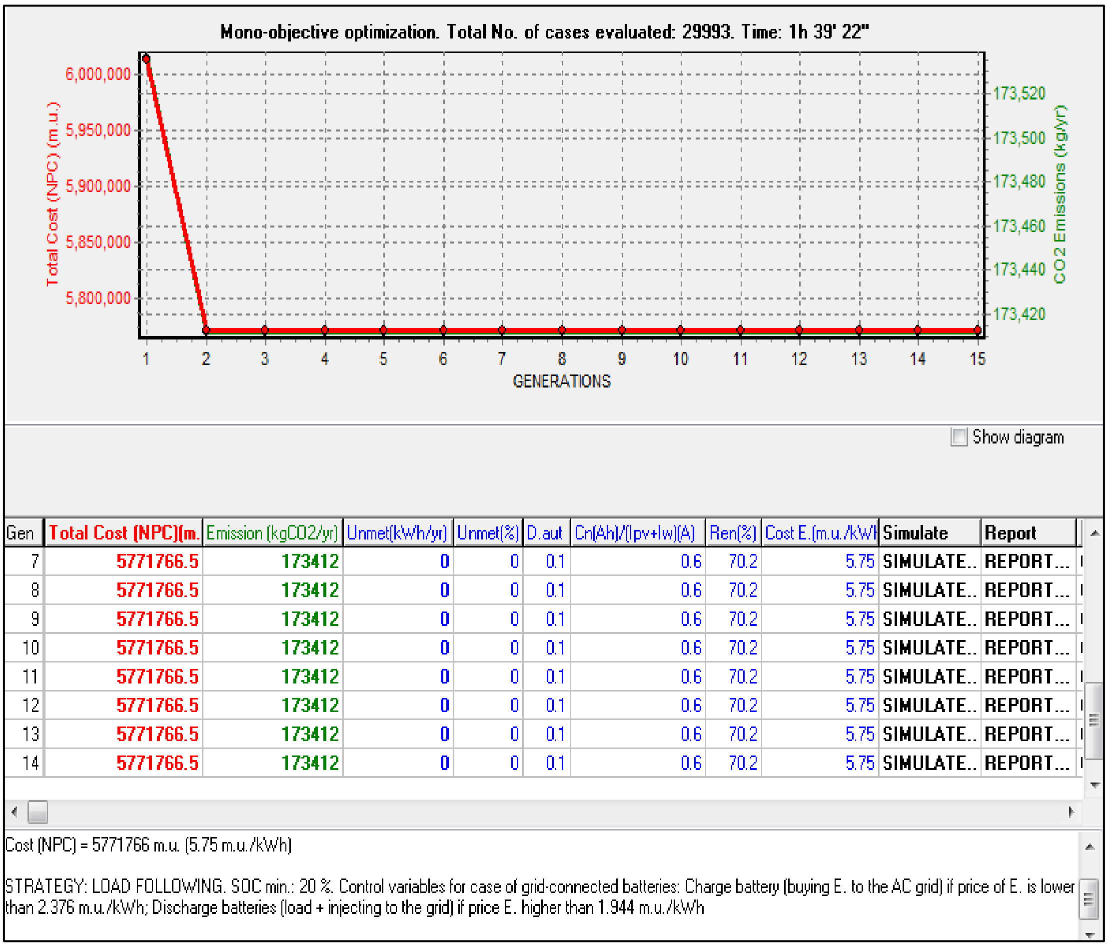


Figure 5.23 The NPC results simulated by HOMER (on top) and iHOGA software (bottom)

Table 5.17 Result comparison from HOMER and iHOGA software

		HOMER		**iHOGA**	**Comments**
		Model-1	**Model-2**		
Size	PV	10.3kW	15.3kW	18kW of PV	PV sized by iHOGA is large by a few kilo-Watt
	WT	10	10	11WT of 18kW	Similar size WT by HOMER and iHOGA.
	T105 (Trojan Battery)	20 batteries (30.5kWh Nominal Capacity)	13 batteries (19.8kWh Nominal Capacity)	Batteries connected as 8strings*3parallel with 36.5kWh	Battery size with Nominal Capacity is compared, Model-1 has a nominal capacity close to the iHOGA sized model.
	Converter	7.07kW	4.33kW	10kW	Bigger converter sized by iHOGA than HOMER.
Economics	NPC:	INR4.25M	INR5.53M	INR5.771M	Large NPC from iHOGA is due to the bigger sized converter. However, iHOGA does not consider the revenue from the HRES system from like HOMER software does to calculate NPC.
	COE:	5.6INR/kWh	5.27INR/kWh	5.75INR/kWh	If COE is calculated by the method iHOGA and HOMER software differ due to the value of NPC. (This discrepancy in software calculated values have been noted in the literature [86, 124]. However, the reason for this discrepancy has not be provided in the literature).
Renewable Energy penetration		71%	72.3%	70.1%	RE penetration from the HRES resulted by HOMER is higher than iHOGA.
Emissions		COx: 16,072kg/yr SOx:69.7kg/yr NOx:: 34.1kg/yr	COx: 15,549kg/yr SOx:67.4kg/yr NOx:33kg/yr	COx: 173412kg/yr	Emissions for poisonous gases like COx, NOx, SOx and other particulate matters are considered in HOMER. iHOGA considers only Cox emissions.
Job creation		-	-	0.0633	This feature is not available in HOMER software
Human Development Index (HDI)		-	-	0.9225	This feature is absent in HOMER software
Autonomy		3.189hr	2.07hr	2.4hr	Autonomy of the system in MODEl-1 and Model-2 is close to 2.4hr

The two optimised models from HOMER: Model-1 and Model-2 are the models chosen as the closest comparable optimised model simulated in comparison with iHOGA simulated model. Model-1 of HOMER has the RE penetration of 71 %, this is comparable to the iHOGA simulated model having RE penetration of 70.1%. However, Model-2 is the HOMER optimised model for with the autonomy of 2.07hr which is comparable to the iHOGA simulated optimised model having an autonomy of 2.4hr. It is observed from the analysis that, the optimum results from both iHOGA and HOMER are very similar for the given constraints. This is observed even when the COE is considered amongst the HRES of the models simulated by HOMER and iHOGA. All the three models have the COE in the range of 5INR/kWh. However, the optimised HRES by HOMER has a greater RE penetration of 71.3% and 72.3% compared to iHOGA software which has 70.1%.

When the size of the optimised HRES is considered for the given constraint, iHOGA sized the HRES system for the least value of NPC. The HOMER optimises the HRES to 100% accuracy, while iHOGA optimizes system close to the optimised value. The optimised model produced by iHOGA has a larger PV penetration of 18kW compared to the two models simulated by HOMER with 10.3kW and 15.3kW respectively. The WT size matches with the iHOGA with 10 and 11 by HOMER and iHOGA simulated models respectively. However, the batteries sized by HOMER in Model-2 and iHOGA are similar, this is evident from the battery autonomy being similar. The converter sized by iHOGA is large compared to the two models resulted by HOMER. This could be due to the large PV penetration in the iHOGA optimised model.

The poisonous gas emissions are clearly explained for different gases like- COx, NOx, Sox, particulate matter in HOMER software. The iHOGA software considers only COx gas emissions. The COx emissions of the iHOGA simulated model and HOMER simulated models are alike. This is directly related to the size of optimised HRES resulted by the software. iHOGA discussed the job creation and HDI. These two results could be one of the important factors to discuss for a developing country like India. The job creation of 0.0663 generated per GWh if this project is sanctioned for installation. Similarly, HDI calculated by iHOGA for the optimised model is 0.9225.

5.4 Software Simulation: Warrnambool Case study

5.4.1 HOMER and iHOGA software simulation for Warrnambool, Australia

HOMER and iHOGA software were used to optimally size the RES for Warrnambool, Australia. As explained earlier, Warrnambool is bestowed with abundant solar and wind energies. These two energies are exploited by sizing the energy sources for a university building in Warrnambool, Australia and their costs are analysed.

5.4.1.1 Resource Availability in Warrnambool

Warrnambool has an average temperature of 14.27^{0}C. It has an oceanic temperate climate. On average, annual rainfall is higher than in other areas of the state. The solar energy in the peak during the summer season (November-January) with the solar energy being least in the June-July. The annual average solar radiation is about 4.18kWh/m^2/day as shown in Figure 5.24. The annual average of the wind speed was found to be 5.96m/s is shown in Figure 5.25.

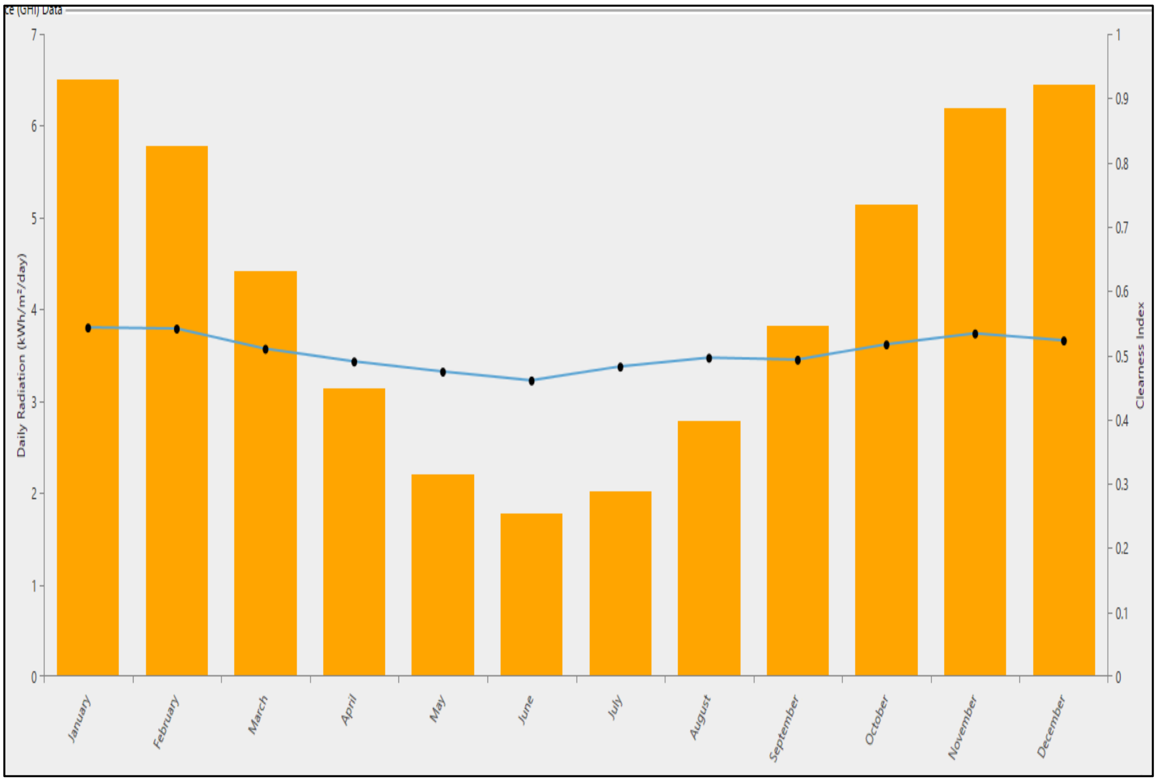


Figure 5.24 Annual average solar radiation in Warrnambool, Australia

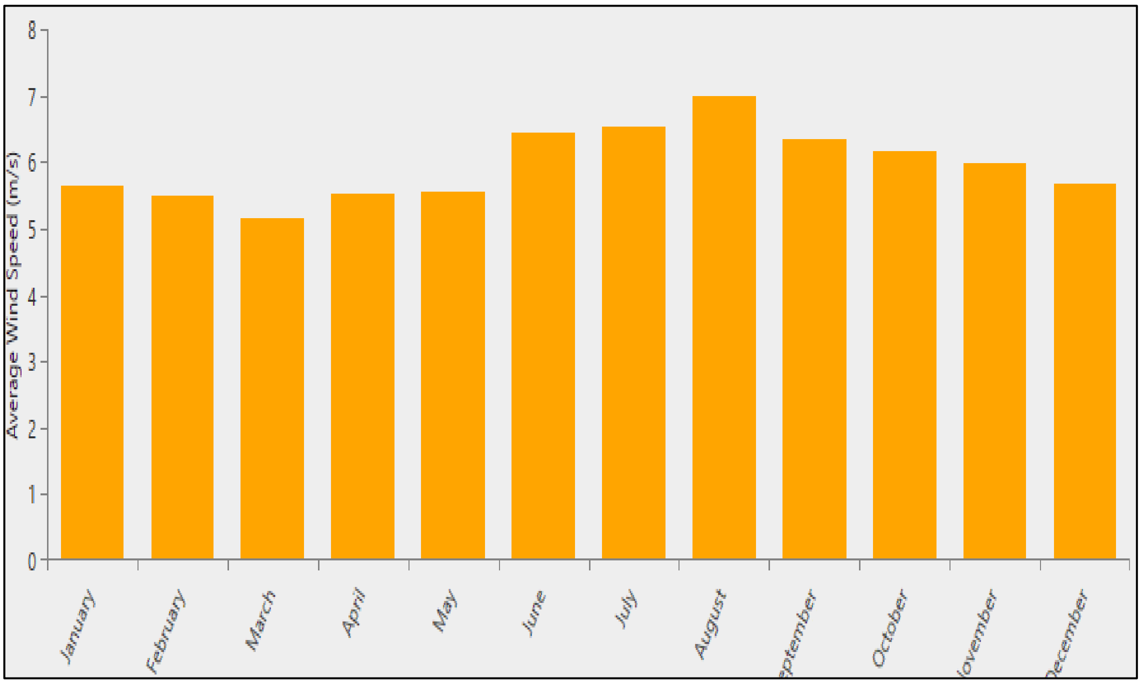


Figure 5.25 Annual average of the wind speed measure near Warrnambool, Australia

The HRES included in the simulation considers a flat plate generic PV, WT of AWS 5.1 which is modeled from the specifications provided by the WT manufacturing company [118] along with a bi-directional converter and Trojan T-105 battery.

5.4.1.2 System Description and Sensitivity Variables used for Warrnambool

The sensitive variables considered to perform the financial analysis. The interest rate provided by a local Australian bank was considered and minimum RE penetration has been used to size the HRES of the system. This means, HRES sized should at least meet the load demand by contributing this amount of RE. The real-time price of the individual components was provided by the RE installer/distributor and these prices were included in the analysis. The prices quoted by the installers were the market prices including the tax and considering the discounts if any, from the Government. This is shown in the Table 5.18. However, it should be noted that these prices though were individual prices in the energy market, there could be a further reduction in price if any RES were to be installed in the real-world for a larger HRES setup.

The HRES setup for university at Warrnambool considers PV and WT as HRES. The interest rate was considered to be 5.32%, which is the interest rate from nationalized bank provides and the present inflation rate of 2.1%. The technical characteristics of the components used in the analysis are modelled using both the software packages. See Appendix C-5. The power curve of the WT is provided in Appendix C-6.

Table 5.18 Inputs used for simulation

Component	Details	Capital Cost & Replacement cost (A$)	Operational and maintenance cost (A$/ year)
Wind Turbine	AWS 5.1kW	35000	20
PV (1kW)	Generic Flat plate	680	10
Bi-direction converter	Generic system converter	240	-
Trojan -105 batteries	AGM	300	12

5.4.2 HOMER Software Simulation for Warrnambool Case study

The HRES is designed for a university building in Warrnambool is shown in Figure 5.26. HOMER evaluates all the possible combinations and sizes the RES according to the constraints.

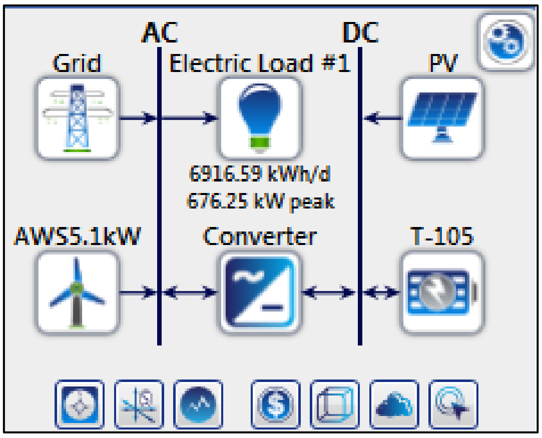
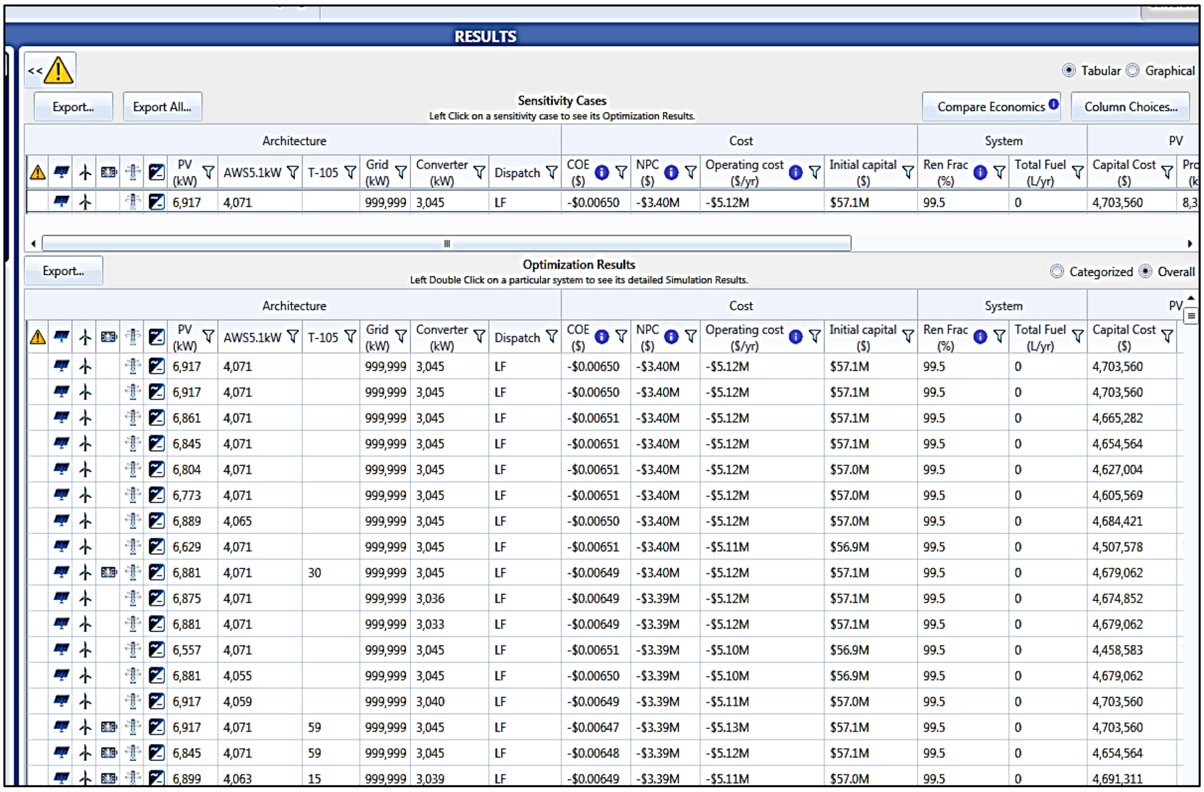


Figure 5.26 Schematic of the HRES used for HOMER Software Analysis

HOMER, after evaluating all the combinations, sizes the RES according to the constraints and displays set of results according to the least value of NPC. Since HOMER provides best of the HRES models by considering all the possible combination of HRES, this system provides an extensive set of results. The variables considered to perform the financial analysis are: the present inflation rate of 2.1% [112, 125] and the discount rate of 5.32% [126]. The HRES of the economically viable models with all the possible combinations is shown in Figure 5.27.

For the HOMER simulation, the size of the system components was scaled according to the specific constraints and the results were tabulated according to the least value of NPC. The results of all the combination evaluated by HOMER for Warrnambool is provided in Table 5.19.


RESULTS

Tabular Graphical

Export... Export All...

Sensitivity Cases

Left Click on a sensitivity case to see its Optimization Results.

Compare Economics Column Choices...

PV (kW)	AWS5.1kW	T-105	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)
6,917	4,071		999,999	3,045	LF	-$0.00650	-$3.40M	-$5.12M	$57.1M	99.5	0	4,703,560

Export...

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

Categorized Overall

PV (kW)	AWS5.1kW	T-105	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)
6,917	4,071		999,999	3,045	LF	-$0.00650	-$3.40M	-$5.12M	$57.1M	99.5	0	4,703,560
6,917	4,071		999,999	3,045	LF	-$0.00650	-$3.40M	-$5.12M	$57.1M	99.5	0	4,703,560
6,861	4,071		999,999	3,045	LF	-$0.00651	-$3.40M	-$5.12M	$57.1M	99.5	0	4,665,282
6,845	4,071		999,999	3,045	LF	-$0.00651	-$3.40M	-$5.12M	$57.1M	99.5	0	4,654,564
6,804	4,071		999,999	3,045	LF	-$0.00651	-$3.40M	-$5.12M	$57.0M	99.5	0	4,627,004
6,773	4,071		999,999	3,045	LF	-$0.00651	-$3.40M	-$5.12M	$57.0M	99.5	0	4,605,569
6,889	4,065		999,999	3,045	LF	-$0.00650	-$3.40M	-$5.12M	$57.0M	99.5	0	4,684,421
6,629	4,071		999,999	3,045	LF	-$0.00651	-$3.40M	-$5.11M	$56.9M	99.5	0	4,507,578
6,881	4,071	30	999,999	3,045	LF	-$0.00649	-$3.40M	-$5.12M	$57.1M	99.5	0	4,679,062
6,875	4,071		999,999	3,036	LF	-$0.00649	-$3.39M	-$5.12M	$57.1M	99.5	0	4,674,852
6,881	4,071		999,999	3,033	LF	-$0.00649	-$3.39M	-$5.12M	$57.1M	99.5	0	4,679,062
6,557	4,071		999,999	3,045	LF	-$0.00651	-$3.39M	-$5.10M	$56.9M	99.5	0	4,458,583
6,881	4,055		999,999	3,045	LF	-$0.00650	-$3.39M	-$5.10M	$56.9M	99.5	0	4,679,062
6,917	4,059		999,999	3,040	LF	-$0.00649	-$3.39M	-$5.11M	$57.0M	99.5	0	4,703,560
6,917	4,071	59	999,999	3,045	LF	-$0.00647	-$3.39M	-$5.13M	$57.1M	99.5	0	4,703,560
6,845	4,071	59	999,999	3,045	LF	-$0.00648	-$3.39M	-$5.12M	$57.1M	99.5	0	4,654,564
6,899	4,063	15	999,999	3,039	LF	-$0.00649	-$3.39M	-$5.11M	$57.0M	99.5	0	4,691,311

Figure 5.27 Snapshot of the HOMER simulated result

Table 5.19 Optimum Sized HRES models simulated by HOMER Software

Model	PV	WT	Battery	Converter	Grid	COE	NPC (A$)	Renewable Energy Fraction
Model-1	6917	4071	-	3045	999,999	-0.00591	-3.09M	99.5
Model-2	6881	4071	30	3045	999,999	-0.00589	-3.08	99.5
Model-3	-	4071	-		999,999	-0.000214	94455	99
Model-4	-	4071	1	30.102	999,999	-0.000214	94748	99
Model-5	6917	-	-	3045	999,999	-0.0105	1.01M	86.6
Model-6	6917	-	13	3042	999,999	-0.0106	1.01M	86.6

The architecture showcases the best economically viable model for a university in Warrnambool. Although this model may not include all the components in the system, on evaluating the HRES combinations, the best-chosen model by HOMER is discussed. The six models discussed in the Table 5-.23, are the possible HRES combination for the most economically viable system. The six models are discussed below:

- *Model-1*: The best HRES model consists of 6,917kW PV with 4,071 WT connected to the grid with the system converter of 3,045kW. This hybrid system with 99.5% of RE penetration has the COE -0.00591A$/kWh. NPC of -A$3.09M (negative number indicates that the HRES is economically beneficial system. Greater the negative value of NPC, more economically beneficial the system is). The Initial Capital Cost of the system is A$57.1M with the Capital Cost of the WT highest of A$51.66M. The operating cost of the system is about -A$50.9M. The Capital Cost of PV is A$4.7M and size of the system converter A$730.8kW. The Capital Cost being maximum compared to other costs of the whole system. However, approximately 209,7571kWh of energy is purchased from the grid by this HRES. In this HRES, 18.2 % of electricity is produced by PV, 81.3% from WT, and 0.46% from the grid purchase in a year making it 99.5% RE fraction. However, 41792591kWh of energy is sold to the grid thus creating revenue through FiTs. It is noted that the grid purchase is much lesser that the energy sold to the grid.
- *Model-2*: The second optimised HRES combination is PV, WT, battery and grid combination. Considering 6,881kW PV, 4,071kW WT along with 30 numbers of T-105 batteries and 3,045kW converter. LF despatch was considered as the despatch strategy with the system having a RE penetration of 99.5%. The NPC of the system is -A$3.08M with COE -0.00589A$/kWh. The operating cost of the system is about -A$5.2M. The Capital Cost of the total system is A$57.1M with the Capital Cost of WT is the highest of A$51.6M. However, the Capital Cost of PV is the second highest value of A$4.6M, while the Capital Cost of system converter and batteries were 730k, A$9k respectively. The O&M cost of the system is -A$ 51M with the O&M of WT being the largest value of A$2.4M. In this HRES, 18.2% of electricity is produced by PV, 81.4% by WT and 0.46% of electricity is purchased from the grid. Approximately, 209,832kWh of energy

is purchased from the grid while thus 41,772,377kWh/year was sold to the grid. This net energy of 4156254kWh/year of energy sold to the grid creates a net revenue through FiTs.

- *Model-3*: The third optimised HRES combination is WT and grid combination without any storage. 4,071kW of WT connected to the grid. The RE penetration of this system is 99%. The NPC of the system is A$94445 with COE 0.00214A$/kWh. The Capital Cost of the system is A$57.1M with the WT having maximum Capital Cost of A$4.64M. In this HRES, 88.4% of electricity is produced by PV and 11.6% of electricity is purchased from the grid. Approximately, 5,514,868kWh/year has been sold to the grid.
- *Model-4*: The fourth model included PV and battery connected to the grid. This system had PV contribution of 6,768kW with 3,045kW converter system connected to the grid through 18 batteries. This HRES contributed 86.4% of RE penetration with NPC -A$597,073 and COE of -0.00632A$/kWh. The Capital Cost of the system is A$5.34M with the PV contributing the maximum Capital Cost of A$4.6M. This HRES contributes 88.2% of electrical energy production from PV and 11.8% from the grid purchase. Nearly 5,471,742kWh of energy is sold to the grid every year from this system.
- *Model-5*: This Model consisted of 4071kW of WT connected to the grid. The COE using this system is -0.000984/kWh with NPC of -A$597073. The Capital Cost of this system is A$51.7M with the Capital Cost of WT being maximum. This system has the RE penetration of 99%. In a year 99% of electricity production is from WT and 0.951% through grid purchase. 34,942,308kWh of energy is sold to the grid through this system.
- *Model-6*: This model consisted of 4,071kW connected to 3 T-105 battery system and to the grid through a system converter of 0.502kW. The COE of this system is -0.000984INR/kWh and NPC of - A$.43,4505. The Capital Cost of the system is highest of 51.6M, WT having the maximum Capital Cost of A$51.6M. In a year, nearly 99% of electricity is produced by WT, while 0.951% of electricity is through grid purchase. However, 34,942,308kWh of energy is sold to the grid through this system.

These aforementioned models are the best six models for the optimised HRES combinations. This concludes the fact that unlike iHOGA which gives the best result for one set of combination (however it has the flexibility to choose the best HRES model with the grid only setup), HOMER can give all the probable combinations of HRES. The next Section further discusses the result comparison of iHOGA and HOMER models for the given set of constraints.

5.4.3 Result Analysis of HRES sized by HOMER and iHOGA software packages

This section considers the same inputs and HRES technical characteristics of the systems described in 5.4.1.1. The HRES is designed by considering PV, WT and battery with 2.4hours of autonomy and connecting them to the grid. The sensitive variables considered to perform the financial analysis are shown in Table 5-18. The HRES was modeled for the annual capacity shortage of 0%, which means that the total load is either met by the RE, battery or by the A.C. grid and no load is unmet. The micro-grid system considered by HOMER and iHOGA for a university building in Warrnambool is shown in Figure 5.28.

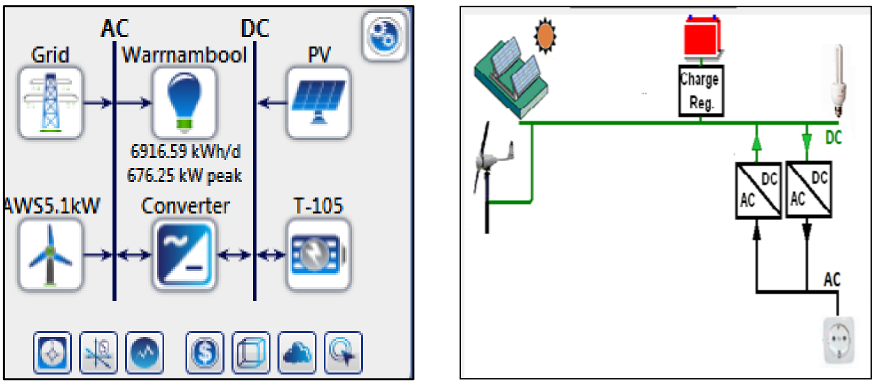


Figure 5.28 The HRES considered for Aralvaimozhi community by HOMER software (left) and iHOGA (right)

The HRES used for the simulation used by HOMER and iHOGA software packages is shown in Figure 5.28. The HRES model for simulation includes a generic 1kW PV, AWS 5.1kW WT, bi-directional system converters, Trojan-105 battery which are connected to the grid in the model. Though this study aims at a grid connected model, it also includes a specific capacity of battery storage to satisfy the load in times of grid failure. The presence of the grid is to create revenue through FiTs. Depending on the availability of the RE, HOMER calculates the best option to charge the battery, either through grid power or through RE, according to the least cost option. The variables considered to perform the financial analysis are shown in Table 5.20. The present inflation rate of 2.1% [125] and the discount rate of 5.32% [127] are considered for the project lifetime of 15years. Meanwhile, 60% of minimum RE penetration is considered. The average power price that the university pay to purchase electricity from the grid is 0.17A$/kWh. The grid sell back price (FiTs) for the state of Victoria is currently 0.113A$/kWh [128].

For the HOMER simulation, the size of the PV, WT and converters were sized by HOMER and iHOGA software packages. These components were modelled for both the software packages. The cost of the PV includes the Solar Trading Certificate (STC) price per kW. The price of the WT is off-the-sale value considered [129].

Table 5.20 Sensitive variables used for simulation

Variables	Discount Rate	5.32%
	Lifetime of the Project	15 years
	Average Grid Power Price	0.17A$/kWh
	Grid Sell Back Price	0.113A$/kWh
Constraints	Minimum renewable energy fraction	60%
	Autonomy	2.4hr

The PV used here is a generic 1kW solar panel with 80% de-rating factor and 25 years lifetime. The AWS 5.1kW wind turbine considered here has a hub height of 10m and lifetime of 20 years. A bi-directional generic converter is used along with a Trojan-105 battery of 6X and Nominal capacity of 1.52kWh with round trip efficiency of 80% and annual throughput of 914.30kWh.The initial state of charge of the batteries considered is 100% and the minimum state of charge of the batteries is 20%.

In current case study, the control strategy considers prioritising RE and battery to meet the load, if in any case RE and battery are not available to meet the load, the grid is flexible to meet the load. Thus the presence of the grid in the designed micro-grid system is to supply any excess energy to the load in case of a deficit in RE supply, it also acts as the dumping unit when there is excess RE thus creating revenue through FiTs.

5.4.4 HOMER software simulated result analysis

This section comprehends the detailed analysis of the best chosen HOMER software model for a definite case. There are two optimised models from HOMER: Model-1 and Model-2 are the models chosen as the optimised model simulated by HOMER. Model-1 of HOMER has the RE penetration of 60.5 %, Model-2 is the HOMER optimized model for with the autonomy of 3hr which is comparable to the minimum autonomy 2.4hr (user defined constraint). The Model-1 consists a 1945kW PV and 236 Trojan batteries with 360kWh Nominal Capacity along with 962kW converter. The NPC of this system is A$3.37M with COE 0.0838A$/kWh. The HOMER optimised result of Model-2 consists of 2017kW of PV and 709 Trojan 105 batteries connected with Nominal capacity 1080kWh/year connected to the grid through a converter of 709kW. The NPC of this system is A$3.47M and COE is 0.0851A$/kWh.

a. Result Analysis of Model-I of HOMER software

➢ ***Techno-Economic Analysis***

The Table 5.21 provides the different costs of individual components in the HRES Model-1. It is observed that the O&M costs is highest of A$2.12M, compared to Capital Cost and salvage. This is due to the energy utilisation from the grid. The Capital Cost of the PV being the highest of A$1.32M compared to the Capital Costs of system converter, and batteries of A$230k and A$70.8k respectively.

Table 5.21 Cost analysis of the HOMER optimised model, Model-I

	Capital (A$)	**O&M (A$)**	**Salvage (A$)**	**Total (A$)**
Generic PV (flat plate)	1,322,876.25	459,358.42	- 332,125.78	1,450,108.89
Grid	0.00	1,517,172.33	0.00	1,517,172.33
System Converter	230,912.50	113,591.96	0.00	344,504.46
Trojan T-105	70,800.00	33,435.25	-43,771.64	60,463.61
System	1,624,588.75	2,123,557.96	-375,897.42	3,372,249.29

The total Capital Cost of the overall system is A$1.62M. When the O&M costs of the PV, grid and batteries are considered, the grid has the highest cost of A$1.51M, it is obvious that nearly 40% of the energy is bought from the grid. However, the PV has the O&M cost being high of A$459k compared to O&M costs of converter and battery to be

A$133k and A$33k respectively. The O&M of grid is not negative (like Aralvaimozhi case) due to the reason that the electricity sold to the grid is less than the electricity bought from the grid. The salvage value of the components includes the remaining cost of the components at the end of the project's lifetime. The salvage value of the total system is -A$375.8k. Thus, the total cost of the overall system is A$3.37M.

Figure 5.29 and Table 5-.22 provides the insight to the energy production of PV and grid in a year and its contribution in electricity production and consumption. The RE production is maximum in the months October to January, the months correspond to the solar energy being maximum and thus energy from PV is maximum. In a year, energy from WT production is approximately 2,340,096kWh with 63.5% of overall energy production compared to grid purchase. The remaining load is met through grid purchase, this corresponds to 36.5% of 1,345,426kWh/year.

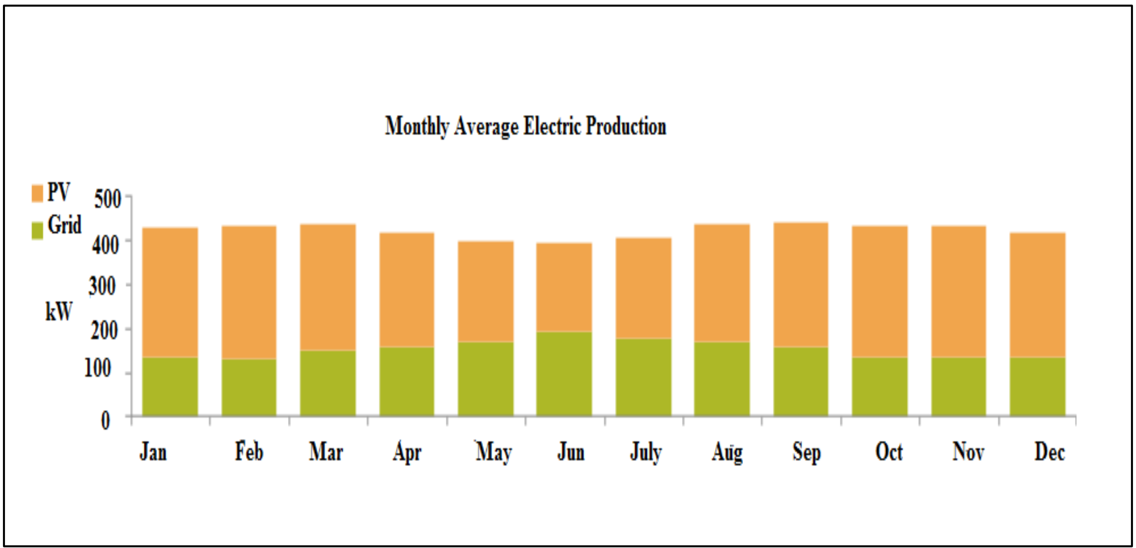


Figure 5.29 Monthly Average Electric Production of the HOMER optimised Model-I

Table 5.22 Details of electricity production and consumption from Model-I

Production			**Consumption**			**Quantity**		
Production	**kWh/yr**	**Percentage**	**Consumption**	**kWh/yr**	**Percentage**	**Quantity**	**kWh/yr**	**Percentage**
Generic PV (flat plate)	2,340,096	63.5	**A.C. Primary Load**	2,524,555	74.1	**Excess Electricity**	167,867	4.55
Grid Purchases	1,345,426	36.5	**Grid Sales**	884,489	25.9	**Unmet Electric Load**	0	0
Total	3,685,523	100	**Total**	3,409,044	100	**Capacity Shortage**	0	0

Thus, there is no load that goes unmet from this system. Approximately 167,867kWh/year of energy is excess on considering this HRES configuration. Figure 5.30 shows the electricity production of PV and grid sales. Is is observed that, the chosen energy components meet the load of Warrnambool university building. The stochastic behaviour of the RE components are much noticeable from these diagrams. However, it is observed that energy sold to the grid is maximum when the RE output is maximum.

Table 5.23 illustrates the monthly grid sales and corresponding energy charge. It can be observed that 1,345,426.4kWh of energy is purchased annually. The grid energy purchase is maximum in the months of May to July, this corresponds to the months were the RE availability is low. Similarly, energy sold to the grid is maximum in the months of October to February, this corresponds to the months when the RE availability is maximum (summer). The energy purchased from the grid due to lack of availability of RE from this HRES. However, this energy purchased price is compensated by the energy sold to the grid in the rest of the months. But this compensation is not too much compared to Aralvaimozhi case study. Thus, there is a yearly revenue of A$13,261.42 generated on considering the current HRES through FiTs.

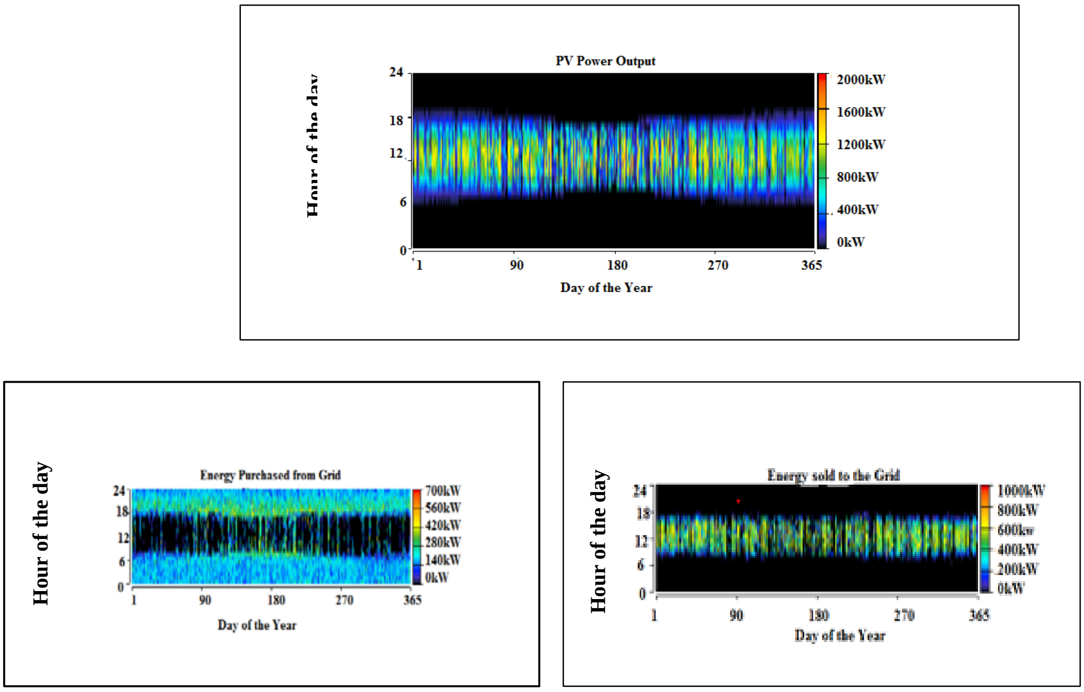


Figure 5.30 Shows the energy output of a PV and Grid sales from HRES of Model-I (top left to bottom anti-clockwise)

Table 5.23 Grid energy sales and grid chargesfrom Model-I

Month	Energy Purchased (kWh)	Energy sold (kWh)	Net Purchased (kWh)	Peak Demand (kW)	Energy Charge (INR)
January	101538.462126	61057.938625	66150.632794	467.418796	A$14,725.91
February	87538.760142	54343.968128	82773.322950	549.345798	A$17,169.07
March	112485.076990	61062.260533	71136.020914	603.165280	A$15,573.6
April	113126.830587	71367.323283	54079.324184	507.8750	A$13,261.42
May	127208.571418	75284.402790	37704.622239	481.41224	A$10,701.00
June	137117.29107	86699.408765	12541.700759	456.452313	A$7,073.96
July	132198.281447	83528.557416	14260.933589	510.255780	A$7,185.49
August	125446.647467	78933.456177	19813.398903	427.9725	A$7,598.30
September	112989.025029	884489.105066	460937.296827	603.165280	A$128,506.04
October	99241.109524	61057.938625	66150.632794	467.41879	A$14,725.91
November	97789.491005	54343.968128	82773.322950	549.345798	A$17,169.07
December	98746.855080	61062.260533	71136.020914	603.165280	A$15,573.67
Annual	1345426.401892	71367.323283	54079.324184	507.875059	A$13,261.42

- ***Poisonous Gas Emissions from the HRES model***

HOMER software has the facility to provide the detailed values of different gas emissions involved when a HRES is considered. For the current system, the poisonous gas emissions are given in Table 5.24. The COx is considered as the prime emission factor considered in any energy related equipment. Here, in this HRES, the CO_2 emission is maximum compared to any other gas emissions. The CO_2 emissions from the considered HRES is 850,309kg/year. The SOx and NOx emissions are 3,686kg/year and 1,803kg/year respectively.

Table 5.24 Poisonous gas emissions from the HRES considered in Model-I

Poisonous emissions	kg/yr
Carbon Dioxide	850,309
Carbon Monoxide	0
Unburned Hydrocarbons	0
Particulate Matter	0
Sulphur Dioxide	3,686
Nitrogen Oxides	1,803

b. Result Analysis of Model-II of HOMER software

This section discusses the results of Model-II. Model-II has been considered in the discussion due to its results having battery autonomy value 3hr, which is close to 2.4hr (user defined constraint). The RE penetration of this HRES system is just above 70%, which is 72.3%.

- ***Techno-Economic Analysis***

The Table 5.25 provides the different types of Costs of individual components in the HRES considered in Model-II. It is observed that the O&M costs is highest compared to Capital Cost and salvage of A$2.12M, this is due to the energy utilisation from the grid. The Capital Cost of the PV being the highest of A$1.37M compared to the Capital Costs of system converter, and batteries of A$233k and A$212k respectively. The total Capital Cost of the overall system is A$1.818M. When the O&M costs of the PV, grid and batteries are considered, the grid has the highest cost of A$1.45M, it is obvious that nearly 40% of the energy is bought from the grid. However, the PV has the O&M cost being high of A$476k compared to O&M costs of converter and battery to be A$114k and A$100k respectively. The O&M of grid is not negative, because the electricity sold to the grid is less than the electricity bought from the grid. The salvage value of the components includes the remaining cost of the components at the end of the project's lifetime. The salvage value of the total system is -A$475k. Thus, the total cost of the overall system is A$3.46M

Table 5.25 Cost analysis of the HOMER optimised model, Model-II

	Capital (A$)	O&M (A$)	Salvage (A$)	Total (A$)
Generic PV (flat plate)	1,371,871.67	476,371.70	- 344,426.73	1,503,816.63
Grid	A0.00	1,435,136.10	0.00	1,435,136.10
System Converter	233,450.00	114,840.22	0.00	348,290.22
Trojan T-105	212,700.00	100,447.44	- 131,500.41	181,647.03
System	1,818,021.67	2,126,795.45	- 475,927.14	3,468,889.98

Figure 5.31 and Table 5.26 provides an insight into the energy production of PV and grid in a year and its contribution in electricity production and consumption. The RE

production is maximum in the months October-January, the months correspond to the solar energy being maximum and thus energy from PV is maximum.

In a year, energy from WT production is approximately 2,426,767kWh with 64.5% of overall energy production compared to grid purchase. The remaining load is met through grid purchase, this corresponds to 35.5% of 1,334,540kWh/year. Thus, there is no load that goes unmet from this system. Approximately 195,573kWh/year of energy is excess on considering this HRES configuration.

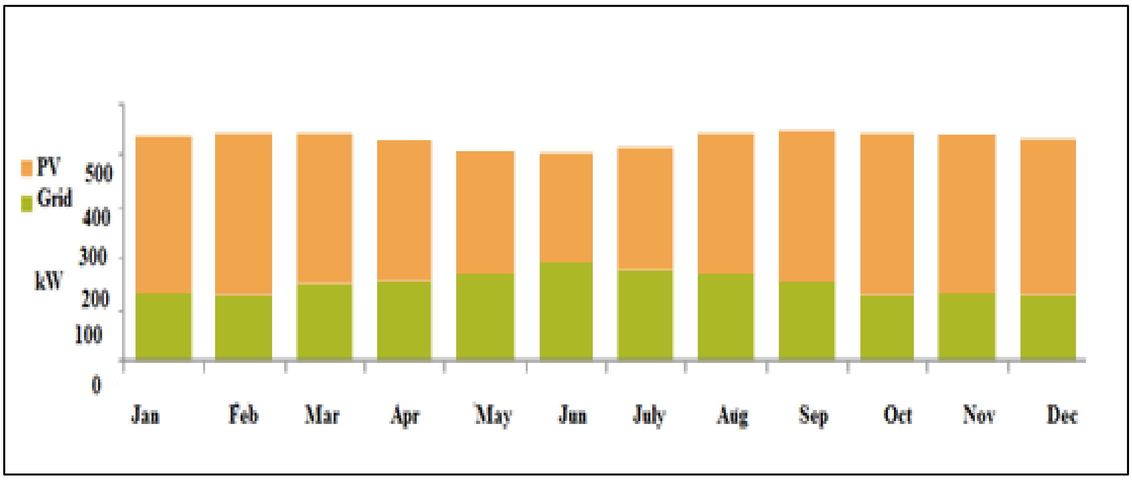


Figure 5.31 Monthly Average Electric Production of the HOMER optimised Model-II

Table 5.26 Details of electricity production and consumption from Model-II

Production			**Consumption**			**Quantity**		
Production	**kWh/yr**	**Percentage**	**Consumption**	**kWh/yr**	**Percentage**	**Quantity**	**kWh/yr**	**Percentage**
Generic PV (flat plate)	2,426,767	64.5	**A.C. Primary Load**	2,524,555	73.1	**Excess Electricity**	195,573	5.2
Grid Purchases	1,334,540	35.5	**Grid Sales**	929,619	26.9	**Unmet Electric Load**	0	0
Total	3,761,306	100	**Total**	3,454,174	100	**Capacity Shortage**	0	0

Figures 5.32 shows the electricity production of PV and grid sales. We see that all the energy components meet the load of Warrnambool university building. The stochastic

behaviour of the RE components are much noticeable from these diagrams. However, it is observed that energy sold to the grid is maximum when the RE output is maximum.

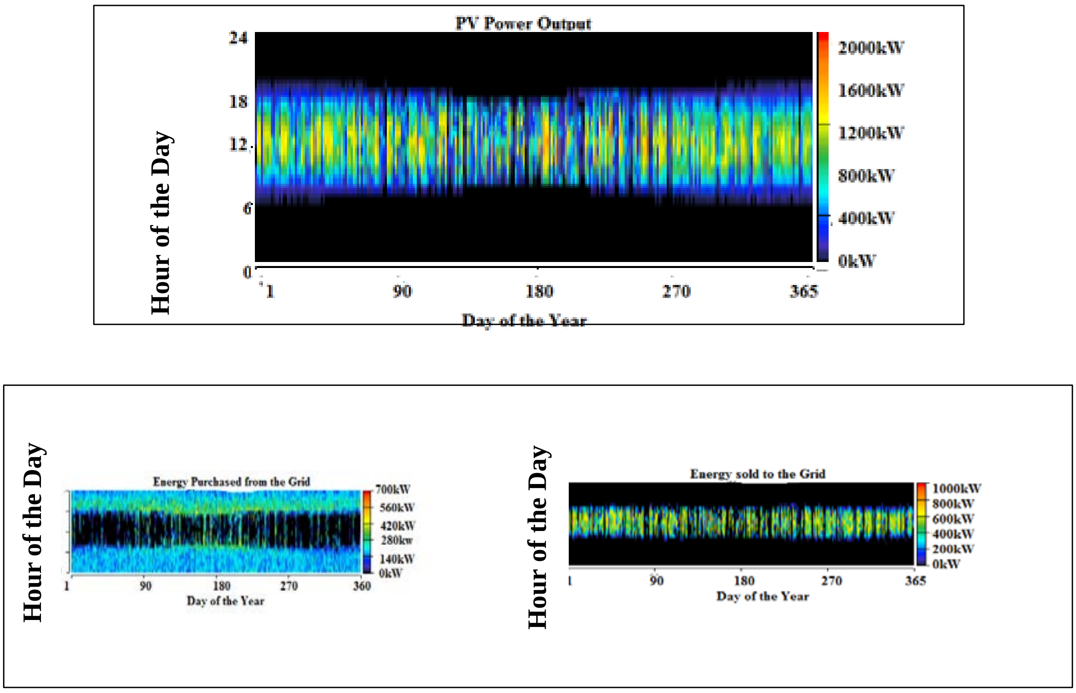


Figure 5.32 Shows the energy output of a PVand Grid sales from HRES of Model-II (top left to bottom anti-clockwise)

Table 5.27 illustrates the monthly grid sales and corresponding energy charge. It can be observed 1334539.6 kWh of energy is purchased annually. The grid energy purchase is maximum in the months of May-July, this corresponds to the months were the RE availability is low.

Similarly, energy sold to the grid is maximum in the months of October to February, this corresponds to the months when the RE availability is maximum (summer). The energy purchased from the grid due to lack of availability of RE from this HRES. However, this energy purchased price is compensated by the energy sold to the grid in the rest of the months. But this compensation is not too much compared to Aralvaimozhi case study. Thus, there is a yearly revenue of A$121,557.49 generated on considering the current HRES through FiTs.

Table 5.27 Grid energy sales and grid chargesfrom Model-II

Month	Energy Purchased (kWh)	Energy sold (kWh)	Net Purchased (kWh)	Peak Demand (kW)	Energy Charge (A$)
January	100433.228599	88230.138212	12203.090387	486.787850	7,103.64
February	86645.698526	84166.735580	2478.962945	414.642836	5,218.93
March	111501.895516	81158.844682	30343.050834	503.416328	9,784.37
April	112169.604678	74464.338794	37705.265884	527.089097	10,654.36
May	126486.663714	64109.003434	62377.660279	467.418796	14,258.42
June	136405.242812	57056.117554	79349.125258	547.633501	16,741.55
July	131389.658552	63899.751837	67489.906714	600.719893	15,115.57
August	124628.097550	74906.534821	49721.562729	503.173752	12,722.34
September	112083.721796	78662.003388	33421.718409	481.141151	10,165.43
October	98481.00969 4	91643.308649	6837.701046	455.825453	6,386.08
November	96817.99069 9	87930.925736	8887.064962	508.633981	6,522.86
December	97496.802290	83390.949490	14105.852800	427.175774	6,883.94
Annual	1334539.614424	929618.652176	404920.962247	600.719893	121,557.49

- ***Poisonous Gas Emissions from the HRES model***

HOMER software has the facility to provide the detailed values of different gas emissions involved when a HRES is considered. For the current system, the poisonous gas emissions are given in Table 5.28. The COx is considered as the prime emission factor considered in any energy related equipment. Here, in this HRES, the CO_2 emission is maximum compared to any other gas emissions. The CO_2 emissions from the considered HRES is 843,429kg/year. The SOx and NOx emissions are 3,657kg/year and 1,788kg/year respectively.

Table 5.28 Poisonous gas emissions from the HRES considered in Model-I

Poisonous emissions	kg/yr
Carbon Dioxide	843,429
Carbon Monoxide	0
Unburned Hydrocarbons	0
Particulate Matter	0
Sulphur Dioxide	3,657
Nitrogen Oxides	1,788

5.4.5 iHOGA software simulation for Warrnambool Case study

This Section introduces the application of iHOGA software for optimally sizing RES. It is noted that the same system specifications have been used for iHOGA as used for HOMER in section 5.4.1. Like HOMER, iHOGA can result in optimum solution by minimizing the cost of the energy systems along the term of the project which would reflect on the NPC. However, iHOGA uses GA technique to find the optimum solution. iHOGA is the software that gives the optimum result minimizing NPC as a mono-objective solution.

Preliminary analysis in section 5.4.1.1 and 5.4.1.2 highlighted Warrnambool's abundant RE resources namely solar and wind energy to be exploited for RE adoption to the university. Figure 5.33 shows the HRES used for RE adoption for university building at Warrnambool. This includes generic PV, WT, set of Trojan batteries connected to the grid. The details of the components used for the study is provided in Table 5.29. The electricity bill was analyzed to find the average electricity price paid by the university for 1kWh, this was 0.17A$/kWh. The feed-in tariff was considered to be 0.113A$/kWh.

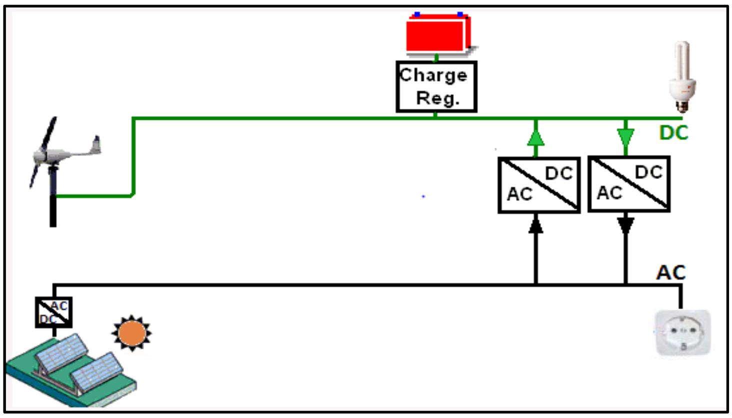


Figure 5.33 The HRES for a university in Warrnambool, Australia

For the control strategy, LF option were considered. This means that, the unmet load from the RE system will be met by the charged batteries. With one day of minimum autonomy, the HRES was sized for a minimum RE fraction of 60%. Grid system used, would act as an additional support in case the energy to the load is not met by the RE system or from the batteries. The grid is also used to dump the excess power after the load is met by the RES.

Table 5.29 The HRES components, component specifications and market price

Components	Specification		Cost	
Solar Panels (PV)	Nominal Voltage	12V	Capital Cost	680
	Shortcut Current	8.23A	O&M Cost	20/yr
	Nominal power	1000Wp		
	Life span	25 yrs		
AWS	Height	12m	Capital Cost	12692
	Rated Power	5100W	Replacement cost	12692
	Life Span	20 yrs	O&M cost	50/yr
Converter	Generic system converter (bi-directional inverter/converter)	-	240	-
Battery	Nominal Capacity	254Ah	Capital Cost	300
	Voltage	6V	O & M cost	12
	SOC	20%		

- ***iHOGA Software Result Analysis***

A single objective function has been discussed for various sensitive cases here. The study conducted primarily explores the probable variables for Australian scenario. The optimisation of HRES has been conducted using iHOGA software.

iHOGA software simulated 15 sets of results value of loads considered. The software analysis performed single objective optimisation considering 5.32% as interest rate and 2.1% inflation rate for a study period of 15 yrs. iHOGA considered the GA for the main algorithm and evaluating all the combination of the secondary algorithm with 84584 cases. For each combination of sensitive cases, iHOGA produced at least 15 results in a tabular column with the last row being the best-optimised result. iHOGA sized the RES with maximum of 111 batteries in parallel, maximum 4023kW PV panels in parallel connection and 20 Wind turbines in parallel , this is shown in Figure 5.34. A generic bi-direction inverter was used for the chosen HRES system.

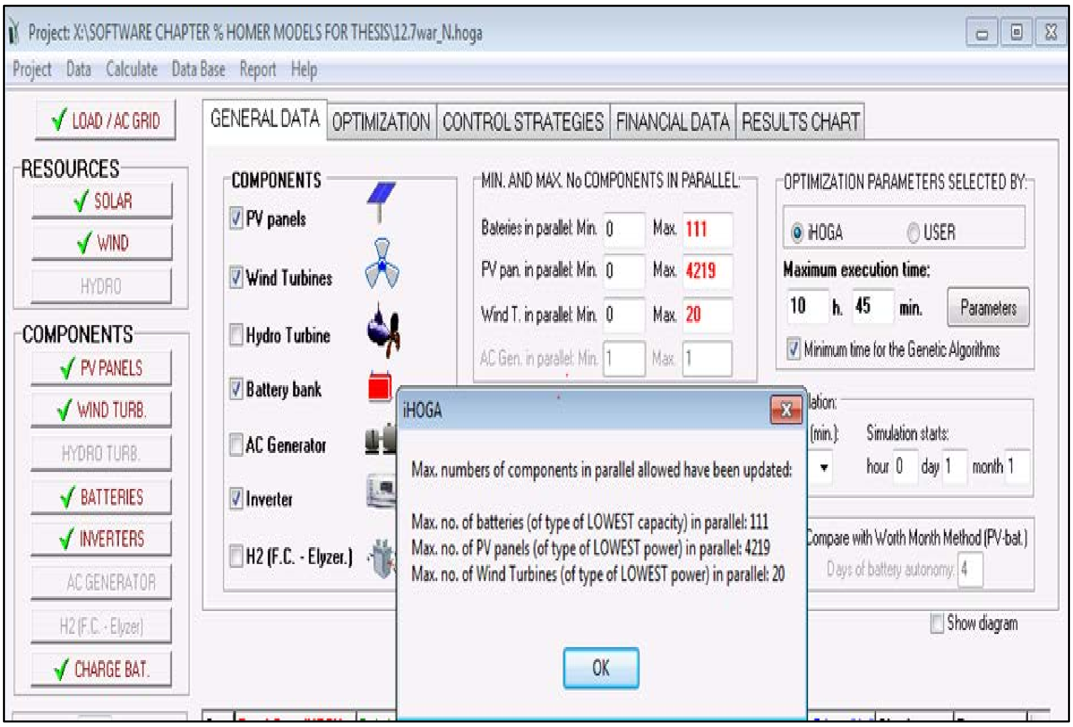


Figure 5.34 Maximum components size chosen by iHOGA for analysis

The mono-objective constraint was chosen to minimise the NPC. The analysis was made by evaluating 84584cases. The control strategy used in the analysis include the minimum SOC of the batteries to be kept as 20 %, and any excess of energy from the renewables/batteries can be sold to the grid. Charge battery if the price of electricity from the grid is lower than 0.187A$/kWh while the battery discharges (load + injecting to the grid) if price electricity is higher than 0.153A$/kWh (these prices were +/- 10% of the electricity purchase price from the grid for Warrnambool). The Primary Algorithm was chosen to be “Evaluating all the combinations” while the Secondary Algorithm was chosen as GA. A set of 15 results were tabulated with the least values of NPC. The resulting chart of the iHOGA simulation is shown in Figure 5.35.

The optimally sized HRES using the defined constraints provided for Warrnambool case study are shown in Figure 5.36. A 1938kW PV and no wind turbines were considered. A 6000 kW bi-directional inverter and 1097.2kWh of batteries 8 in series and 90 in parallel combinations were sized.

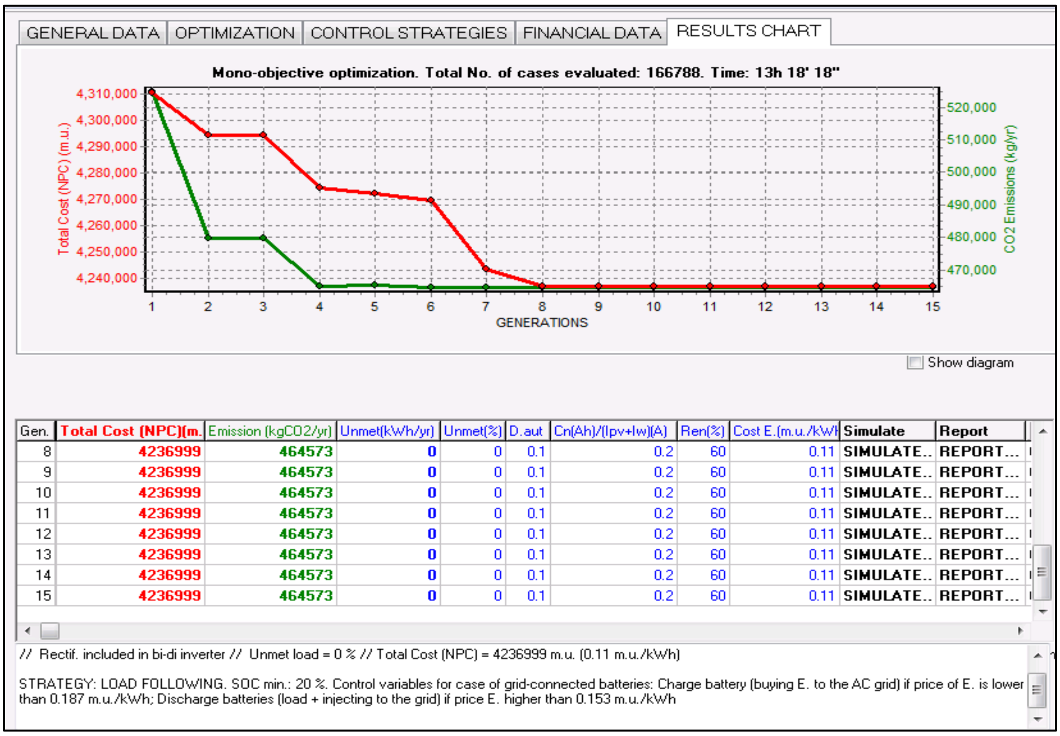


Figure 5.35 Snapshot of the optimum result simulated by iHOGA

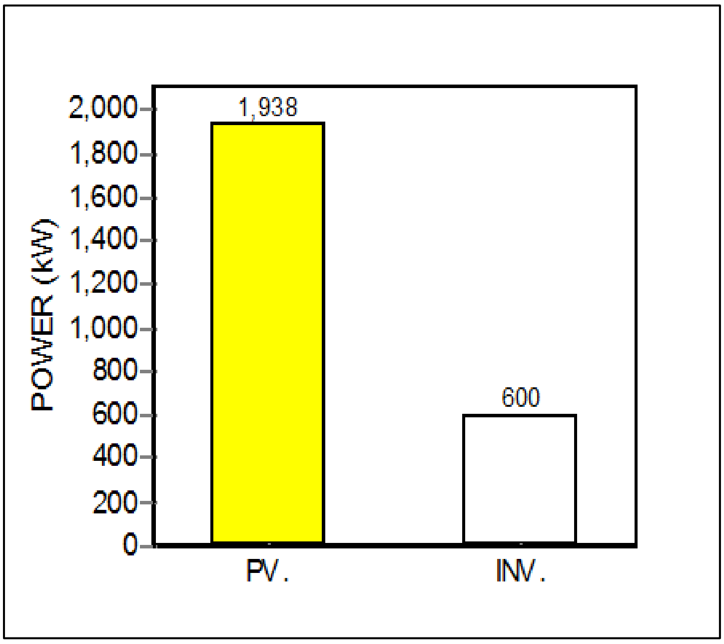


Figure 5.36 Optimum sized HRES for Aralvaimozhi case study simulated by iHOGA

The energy balance of each of the components in a year is shown in the Figure 5.37. In a year 9249248kWh of energy is delivered by PV. 6409kWh/yr of energy is used to charge the batteries while 141kWh/yr is the energy discharged by the batteries.

Approximately, 7,734,508kWh/yr of excess energy is sold to the grid by the HRES system and 1,006,393kWh of energy, is purchased to meet the load.

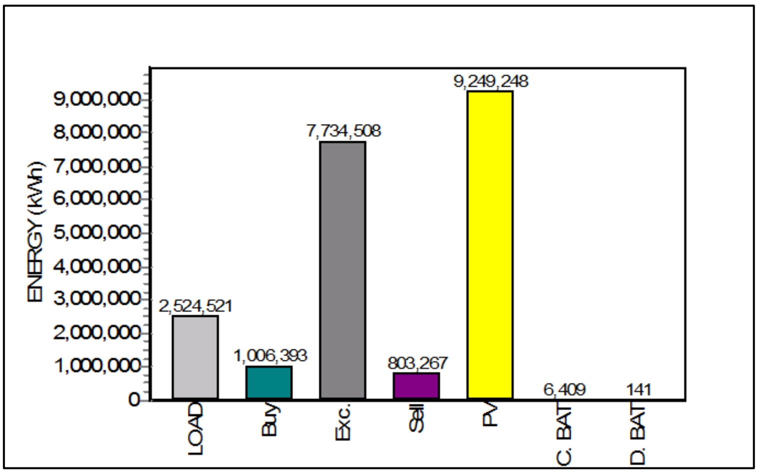


Figure 5.37 Energy generation details by the optimum sized HRES

iHOGA simulated results of all the components in a year is shown in Figure 5.38. It is observed that most of the micro-grid set up designed for Warrnambool meets total university's load. PV supplies a maximum portion of the energy. The batteries charge and discharge efficiently according to the system constraint provided. While a very small amount of energy is bought from the grid in times of lack of RE supply. Nearly 60% of energy is met by the chosen RE making the system optimised with least value of NPC. Figure 5.39 shows the power output of the optimum sized HRES in a year.

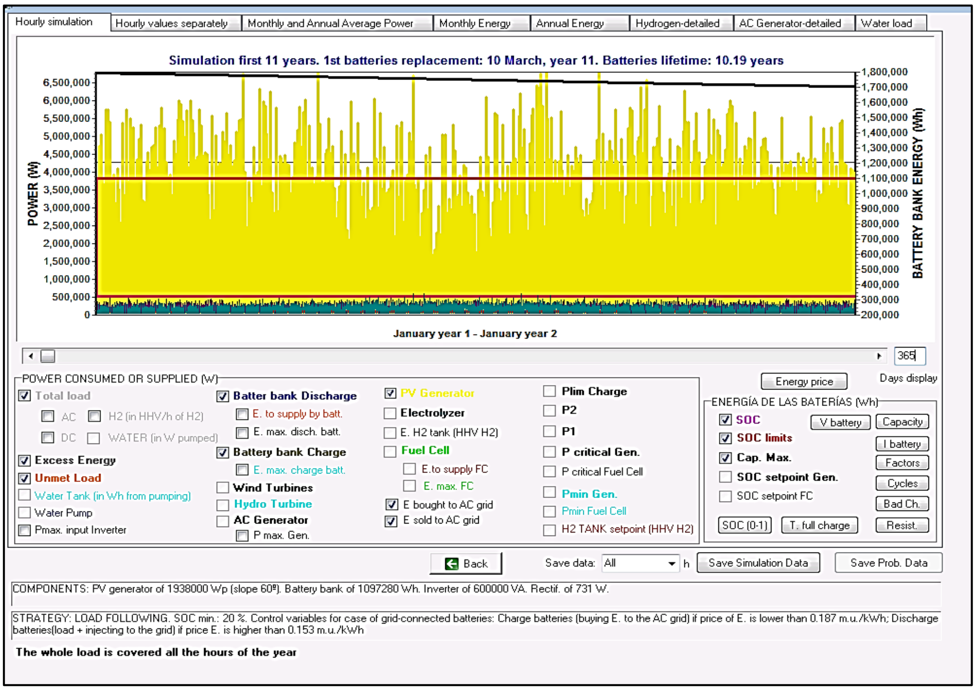


Figure 5.38 Power output of the optimum sized HRES in a year

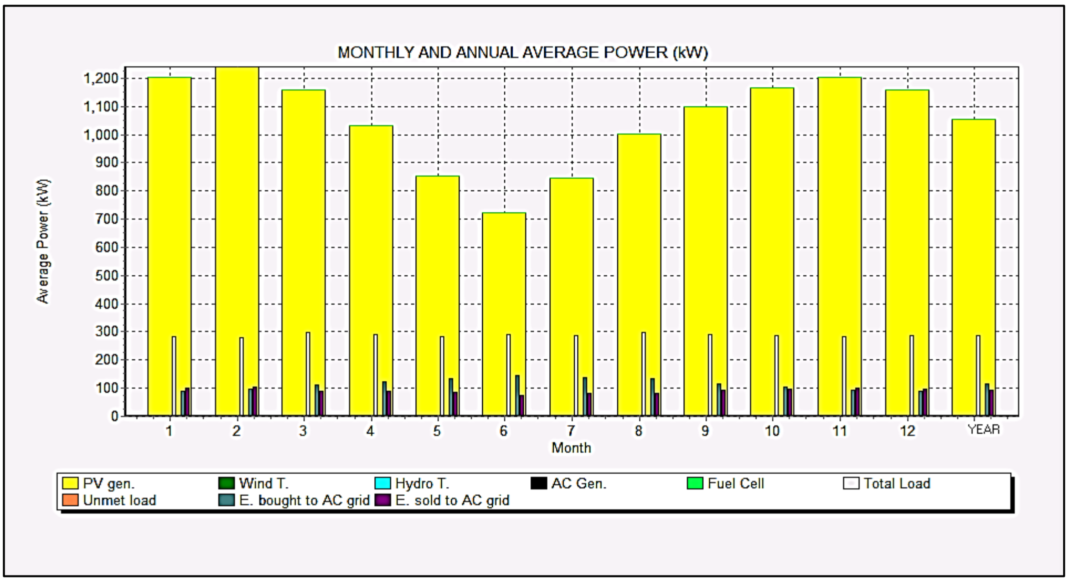


Figure 5.39 Monthly average output of the optimum HRES model

The NPC of the system for the given constraint is discussed in the Figure 5-.40. The total NPC of the HRES considered by iHOGA software for university building in Warrnambool is A$4.23M with the COE of 0.11A$/kWh. The total NPC of PV being the highest of A$1.54M. The total NPC of batteries and inverters are A$0.4M and A$0.144M respectively.

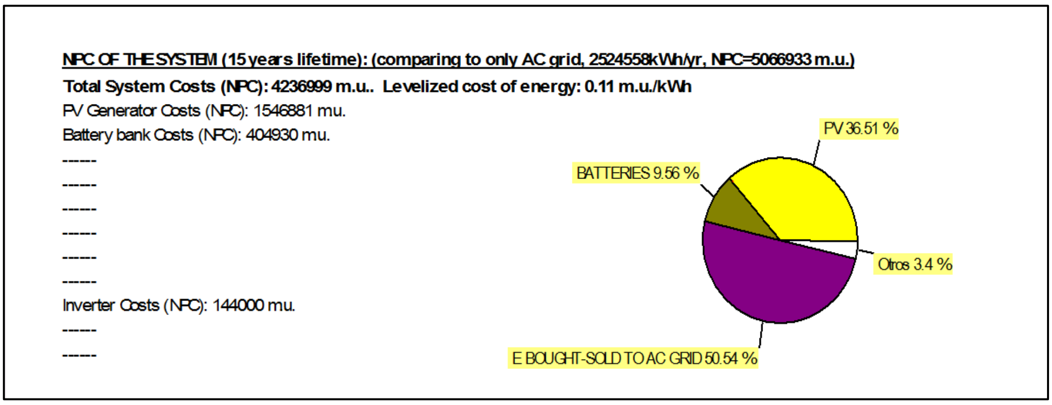


Figure 5.40 NPC details of every components of the optimised HRES

When the individual costs of HRES system is analysed, it is observed that, the Capital Cost of the HRES system is A$1.76M, with the Capital Cost of PV to be the highest value. The Capital Costs of PV, converter and batteries are A$1.31M, A$0.144M and A$0.3M respectively. The O&M costs of the HRES A$0.331M. The total grid sales in 15 years is -A$1.06M. The negative sign indicates that the energy sold to the grid is higher than the energy purchased from the grid. It is observed that, the Capital Cost of WT has not been considered in the cost evaluation, which implies the fact that, the WT has not been considered as an optimised set up for the given location and control strategies described.

5.4.6 Result comparison between HRES simulated by HOMER and iHOGA software for Warrnambool

HOMER and iHOGA software packages simulates the results considering the user defined constraints and tabulates the results according to the least value of NPC. The best HRES with the least value of NPC is on the topmost result (Result 1) in the tabular column according to HOMER, whilst the 15th solution (last solution) is the best solution with the least value of NPC. The snapshot of the tabulated result from HOME and iHOGA software packages is shown in Figure 5.41.

The two optimised models from HOMER: Model-1 and Model-2 are the models chosen as the closest comparable optimised model simulated in comparison with the iHOGA simulated model. Model-1 of HOMER has the RE penetration of 61.4%, this is comparable to the iHOGA simulated model having RE penetration of 60%. However, Model-2 is the HOMER optimised model with the autonomy of 2.07hr which is comparable to the iHOGA simulated optimized model having an autonomy of 2.4hr. It is observed from the analysis that the optimum results from both iHOGA and HOMER are very similar for the given constraints. This is observed even when the COE is considered amongst the HRES of the models simulated by HOMER and iHOGA. All the three models have the COE in the range of 0.1A$/kWh. However, the optimised HRES by HOMER has a greater RE penetration of 60.5% and 61.4% compared to iHOGA software which has 60%.

When the size of the optimised HRES is considered for the given constraint, HOMER and iHOGA sizes the system for the least value of NPC The best model produced by both the software has been compared and they are summarised in Table 5.30. The HOMER optimizes the HRES to 100% accuracy, while iHOGA optimizes system close to the optimised value. The optimised model produced by iHOGA has a PV penetration of 1938kW, which is smaller than Model-1 and smaller than Model-2 of HOMER simulated results. The WT size is not considered as an optimum solution for the given scenario by iHOGA and HOMER. However, the batteries sized by HOMER in Model-2 and iHOGA are similar, this is evident from the battery autonomy being similar. The converter sized by iHOGA is small compared to the two models resulted by HOMER. This could be due to the large PV penetration in the HOMER optimized model.

The poisonous gas emissions are clearly explained for different gases like- COx, NOx, SOx, particulate matter in HOMER software. The iHOGA software considers only COx gas emissions. The COx emissions of the iHOGA simulated model is smaller than HOMER simulated model. This is due to the PV size of the HRES sized by iHOGA being smaller than HOMER sized PV. iHOGA discussed the job creation and HDI. These two results could be one of the important factors to discuss for a social benefit of any country in general. The job creation of 5.9247 generated per GWh if this project is sanctioned for installation. Similarly, HDI calculated by iHOGA for the optimised model is 1.2852.

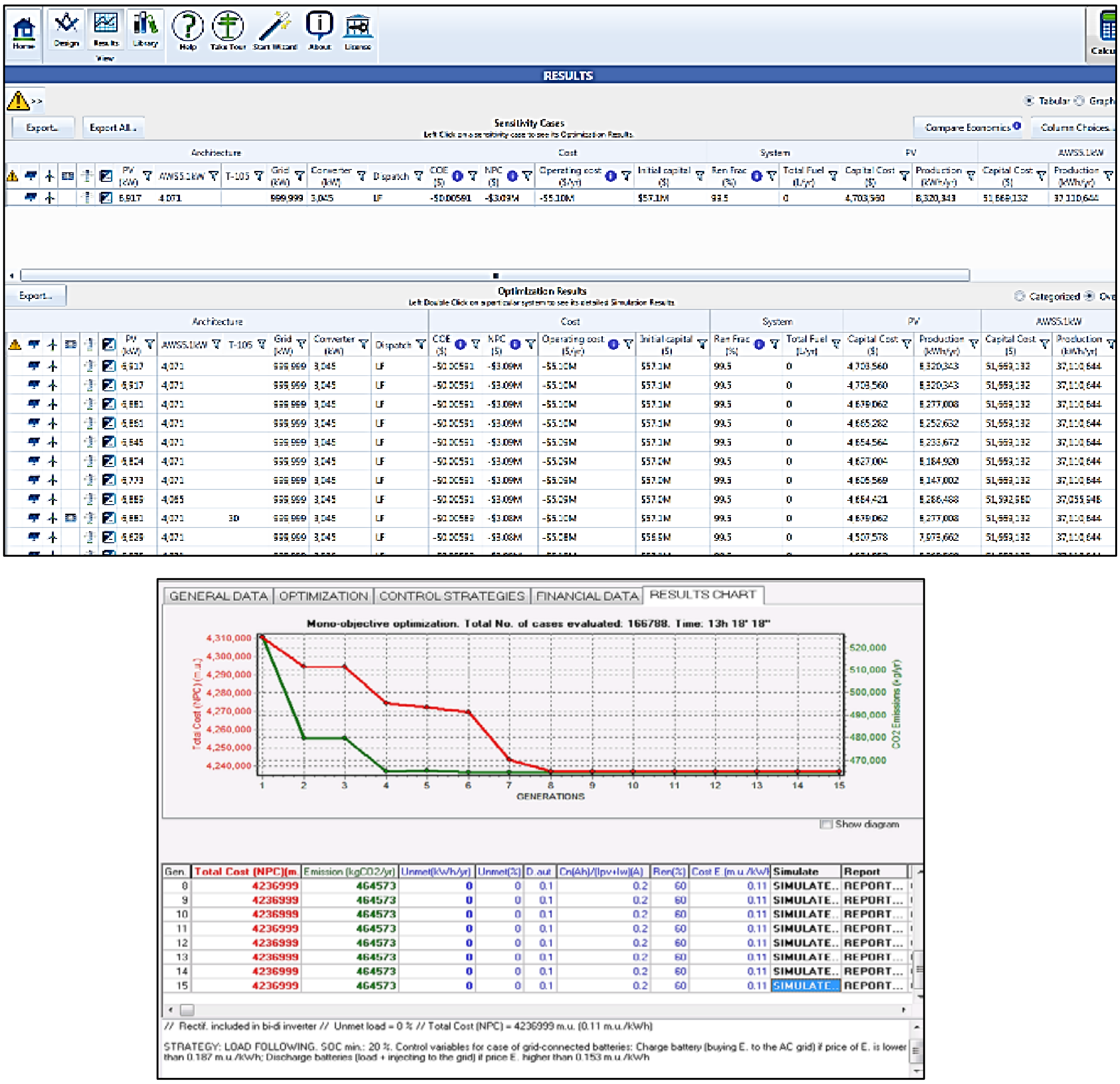


Figure 5.41 The NPC results simulated by HOMER (on top) and iHOGA software (bottom)

Table 5.30 Result comparison from HOMER and iHOGA software

		HOMER Results		iHOGA results	Comments
		Model-1	Model-2		
Architecture	**PV (kW)**	1945	2017	1938	PV size is similar between HOMER simulated Model-1 and iHOGA simulated HRES.
	AWS 5.1kW	-	-	-	Both HOMER and iHOGA do not consider the wind turbine for the optimal solution
	Converter (kW)	962	973	600	The size of converter is smaller than in HOMER due to the smaller size of PV compared to HOMER,
	Trojan-105	236 of 360kWh Nominal Capacity	709 1080kWh Nominal Capacity	8series x90Parallel 1097.2kWh	When nominal capacity of the batteries are considered, Model 1 of HOMER is almost similar to iHOGA result.
Economics	***NPC (A$)***	3.37M	3.47	4.23M	NPC of iHOGA is large than HOMER simulated result
	COE (A$/kW)	0.0838	0.0851	0.11	COE of iHOGA simulated model is larger than HOMER simulated results
	Autonomy	0.998	3hr	2.4hr	The autonomy of all the HOMER and iHOGA simulated models is in2hr to 3hr range.
Renewable energy Fraction		60.5%	61.4%	60%	The RE of HOMER simulated model is slightly large than iHOGA simulated model.
Poisonous Gas emissions(kg/yr)		Carbon Dioxide 850,309 kg/yr Sulfur Dioxide 3,686 kg/yr Nitrogen Oxides 1,803 kg/yr	Carbon Dioxide 843,429 kg/yr Sulfur Dioxide 3,657 kg/yr Nitrogen Oxides 1,788 kg/yr	Carbon Dioxide: 464,573kgCO_2/yr	HOMER considers different poisonous gas emissions like Cox, NOx and SOx. However, iHOGA considers only COx emissions.
HDI		-	-	1.2852	This feature is absent in HOMER
Jobs		-	-	5.9247	This feature is absent in HOMER

5.5 Conclusion

This study highlights the application of HRES for the improvement of micro-grid and forms an example model for mitigating GHG emission for a community and university building by using HOMER and iHOGA software packages. HOMER is a widely used software for economic optimisation of HRES, however iHOGA is not much explored like HOMER. This study is to compare and contrast the results obtained by both the software packages. Although both the software minimises the NPC of the system, HOMER results are 100% accurate for all the combination of the HRES system. This is not true in case of iHOGA. The control strategy is well defined in iHOGA compared to HOMER. The value of the load is very high and the combinations of HRES required including the control strategies makes iHOGA to simulate results much slower compared to HOMER software.

In the economically optimised RES model discussed, there is some amount of energy penetration to the grid, to account for the revenue earned through FiTs. Relying completely on the HRES connected to the grid can lead to problems in times of grid failure, while considering a stand-alone system could lead to either unmet load in times of peak load demand or could lead to a larger sized HRES. This has led to exploring the option of considering a battery connected to the grid. Factoring the FiTs (which are fluctuating), the rebates that the Government provides and the stochastic behaviour of RE, the current optimally sized HRES setup would answer all the aforementioned ambiguities of relying only on electric grid. Since the RE sector is progressing remarkably, using this as the energy source to provide a green energy solution and mitigate CO_2 emissions is the need of the hour in communities in India and buildings like universities in Australia. The model discussed above not only caters to the energy demand, but also comes with the heavy pricing of HRES.

HOMER software has been used to size the HRES for a community in Aralvaimozhi, India and Warrnambool, Australia. The results showcase the abundant availability of wind energy at Aralvaimozhi, when tapped efficiently along with the solar energy and storage setup like a battery can support the community load for better reliability and efficiency.

In case of Warrnambool, while the optimised model does not include wind energy adoption, a sole reliance on PV, battery and grid is observed. This section completely deals with the economic analysis of sizing of HRES for both the case studies. However, in both the case studies, the cash flow is negative, hence the rate of return and payback period becomes out of scope for a highly expensive HRES model. Thus only NPC and COE has been discussed in the economics of HRES of both the case studies. It is observed that, there are many positive and negative aspects that is dealt with both the software packages. The optimum sizing and economic analysis results in a similar sizing and economics of the HRES sized for both the case study areas.

The electric grid in India is very old. The existing poor grid infrastructure is inefficient and has caused unmet demand for the energy required. Urban population growth has started to drive up the demand in new sectors such as buildings, air-conditioning and transportation. This has led to India's uptake of RE which are also being driven with the introduction of new and cheaper technologies.

One of these new and exciting options considered for this current study case is RES along with battery connected to the grid. Since the RE sector is progressing remarkably, using this as the energy sources to provide a green energy solution and mitigate CO_2 emissions is the need of the hour in India. The models discussed not only caters to the energy demand of the Aralvaimozhi community but also a reduced GHG emissions and green energy option for the community. This would result in avoiding the power shortages, blackouts or power thefts which are the most common and crucial challenges faced by India [130-132]. These models clarify that the smaller-emission RE option could be made possible by initiating bank loans; however, these values are dependent on the prices of HRES and other sensitive variables like inflation rate and RE availability. A further analysis has been conducted on the same case study area in Chapter 6 which discusses the TBL analysis for different sensitive cases.

Chapter 6

Probability and Sensitivity analysis using iHOGA software and Triple Bottom Line Analysis of the results

6.1 Introduction

This chapter introduces the probable variables that affect the optimum sizing like the price of HRES, electrical load etc. which in turn have an impact on the economics of the RES. From the model discussed in Chapter 5, the analysis of probable variables in the HRES and load are considered and the TBL analysis has been discussed here. This chapter discusses the probability analysis and sensitivity for a small community in Aralvaimozhi, India and a university building in Warrnambool, Australia. Their results are analysed and discussed individually in detail.

6.2 Probability analysis using iHOGA software

6.2.1 Aralvaimozhi

From Chapter 5 it was understood that the simulation results from HOMER and iHOGA were almost the same. However, the discussion did not include the probable variables that would impact the energy economics of the HRES system for the community or university. The HRES system discussed in Chapter 5 is considered again, introducing the probable variables as load and HRES prices etc., the TBL analysis has been conducted. From the simulation results obtained using the iHOGA software, the techno-economic, social and environmental impact for Aralvaimozhi community are discussed.

Preliminary analysis in Section 5.2 from Chapter 5 highlighted Aralvaimozhi's abundant energy resources availability namely solar and wind energy which could be exploited for RE adoption to the community. Figure 6.1 shows the HRES used for RE adoption in Aralvaimozhi community. This includes generic PV, UE1500 WT, set of Trojan batteries connected to the grid. The details of the components used for the study are provided in Table 6.1. The electricity bill was analysed to find the average electricity price paid by the community for 1kWh, this was INR2.16/kWh. The FiT though was not given for Tamil Nadu in any literature, however, it is reasonable to consider INR5.1/kWh.

For the control strategy, LF option was considered. This means that, the unmet load from the RE system will be met by the charged batteries. A bidirectional inverter of 100kVA of acquisition cost INR6850,000 was included. With one day of minimum autonomy, the HRES was sized for a minimum RE fraction 70% grid system used, would act as an additional support in case the energy to the load is not met by the RES or from the batteries. The grid is also used to dump the excess power after the load is met by the RES.

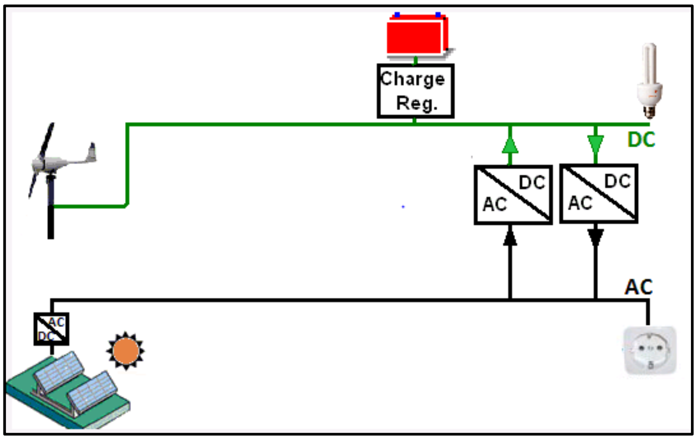


Figure 6.1 The HRES for Aralvaimozhi community, India

Table 6.1 Specifications of HRES components used for analysis

Components	Specification		Cost	
Solar Panels (PV)	Nominal Voltage	12V	Capital Cost	79600/yr
	Shortcut Current	8.23A	O&M Cost	100/yr
	Nominal power	1000Wp		
	Lifespan	25 yrs		
Converter -	Generic system converter (bi-directional inverter/converter) rated 1kVA	-	Capital	68500/yr
UE 1500 Wind Turbine	Height	12m	Capital Cost	250,000
	Rated Power	1500W	Replacement cost	250000
	Life Span	20 yrs	O&M cost	10/yr
Battery	Nominal Capacity	254Ah	Capital Cost	19500
	Voltage	6V	O & M cost	20
	SOC	20%		

6.2.1.1 Introduction to different sensitive cases for Aralvaimozhi community

If the optimisation method considered is the multi-objective optimisation, as in many cases, the results thus produced may be mutually counterproductive. Depending on the objectives selected to be optimised, the many solutions provided by the system, many of them may offer the least emission and others may provide the least cost or unmet load.

The solution presented will be in a sorted manner with the best ones on top. In contrast, the aforementioned objective, a single objective function has been discussed for various sensitivity cases instead. The study conducted primarily explores the probable variables for Indian scenario. The variation in the price of the RES in the energy market, forms one of the major criteria of analysis. Although the bill analysed for the community is for more than a year (which is the normal duration used in the literature to study the load). It was observed that the community had a moving population, which means that not all the people in the community had owned the house they lived in. Since some of the community leased or rented the property, the load would be a variable value.This was considered as the second sensitivity case. The load used in the analysis was considered with variable values, with 0.75 times and 1.15 times the actual load. Such analysis for optimisation of HRES has not been observed in the literature survey, no such study has been conducted using the iHOGA software.

iHOGA software simulated 15 sets of results for each value of loads considered. i.e. 3 values of load x 5 combinations of acquisition costs =15 sensitivity cases. Each of these 15 cases were simulated by iHOGA software. Single objective optimisation considering 15.5% as interest rate and 7.13% inflation rate for a study period of 15 years was considered. iHOGA used the GA for the main algorithm and evaluating all the combination of the secondary algorithm with 126,601 cases. For each combination of sensitivity cases, iHOGA produced at least 150 results in the form of a tabular column with the first row being the best-optimised result. iHOGA sized the RES with maximum 3 batteries in parallel, maximum 132 PV panels in parallel connection and maximum of 20 WT in parallel connection which is shown in Figure 6.2. A generic bi-directional inverter was used for the chosen HRES system.

The single-objective constraint was chosen to minimise the NPC. However, each of these results reflected CO_2 emissions and job creation criteria. For a developing country like India, it is a prime requirement to understand the job creation prospects when such projects are to be sanctioned. This objective is unique for iHOGA software, where the job creation data of each technology (number of jobs per GWh of generated energy) is considered by the software.

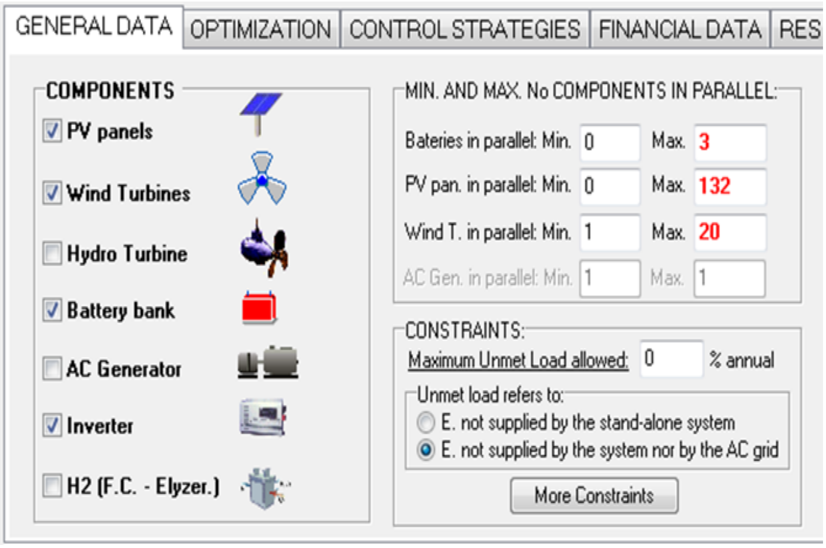


Figure 6.2 Minimum and Maximum number of components chosen by iHOGA for simulation

6.2.1.2 Analysis of Each of the Sensitivity Cases

This section summarises the optimum sized HRES system for every sensitivity case. The sensitivity analysis includes the variation in the load and price of the HRES system. Considering the actual load of Aralvaimozhi as183.4kWh/day, additional of 0.75 times this load and 1.15 times the actual load have been considered in the analysis. With the technological development in the RE world, it is necessary to analyse the impact of the variation of the price of the RES. Hence, variation of PV, WT and battery have been studied when the price reduces by 50%. The size of HRES with least value of NPC is showed in Figure 6.3.

- Sensitivity 1: For the Sensitivity1 considering the load to be 183.4kWh/day and probability of all the prices of the components to be 1(which is equivalent the current market price of the components), iHOGA evaluated 199,290 iterations. The NPC ranging from INR6.5M to INR5.77M with COE varying between INR6.48/kWh and INR5.75/kWh. The best system configuration includes: 18kW from PV inclined at an angle of 60^0, 16.5kW power from 11UE 1500 WT, Trojan 105 batteries with 8 strings of 3 batteries connected in parallel with a total energy of 36.5kWh with 2.4hour autonomy with the bi-directional inverter sized to 10kW. This HRES had the RE penetration of 70.2% with COE INR5.75/kWh and 173412 kg CO_2/yr of emissions.

- Sensitivity 2: This sensitivity study is done by considering the load to be 183.4kWh/day and probability of all the prices of the components to be 0.5 (which is 50% equivalent the current market price of the components). iHOGA evaluated 199,290 cases. The NPC varied from INR2.87M to INR2.8M. The best model chosen by iHOGA with least NPC includes: 15kW PV, 18kW of 12 UE 1500 WT, 10 kW converter, 8strings of 3 parallel Trojan 105 batteries with a nominal capacity of 36.5kWh with 2.4hour of autonomy. This system had RE penetration of 70.3% with COE of INR2.79/kWh with 188,284kg CO_2/yr of emissions.
- Sensitivity 3: This sensitivity study is done by considering the load to be 183.4kWh/day and probability the price of only PV to be 0.5(which is 50% equivalent the current market price of the component). iHOGA evaluated 199,290 cases of simulations. The NPC varied from INR5.12M to INR4.71M with COE ranging between INR5.1/kWh and INR4.7/kWh. The optimised system consists of 29kW PV, 12kW of 8 WT and 10kW inverter with a Trojan battery of 36.5kWh nominal capacity. This optimised system had emissions 128,999kgCO_2/yr and COE INR 4.7/kwh and RE penetration of 70%.
- Sensitivity 4: This sensitivity study is done by considering the load to be 183.4kWh/day and probability of only the price of WT to reduce by 50%. The NPC was ranged between INR3.54M to INR3.48M with COE ranging between INR3.53/kWh and INR3.47/kWh respectively. The optimised system consists of 6kW PV, 27kW of 18WT and 1kW inverter with a Trojan battery of 36.5kWh nominal capacity. The least value of NPC for the HRES system had the RE penetration of 70.4% with and CO_2 emission 278,190kgCO_2/yr.
- Sensitivity 5: This sensitivity study is done by considering the load to be 183.4kWh/day and probability the price of only the battery to be 50% of its actual cost. iHOGA resulted in 15 generations after evaluating 19,1850 simulations. The NPC varied from INR5.86M to INR5.46M with COE ranging from INR5.84/kWh and INR5.44/kWh. The HRES include: 18kW PV, 11 WT of 16.5kW and 10kW inverter with a Trojan battery of 36.5kWh nominal capacity. The COE of this HRES system was the INR5.44/kWh with had 70.2% of RE penetration and 173,412kgCO_2/yr of emissions.

- Sensitivity 6: This analysis consider the load to be 137.55kWh/day (i.e 75% of the actual load) and the probability of all the prices of the components to be 1(which is equivalent the current market price of the components). The NPC varied from INR4.34M to INR4.17M with COE varied between INR5.77/kWh and INR5.54/kWh. The best system configuration includes: 14kW PV, 8WT of 12kW and 10kW inverter with a Trojan battery of 24.3kWh nominal capacity considering 0.1day (2.4hours) autonomy. The results had the RE penetration of 70.1% and COE of INR5.54/kWh with 126,301kgCO_2/yr of emissions.
- Sensitivity 7: This sensitivity study is done by considering the load to be 137.55kWh/day and probability of all the prices of the components to be 0.5(which is 50% equivalent the current market price of the components). The NPC varied from INR2.16M to INR20.1M. The best model chosen by iHOGA with least NPC includes: 14kW PV, 8WT of 12kW and 10kW inverter with a Trojan battery of 24.3kWh nominal capacity with 2.4hr of autonomy. This system had the COE of INR2.67/kWh with RE penetration of 70.1% and 126,301kgCO_2/yr of emissions.
- Sensitivity 8: This sensitivity study is done by considering the load to be 137.55kWh/day and probability of the price of only PV to be 0.5(which is 50% equivalent the current market price of the component). The NPC varied from INR3.57M to INR3.4 with COE ranging between INR4.74/kWh and INR4.52/kWh. The optimised system includes: 31kW PV, 5 WT of 7.5kW and 10kW inverter with a Trojan battery of 24.3kWh nominal capacity. This optimised system had COE INR 4.52/kWh with 70.1% of RE penetration and emissions of 81874kgCO_2/yr.
- Sensitivity 9: This sensitivity study is done by considering the load to be 137.55kWh/day and probability of only the price of WT to reduce by 50%. The NPC varied from INR2.67M to INR2.56Lac with COE ranging in the range INR3.55/kWh and INR3.4/kWh. The size of HRES with least NPC included: 4kW PV, 21kW of 14 WT and 1kW inverter with a Trojan battery of 24.3kWh nominal capacity considering 0.1day autonomous. The results had the RE penetration of 70.1% with COE of INR3.4/kWh and 216,184 kg CO_2/yr of emissions.

- Sensitivity 10: This sensitivity study is done by considering the load to be 137.55kWh/day and probability of the price of only the battery to be 50% of its actual cost. The NPC varied from INR4.18M to INR3.96M with COE ranging from INR5.55/kWh and INR5.27/kWh. The HRES consisted of: 14kW PV, 12kW WT and 10kW inverter with a Trojan battery of 24.3kWh nominal capacity considering 0.1day autonomous for the best model with least NPC. This model had 70.1% of RE penetration with COE of INR5.27/kWh and emissions of 126,301kg CO_2/yr.
- Sensitivity 11: Considering the load to be 210.91kWh/day (i.e 1.15 times the actual load) and the probability of all the prices of the components to be 1(which is equivalent the current market price of the components) iHOGA evaluated 199290 iterations. The NPC ranging from INR6.78M to INR6.56Mwith COE varied between INR5.88/kWh and INR5.69/kWh. The best system configuration includes: 19kW PV, 13 WT of 19.5kW T and 10kW inverter with a Trojan battery of 36.5kWh nominal capacity considering 0.1day autonomy. The best HRES model with least NPC had the RE penetration of 70.1% and COE of INR5.69/kWh with CO_2 emission of about 204,681kg CO_2/yr.
- Sensitivity 12: This sensitivity study is done by considering the load to be 210.91kWh/day and probability of all the prices of the components to be 0.5(which is 50% equivalent the current market price of the components). The NPC varied from INR3.23M to INR3.2M. The best model chosen by iHOGA with least NPC includes: 14kW PV, 15 WT of 22.5kW and 10kW inverter with a Trojan battery of 36.5kWh nominal capacity considering 0.1day autonomous. This system had the COE of INR2.78/kWh with RE penetration of 70.2% and 234,474kg CO_2/yr of emissions.
- Sensitivity 13: This sensitivity study is done by considering the load to be 210.91kWh/day and probability of only the price of PV to be 0.5(which is 50% equivalent the current market price of the components). The NPC varied from INR5.63M to INR5.48M with COE ranging between INR4.88/kWh and INR4.75/kWh. The optimised system consisted: 30kW PV, 10 WT of 15kW and 10kW inverter with a Trojan battery of 36.5kWh nominal capacity considering

0.1day autonomous. This optimised system had 70.2% of RE penetration and COE INR4.75/kWh with 160,178kg CO_2/yr of emisions.

- Sensitivity 14: This sensitivity study is done by considering the load to be 210.91kWh/day and probability of only the price of WT to reduce by 50%. The NPC varied from INR4.1M to INR3.89M with COE ranging in the range INR3.55/kWh and INR3.37/kWh. The size of HRES with least NPC included: 8kW PV, 19WT of 28.5kW WT and 1kW inverter with a Trojan battery of 36.5kWh nominal capacity considering 0.1day autonomous was considered. The results had the RE penetration of 70.1% with COE of INR3.37/kWh and 29,4547kg CO_2/yr of emissions.
- Sensitivity 15: This sensitivity study is by considering the load to be 210.91kWh/day and probability of the price of only the battery to be 50% of its actual cost. The NPC varied from INR6.52M to INR6.26M with COE ranging from INR5.65/kWh and INR5.42/kWh. The HRES of the best model includes: 19kW PV, 13 WT of 19.5kW and 10kW inverter with a Trojan battery of 36.5kWh nominal capacity considering 0.1day autonomous. The COE of this HRES system was INR5.42/kWh with 70.1% RE penetration and 20,4681kgCO_2/yr of emissions.

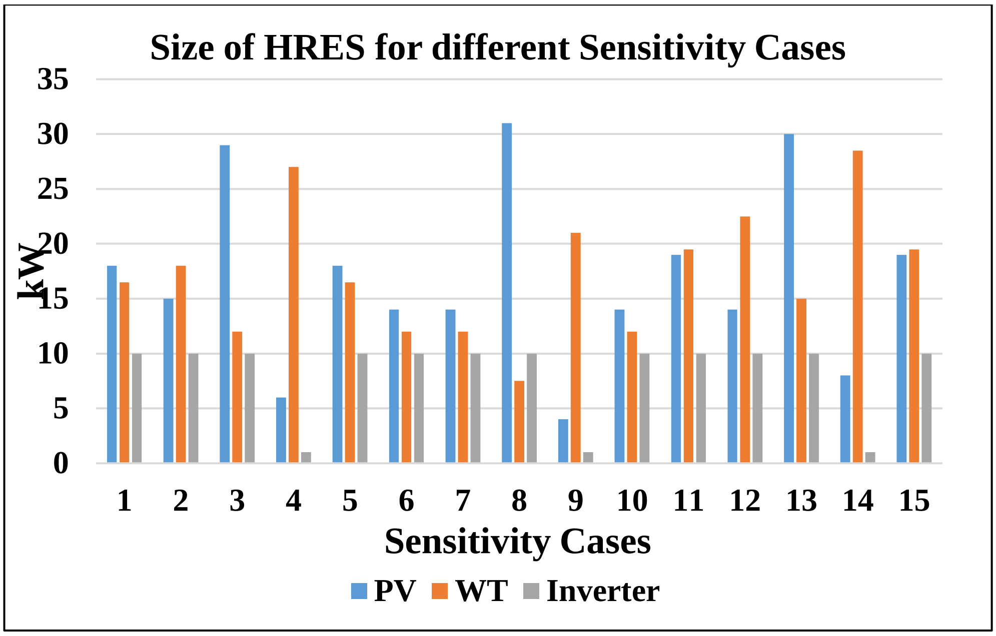


Figure 6.3 Size of HRES components with least NPC for all the sensitivity cases

6.2.1.3 Triple Bottom line analysis of sensitive cases for Aralvaimozhi Case study

In conventional accounting, TBL approach is commonly used to conclude the profitability or the loss of any project which summarises the revenues/expenses. In the current study, TBL analysis includes the discussion on the techno-economic, social and environmental aspects involved in adopting HRES for Aralvaimozhi community. The techno-economic analysis elucidates the costs involved (NPC) for the adopting the technology, while the social aspect explains the job creation aspect if this project adopted, while the environmental aspects include the CO_2 emissions from the HRES. Table 6.2 shows the NPC, emissions, jobs creation of the best-generated result for each sensitivity case

All the sensitivity cases provided in the Table 6.2 considers HRES connected to the grid through battery storage with autonomous of 0.1day. For the current market price of the technology, the results clearly elucidate that the NPC of the system is directly related to the load of the community. When the community load is 0.75 times actual load (Sensitivity 6), there is a decrease in NPC by 1.45 times the actual NPC (Sensitivity 1). If the load increases by 1.15times the actual load, the NPC increase by INR1.6M. There is an inverse relationship observed between NPC, CO_2 emissions. For any given load value, the market price of the HRES has a larger impact on the NPC and COE. As the market price of the HRES drops by more than 50% of the current price, the COE reduces to a minimum of approximately INR 2.8/kWh for all the loads considered. Observing the NPC and COE, with 50% decrease in both the prices of PV and WT respectively results in a sharp decrease in NPC and COE.

The decrease in the price of WT by 50% has a phenomenal impact on the economics of the system with the COE reducing to half of the actual price. When the acquisition cost of all the HRES components drops by a minimum of 50% of its present acquisition cost, there is a remarkable decrease in the NPC of the HRES. However, there is not much impact when the battery price is reduced to 50%. It could be due to the fact that the battery autonomy considered is only about 2.4hours. This is evident on the NPC and COE in Sensitivity 5, 10, 15. If the PV, WT and the battery prices drop by 50% respectively of the present market price, COE reduces by 3INR/kWh.

Table 6.2 Results of all sensitivity cases with least value of NPC

	Load (kWh/day)	**Sensitivity multiplier**			**NPC (INR)**	**Emis. CO_2 (kg/yr)**	**Renewable Energy Penetration**	**LCOE. (INR/kWh)**	**Jobs creation**
		Pr.PV(x)	Pr.W.T.(x)	Pr.Bat (x)					
1	183.4	1	1	1	5771766.5	173412.7	70.25	5.75	0.0633
2		0.5	0.5	0.5	2804724.75	188284.8	70.3	2.79	0.0549
3		0.5	1	1	4715987.5	128999.4	70.03	4.7	0.0944
4		1	0.5	1	3487599.5	278190.91	70.45	3.47	0.0318
5		1	1	0.5	5467449.5	173412.7	70.25	5.44	0.0633
6	137.55	1	1	1	4171106.5	126301.7	70.06	5.54	0.0488
7		0.5	0.5	0.5	2011028.62	126301.7	70.06	2.67	0.0488
8		0.5	1	1	3406837	81874.9	70.15	4.52	0.0978
9		1	0.5	1	2561502	216184.8	70.15	3.4	0.0227
10		1	1	0.5	3968228.5	126301.7	70.06	5.27	0.0488
11	210.91	1	1	1	6568269	204681.7	70.08	5.69	0.0679
12		0.5	0.5	0.5	3208158.5	234474.09	70.17	2.78	0.0542
13		0.5	1	1	5480131	160178.5	70.16	4.75	0.099
14		1	0.5	1	3896409.75	294547.59	70.1	3.37	0.0388
15		1	1	0.5	6263952	204681.7	70.08	5.42	0.0679

India has been consistently working on mitigating the GHG emissions as it exhibits the impact on the climate change. As part of this mitigating plan, it has formulated National Action Plan on Climate Change and is a part of UNFCC it has aimed to mitigate GHG of its GDP by 20-25% by 2020. A study conducted has found an affirmative and explicit impact of financial development on per capita CO_2 emissions which further elaborates on alleviating environmental issues [36]. Thus, it is necessary to see how the adoptability of HRES impacts the environment. From the Figure 6.4, it can concluded that those HRES with a smaller value of NPC has larger CO_2 emissions, while the HRES having smaller CO_2 emissions had larger NPC. The CO_2 emissions are least of 81874.9/yr for HRES with NPC of INR3.4M and the emission is maximum for Sensitivity 14 with 294,547.59 kgCO_2/yr. If the CO_2 emission trend is observed, Sensitivity 3, 6, 8, 10 have CO_2 emissions less than 13,000kg/yr.

Thus it could be concluded that the load and capital cost of the HRES has an inverse effect on the CO_2 emissions. The social factor considered in this study is the job creation due to the adoption of HRES to the Aralvaimozhi community. Employment created by PV and wind power is considered in jobs per MW of peak power [37]. Figure 6.5 shows the NPC and jobs created for the best solution for each sensitivity case. Job creation is maximum of 0.99 for Sensitivity case 13. This concludes that, higher the value of load with larger HRES utilisation, larger the number of jobs created.

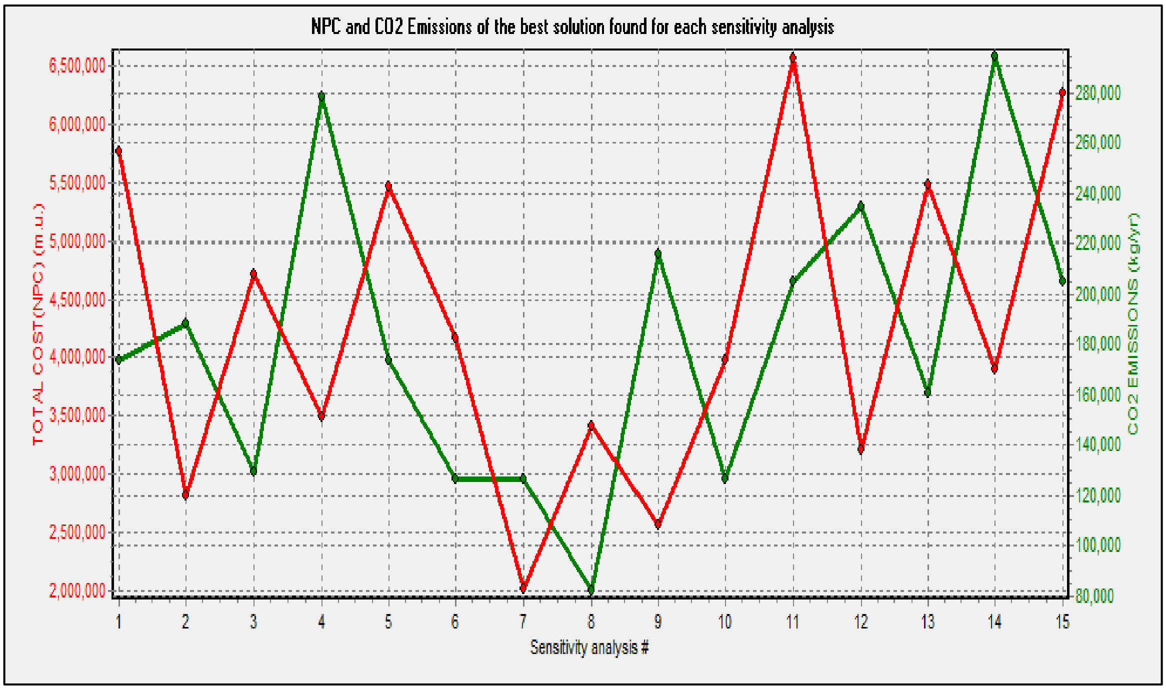


Figure 6.4 NPC and CO_2 emissions for all the different cases

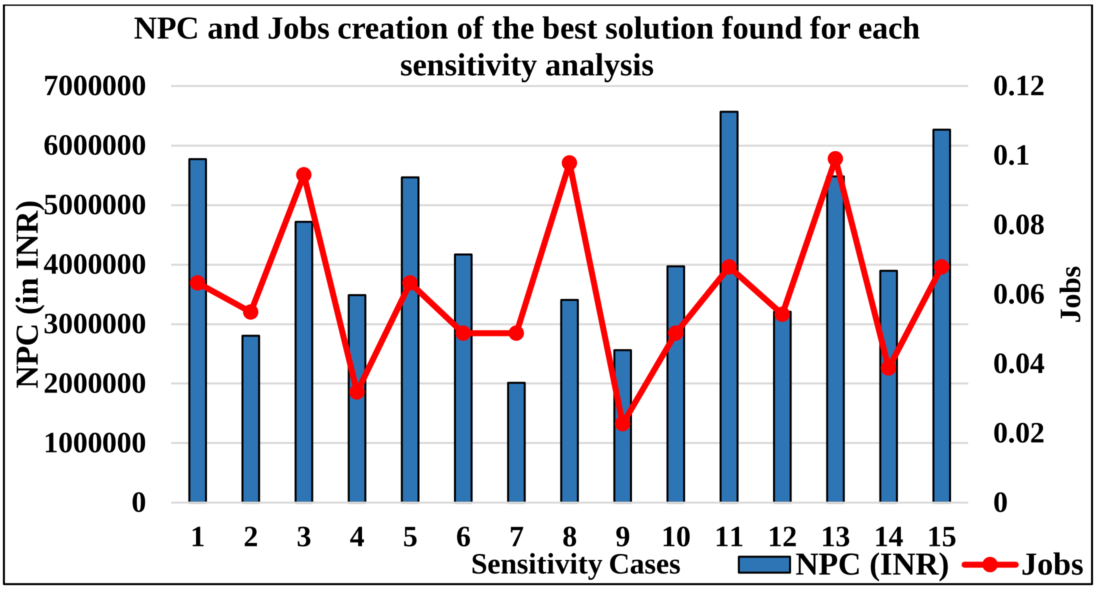


Figure 6.5 NPC and Jobs creation for different sensitivity cases.

The relationship between the NPC and RE penetration shown in Figure 6.6. The RE constraint for the analysis was kept to a minimum of 70%. The system with maximum RE penetration is for Sensitivity 4 with 70.45%. The NPC of the system is INR3.48M. This implies that, the battery helps in storing RE efficiently, thus improving the RE penetration. The RE penetration is least of 70.0% for Sensitivity 3. When Sensitivity 1 and 11 are considered, the NPC increases with the load due to the size of the HRES required to meet the load. However, smaller the load, smaller the HRES size required and hence smaller number of jobs will be created. This is observed in Sensitivity 2, 7, 12.

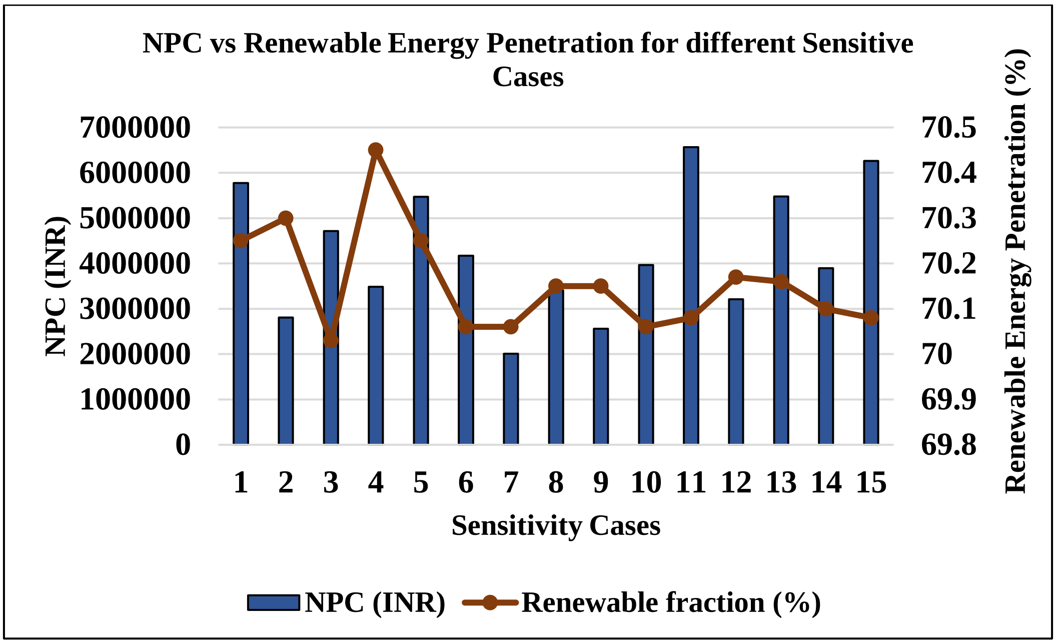


Figure 6.6 NPC and Renewable energy penetration for different sensitivity cases

6.2.1.4 Discussion of results from TBL analysis for Aralvaimozhi community

From the TBL analysis it could be concluded that if NPC is considered as the prime factor to decide the economic viability, it is understood that, other than the load capacity, the acquisition cost also plays a crucial part. However, HRES with smaller NPC has larger emission and smaller job creation. This implies a balance between these factors is necessary to decide the best HRES as all the three factors crucially affect the community to adopt HRES. It was also observed that, as the market price of the HRES drops to 50% of the current price, the COE reduces at least by INR3/kWh for all the loads considered. The COE from HRES is larger than the power purchased from the electricity grid. However, when the HRES price drops by 50%, the COE from the HRES is comparable with the grid power purchase price has been observed from Figure 6.7.

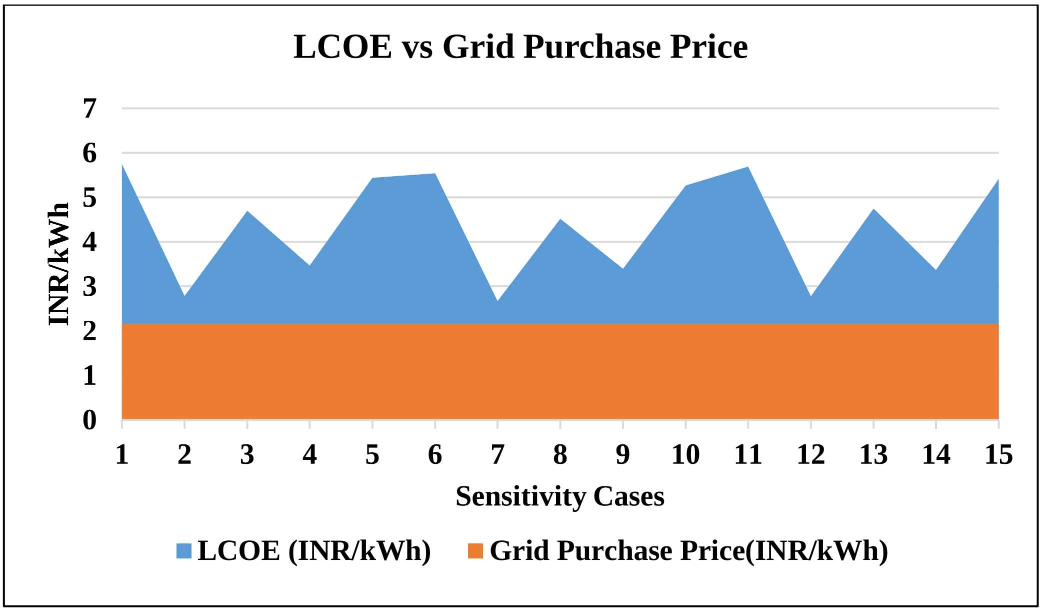


Figure 6.7 The LCOE from HRES and the Grid electricity price comparison

Hence there is a necessity for further rebates to be provided for HRES to be adopted easily for general community in India, especially when the HRES involves WT and battery setup. This implies that there is an urgent need in the revolution of RE price to challenge the grid power price. Other than financial challenges, the much prevalent corruption and politics in India would be one of the biggest challenges or hurdles for a community like Aralvaimozhi to overcome and become one of the model communities in terms of HRES adoption. This study clearly examines the possible HRES adoption and its impacts by performing TBL for a small community in India. There is definitely a compromise between least CO_2 emitted system and least NPC HRES system. This critical relationship between the economic environmental and social factors have been thoroughly studied for different options and the results are critically examined.

6.2.2 Warrnambool

From Chapter 5 it was understood that the results from HOMER and iHOGA were almost similar. However, the discussion did not include the probable variables that would impact the energy economics of the HRES system for the university. From the HRES system discussed in Chapter 5, considering the probable variables as load and HRES prices, the TBL analysis has been conducted and the results are discussed:

6.2.2.1 Introduction to different sensitive cases for a university building in Warrnambool

Preliminary analysis in Section 5.2 in Chapter 5 highlighted Warrnambool's abundant RE sources namely solar and wind energy to be exploited. Figure 6.8 shows the HRES used for RE adoption for Warrnambool, Australia. The HRES model for simulation includes a generic 1kW PV, AWS 5.1kW WT, converters, Trojan 105 battery which is connected to the grid in the model. The specifications of the HRES in the study is shown in Table 6.3. The sensitivity variables considered as inputs to perform the financial analysis. The present inflation rate of 2.1% and the discount rate of 5.23% are considered for the project lifetime of 15years. Meanwhile, 60% of minimum RE penetration is considered. The average power price that the university pay to purchase electricity from the grid is 0.17A$/kWh. The grid sells back price (FiTs) for the state of Victoria is currently 0.113A$/kWh.

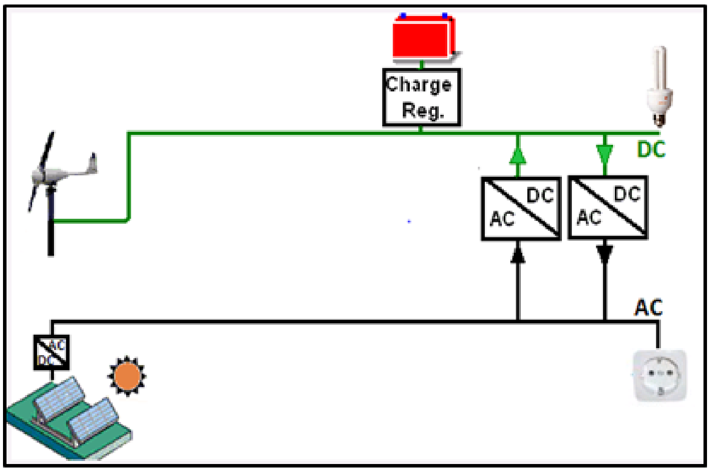


Figure 6.8 The HRES for Warrnambool University building community, India

Table 6.3 Specifications of HRES components used for analysis

Components	Specification		Cost	
Solar Panels (PV)	Nominal Voltage	12V	Capital Cost	680
	Shortcut Current	8.23A	O&M Cost	20/yr
	Nominal power	1000Wp		
	Life span	25 yrs		
AWS	Height	12m	Capital Cost	12692
	Rated Power	5100W	Replacement cost	12692
	Life Span	20 yrs	O&M cost	50/yr
Converter	Generic system converter (bi-directional inverter/converter)	-	240	-
Battery	Nominal Capacity	254Ah	Capital Cost	300
	Voltage	6V	O & M cost	12
	SOC	20%		

For the control strategy, LF option was considered, this means the unmet load from the RES will be met by the charged batteries. A bi-directional inverter of 100KVA was included. With 0.1day of minimum autonomy, the HRES was sized for a minimum RE fraction of 60%. Grid system included in the model, would act as an additional support in case the energy to the load is not met by the RES or from the batteries. The grid is also used to dump the excess power after the load is met by the RES. The sensitivity cases include the probable variables that could have a larger impact on the economics. For example, the price of the components, the variation in load, the variation of wind energy and solar radiation at the location. In this study the sensitivity study was:

1. Sensitivity analysis for load
   a. The base case with Average load =6916.59kWh/day
   b. Base Case x 0.75 scale factor = 5187.45kWh/day
   c. Base Case x 1.05 scale factor = 7954.06kWh/day
2. Sensitivity analysis for acquisition cost of the components
   a. Base case=Present Cost of PV, WT, batteries
   b. 0.5x acquisition cost of PV, 0.5x WT acquisition cost, 0.5x batteries cost
   c. 0.5x acquisition cost of PV, 1x WT acquisition cost, 1x batteries cost
   d. 1x acquisition cost of PV, 0.5x WT acquisition cost, 1x batteries cost
   e. 1x acquisition cost of PV, 1x wind turbine acquisition cost, 0.5x batteries cost

The variation in the price of RES in energy market forms one of the major criteria for analysis. Although the bill analysed for the university is for more than a year. The load of the university may not be same always, hence this was considered as the second sensitivity case. The load used in the analysis was considered with variable values, with 0.75 times and 1.15 times the actual load. Such analysis for optimisation of HRES has not been observed in the literature, no such study have ever been conducted using iHOGA software.

iHOGA software simulated 15 sets of results for each value of loads considered. i.e 3 values of load x 5 combinations of acquisition costs=15 sensitivity cases. Each of these 15 cases were simulated by iHOGA software performed single objective optimisation considering 5.32% as interest rate and 2.1% inflation rate for a study period of 15 years. iHOGA considered GA for main algorithm and evaluating all the combination of the secondary algorithm with 787455 cases. For each combination of sensitivity cases, iHOGA produced at least 15 results in the form of tabular column with the last row being the best optimised result.

iHOGA sized the RES consisting PV, WT and batteries as shown in Figure 6.9. A generic bi-directional inverter was used for the chosen HRES system. NPC, CO_2 emissions and job creation prospects have been discussed for each of the sensitivity cases. For a developed country like Australia, it is a prime requirement to understand the job creation prospects when such projects are to be sanctioned. This objective is very unique for iHOGA software, were the job creation data of each technology (number of jobs per GWh of generated energy) is considered by the software.

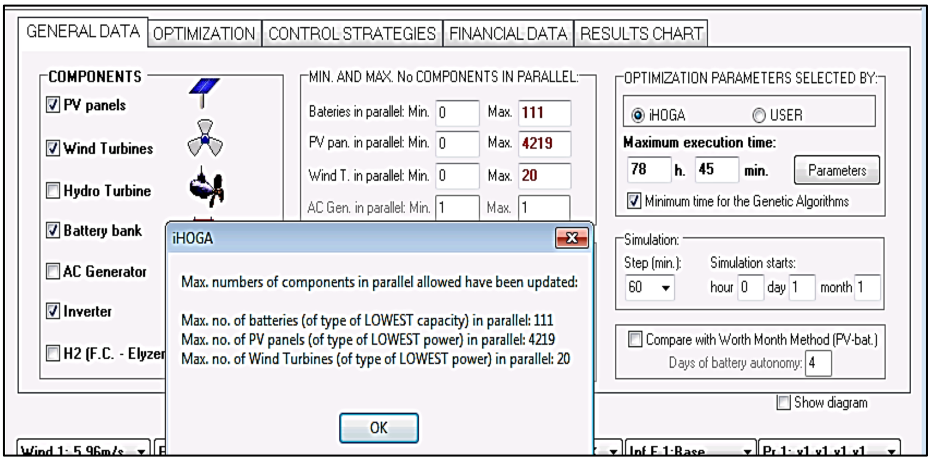


Figure 6.9 Minimum and Maximum number of components chosen by iHOGA for simulation

6.2.2.2 Analysis of Each of the Sensitivity Cases

This section summarises the optimally sized HRES system for every sensitivity case. The sensitivity analysis includes the variation in the load and price of the HRES system. Considering the actual load of Warrnambool 6916.59kWh/day, additional of 0.75 times this load and 1.15 times the actual load has been considered in the analysis. With the technological development in the RE world, it is necessary to analyse the impact of the variation of the price of the RES. Hence variation of PV, WT, and battery has been studied when the price reduced by 50%. However, it is observed that the optimized HRES for university building considers only PV penetration along with battery connected to the grid. The size of HRES for all the sensitivity cases is shown in Figure 6.10.

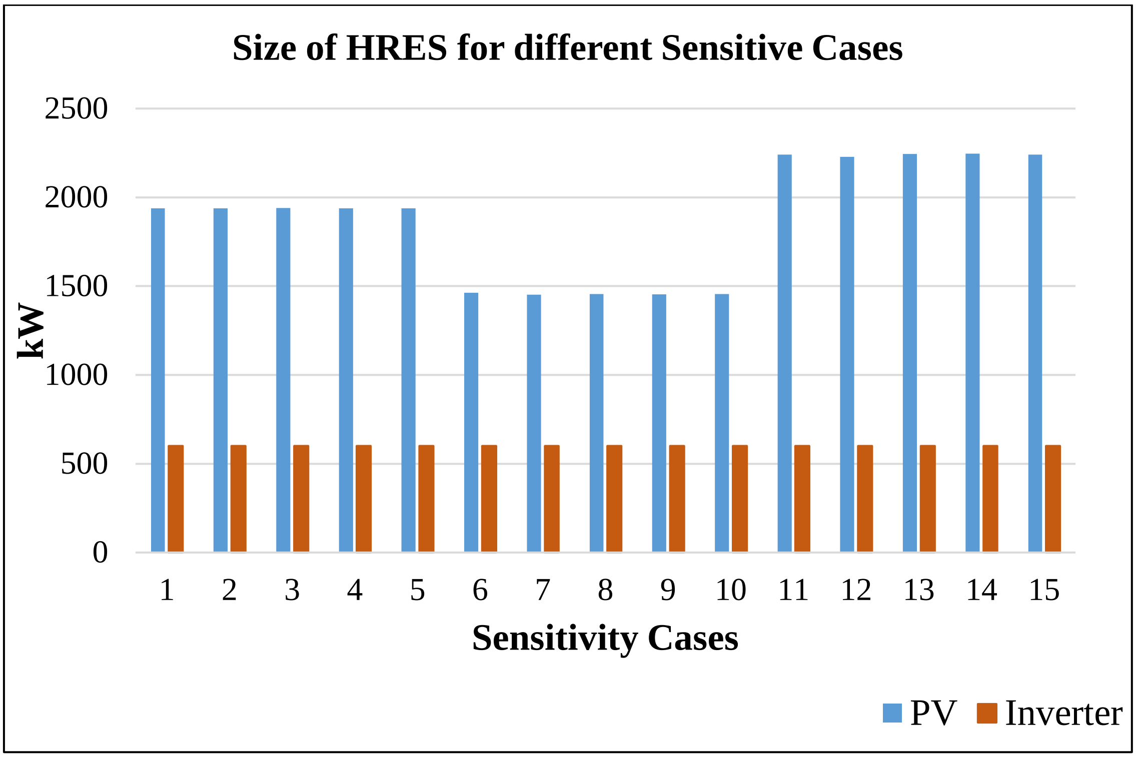


Figure 6.10 Size of HRES components with least NPC for all the sensitivity cases

- Sensitivity 1: For the Sensitivity 1 considering the load to be 6916.59Wh/day and probability of all the prices of the components to be 1 (which is equivalent the current market price of the components) iHOGA evaluated 78,7455 iterations. The NPC ranging from A$4.3M to A$4.23M. The best system configuration includes 1938kW from a solar panel with solar panels inclined at an angle of 600. Trojan 105 batteries with 8 strings of 90 batteries connected in parallel with a total energy of 1097.2kWh considering 2.4hour autonomous with 100% of the load being met the bidirectional inverter was sized to

600kW for the HRES to be included. The results had the A RE penetration of 60% with COE of 0.11A$/kWh and 464573 kg CO_2 /yr emissions.

- Sensitivity 2: This sensitivity study is done by considering the load to be 6916.59kWh/day and the probability of all the prices of the components to be 0.5 (which is 50% equivalent the current market price of the components) iHOGA evaluated 787455 cases. The NPC varied from A$3.42M to A$3.44M. The best model chosen by iHOGA with least NPC includes 1,938kW PV, 600 kW inverter. 8strings of 90 parallel Trojan 105 batteries with a Nominal capacity of 1,0972.5kWh with 2.4hour of autonomy is chosen to be the best configuration. This system with least value of NPC had the COE of 0.09A$/kWh with RE penetration of 60% and 464,573kgCO_2 /yr emissions.
- Sensitivity 3: This sensitivity study is done by considering the load to be 6916.59kWh/day and probability the price of PV to be 0.5 (which is 50% equivalent the current market price of the components). iHOGA evaluated 78,7455 cases of simulations. The NPC varied from A$3.68M to A$3.57M with COE 0.09A$/kWh. The optimized system consists of 1941kW PV, 600kW inverter with a Trojan battery of 1097.2kWh nominal capacity. This optimised system had COE 0.09A$/kWh and RE penetration of 60% and 464608kgCO_2/yr emissions.
- Sensitivity 4: This sensitivity study is done by considering the load to be 6916.59kWh/day and probability of all the price of WT to reduce by 50%. The NPC was ranged between A$4.4M to A$4.23M. The COE of the HRES is 0.11A$/kWh. The optimized system consists of 1,939kW PV, 600kW inverter with a Trojan battery of 1097.2kWh nominal capacity. The least value of NPC for the HRES system had the RE penetration of 60% with and 464,590kgCO_2 /yr of emissions.
- Sensitivity 5: This sensitivity study is done by considering the load to be 6916.59kWh/day and probability the prices of the battery to be 50% of its actual cost. iHOGA resulted in 15 generations after evaluating 78,7455 simulations. The NPC varied from A$4.26M to A$4.08M with COE 0.11A$/kWh. The HRES with 1,938kW PV, 600kW inverter with a Trojan battery of 1097.2kWh nominal capacity. The COE of this HRES system was 0.11A$/kWh with 60% of RE penetration and 46,4573kgCO_2/yr of emissions.
- Sensitivity 6: Considering the load to be 5187.45kWh/day (i.e. 75% of the actual load) and the probability of all the prices of the components to be 1 (which is equivalent

the current market price of the components). The NPC ranging from A$2.86M to A$2.64M with COE varied between 0.1A$/kWh and 0.09A$/kWh. The best system configuration includes 1463kW PV, 600kW inverter with a Trojan battery with 8 strings and 68 parallel combinations of 829kWh nominal capacity considering 0.1day autonomous. The best HRES had COE of 0.09A$/kWh with RE penetration of 60% and 351,353kgCO_2/yr of emissions.

- Sensitivity 7: This sensitivity study is done by considering the load to be 5187.45kWh/day and probability of all the prices of the components to be 0.5(which is 50% equivalent the current market price of the components). The NPC varied from A$2.11M to A$2.03M. The best model chosen by iHOGA with least NPC includes 1,452kW PV, 600kW inverter with a Trojan battery of 829kWh nominal capacity with 2.4hr of autonomy. This system had the COE of 0.07A$/kWh with RE penetration of 60% and 351,210kgCO_2/yr emissions.
- Sensitivity 8: This sensitivity study is done by considering the load to be 5187.45kWh/day and probability the price of PV to be 0.5(which is 50% equivalent the current market price of the components). The NPC varied from A$2.2M to A$2.14M with COE 0.08A$/kWh. The optimized system consists of 1455kW PV, 600kW Inverter with a Trojan battery of 829kWh nominal capacity. This optimized system had COE 0.08A$/kWh with 60% of RE penetration and 351,248kgCO_2/yr emissions.
- Sensitivity 9: This sensitivity study is done by considering the load to be 5187.45kWh/day and probability of all the price of WT to reduce by 50%. The NPC varied from A$2.85M to A$2.63M with COE ranging in the range 0.1A$/kWh and 0.09A$/kWh. The size of HRES with least NPC included 1,453kW PV, 600kW Inverter with a Trojan battery of 829kWh nominal capacity considering 0.1day autonomous is considered. The results had the RE penetration of 60% with COE of 0.09A$/kWh and 351,223 kg$CO_2$/yr of emissions.
- Sensitivity 10: This sensitivity study is done by considering the load to be 5187.45kWh/day and probability the prices of the battery to be 50% of its actual cost. The NPC varied from A$2.71M to A$2.52M with COE 0.09A$/kWh. The HRES with 1,455kW PV, 600kW Inverter with a Trojan battery of 829kWh nominal capacity considering 0.1day autonomous is the best model with the least NPC with 60% of RE

penetration. The COE of this HRES system was 0.09A$/kWh and 351,248kg CO_2/yr of emissions.

- Sensitivity 11: Considering the load to be 7954.07kWh/day (i.e. 1.15 times the actual load) and the probability of all the prices of the components to be 1(which is equivalent the current market price of the components) iHOGA evaluated 787455 iterations. The NPC ranging from A$5.23M to A$5.18M with COE 0.12A$/kWh. The best system configuration includes 2,240kW PV, 600kW Inverter with a Trojan battery of 1267.9kWh nominal capacity with 8strings of 104parallel connection on considering 0.1day autonomous. The best HRES with least NPC had the RE penetration of 60% with CO_2 emission of 52,9851kgCO_2/yr.
- Sensitivity 12: This sensitivity study is done by considering the load to be 7954.07kWh/day and probability of all the prices of the components to be 0.5(which is 50% equivalent the current market price of the components). The NPC varied from A$4.36M to A$4.25M. The best model chosen by iHOGA with least NPC includes 2228kW PV, 600kW Inverter with a Trojan battery of 1267.9kWh nominal capacity considering 0.1day autonomous. This system had the COE of 0.1A$/kWh with RE penetration of 60% and 52,9610kg CO_2/yr emissions.
- Sensitivity 13: This sensitivity study is done by considering the load to be 7954.07kWh/day and probability the price of PV to be 0.5 (which is 50% equivalent the current market price of the components). The NPC varied from A$4.53M to A$4.42M with COE 0.1A$/kWh. The optimised system consists of 2,244kW PV, 600kW inverter with a Trojan battery of 1267.9kWh nominal capacity considering 0.1day autonomous. This optimized system had COE of 0.1A$/kWh with 60% of RE penetration and 529,931kg CO_2/yr of emissions.
- Sensitivity 14: This sensitivity study is done by considering the load to be 7954.07kWh/day and probability of all the price of WT to reduce by 50%. The NPC varied from A$5.29M to A$5.19M with COE 0.12A$/kWh. The size of HRES with least NPC included 2246kW PV, 600kW Inverter with a Trojan battery of 1267.9kWh nominal capacity considering 0.1day autonomous was considered. The results had the RE penetration of 60% with COE 0.12A$/kWh and 529972kg CO_2/yr of emissions.
- Sensitivity 15: This sensitivity study is by considering the load to be 7954.07kWh/day and probability the prices of the battery to be 50% of its actual cost. The

NPC varied from A$5.04M to A$5.02M with COE 0.12A$/kWh. The HRES with 2,241kW PV, 600kW Inverter with a Trojan battery of 1267.9kWh nominal capacity considering 0.1day autonomous. The COE of this HRES system is 0.12A$/kWh with 60% RE penetration and 529,872 kgCO_2/yr of emissions.

6.2.2.3 Triple Bottom Line analysis of sensitive cases for Warrnambool Case study

TBL approach is commonly used to conclude the profitability or the loss of any project which summarises the revenues/expenses. In the current study, TBL analysis includes the discussion on the Techno-economic, social and environmental aspects involved in adopting HRES for the university in Warrnambool. The Techno-economic analysis elucidates the costs involved (NPC) for the adopting the technology, while the social aspect explains the job creation aspect if this project adopted, while the environmental aspects include the CO_2 emissions from the HRES. Table 6.4 summarises the NPC, Emissions, jobs creation of the best-generated result for each sensitivity case.

All the Sensitivity cases provided in Table 6.4 consider the HRES connected to the grid through battery storage with autonomous of 0.1 days. For the current market price of the technology, the results clearly elucidate that the NPC of the system is directly related to the load of the community. When the community load is 0.75* actual load (Sensitivity 6), there is a decrease in NPC by A$1.6M the actual NPC (sensitivity 1). If the load increases by 1.15times the actual load, the NPC increase by A$0.95M.There is an inverse relationship observed between NPC, CO_2 emissions. For any given load value, the market price of the HRES has more significant impact on the NPC and LCOE. As the market price of the HRES drops by more than 50% of the current price, the COE reduces to a minimum of approximately A$0.02/kWh for all the loads considered.

Observing the NPC and COE, with a 50% decrease in the PV price, the results show a considerable decrease in NPC and LCOE. When the acquisition cost of all the components drops by a minimum of 50%, there is a remarkable decrease in the NPC of the HRES. However, there is not much impact when the battery price is reduced to 50%. It could be due to the fact that the battery autonomy considered is about 2.4hours only. This is evident on the NPC and LCOE in Sensitivity 5, 10, 15.

Australia is one of the highest per capita GHG emitter. A study conducted has found an affirmative and explicit impact of financial development on per capita CO_2 emissions which further elaborates on financial development helps in alleviating environmental issues [91]. Thus, it is necessary to see how the adoptability of HRES impacts the environment.

From Figure 6.11, it is concluded that those HRES with a smaller value of NPC and CO_2 emissions. The CO_2 emissions are least of 351,210.41kg/yr for HRES with 2.03M for Sensitivity 7 and the emission is maximum emission for Sensitivity 14 with 529,972.81kgCO_2/yr. If the CO_2 emission trend is observed, Sensitivity 6, 7, 8,9,10 have CO2 emissions less than 352,000kg/yr. Thus it could be concluded that the load and capital cost of the HRES has a direct effect on the CO_2 emissions. The social factor considered in this study is the Job creates due to the adoption of HRES to the university building at Warrnambool. Employment created by photovoltaic adoption is considered in jobs per MW of peak power [24]. Figure 6.12 shows the NPC and jobs created the best solution for each sensitivity case. Job creation is a maximum of 6.8392 for sensitivity case 15. This concludes higher the value of load with larger HRES utilization, larger the number of jobs created.

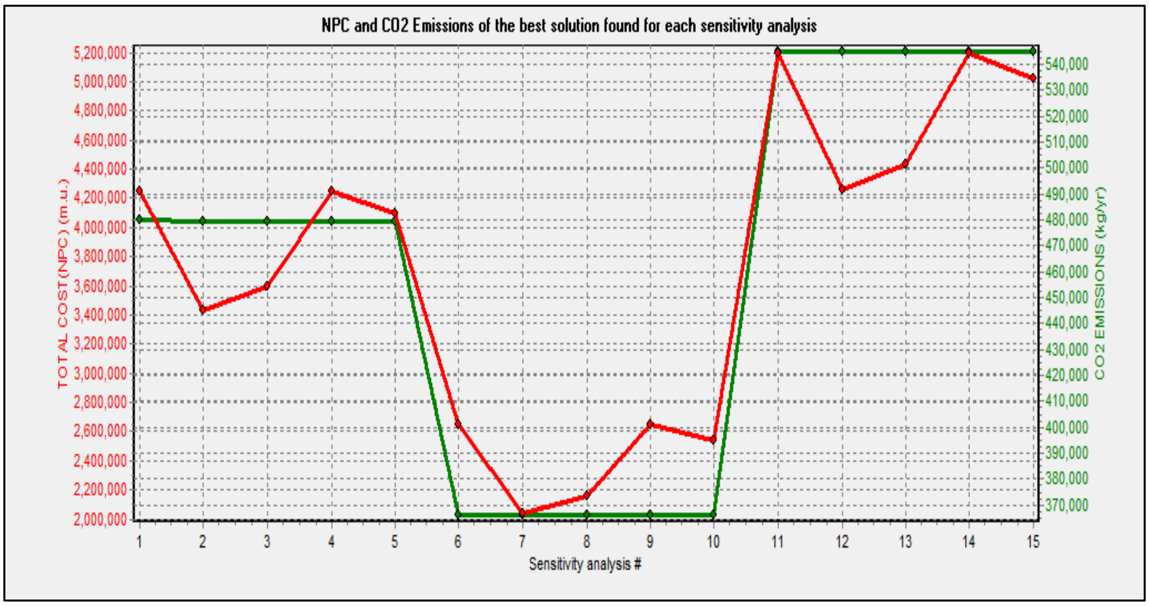


Figure 6.11 NPC and CO_2 emissions for all the different cases

Table 6.4 Results of all sensitivity cases with least value of NPC

Load (kWh/d)	Sensitivity multiplier			NPC (A$)	Emission. CO_2(kg/yr)	Renewable Energy Penetration	LCOEA$/ kWh)	Jobs creation
	Pr.PV(x)	Pr.W.T.(x)	Pr.Bat (x)					
6916.59	1	1	1	4236999	464573	60	0.11	5.9247
	0.5	0.5	0.5	3426688	464573	60	0.09	5.9247
	0.5	1	1	3578185	464608.31	60	0.09	5.9307
	1	0.5	1	4237483	464591	60	0.11	5.9277
	1	1	0.5	4085608	464573	60	0.11	5.9247
5187.45	1	1	1	2644606.75	351353.59	60.03	0.09	4.4727
	0.5	0.5	0.5	2031287.62	351210.41	60	0.07	4.4398
	0.5	1	1	2145821.75	351248.59	60.01	0.08	4.4488
	1	0.5	1	2639946.5	351223.19	60	0.09	4.4428
	1	1	0.5	2526137.5	351248.59	60.01	0.09	4.4488
7954.07	1	1	1	5188095	529851.38	60.02	0.12	6.846
	0.5	0.5	0.5	4250446	529610.62	60	0.1	6.81
	0.5	1	1	4427341.5	529931.88	60.03	0.1	6.858
	1	0.5	1	5190954	529972.81	60.03	0.12	6.864
	1	1	0.5	5013257	529872.31	60.02	0.12	6.849

The relationship between the NPC and RE penetration as shown in Figure 6.13. The RE constraint for the analysis was kept to a minimum of 60%. The system with maximum RE penetration is for Sensitivity 2 with 60.03%. The NPC of the system is the A$3.42M. This implies prices of PV and battery helps in the larger utilization of solar energy and thus improving the RE penetration. The RE penetration is least of 60% for sensitivity cases 4,5,6,11,12. When sensitivity 1 and 11 are considered, the NPC's increase with the load which is due to the size of the HRES needed to meet the load criteria. However, smaller the load, smaller the HRES size required a hence smaller number of Jobs will be created, this is observed in sensitivity cases 6, 7, 8,9,10.

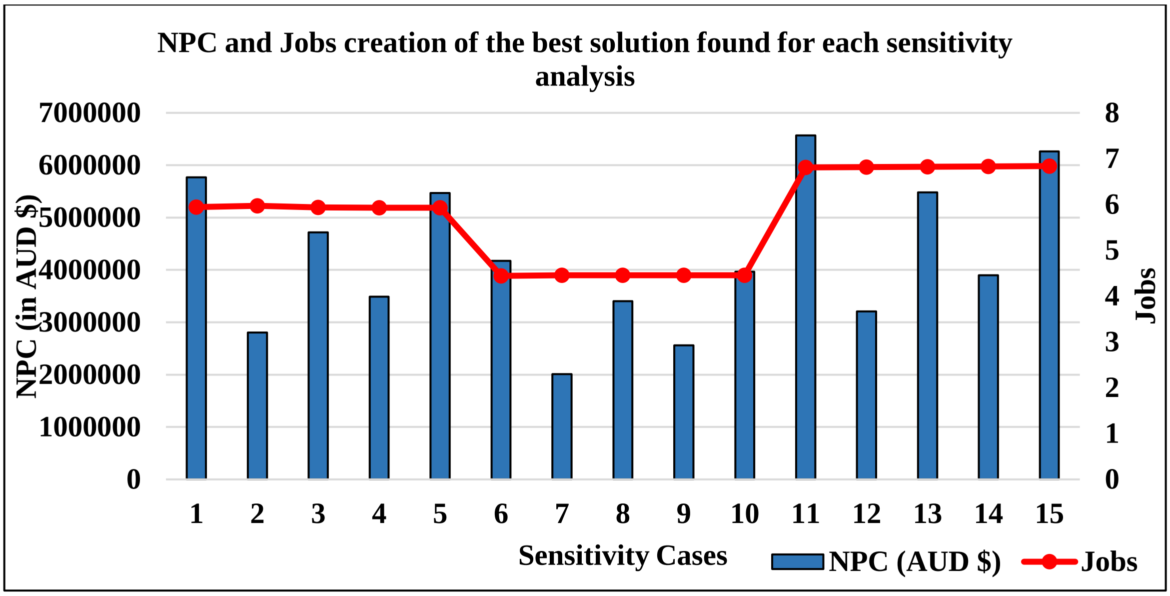


Figure 6.12 NPC and Jobs creation for different sensitivity cases.

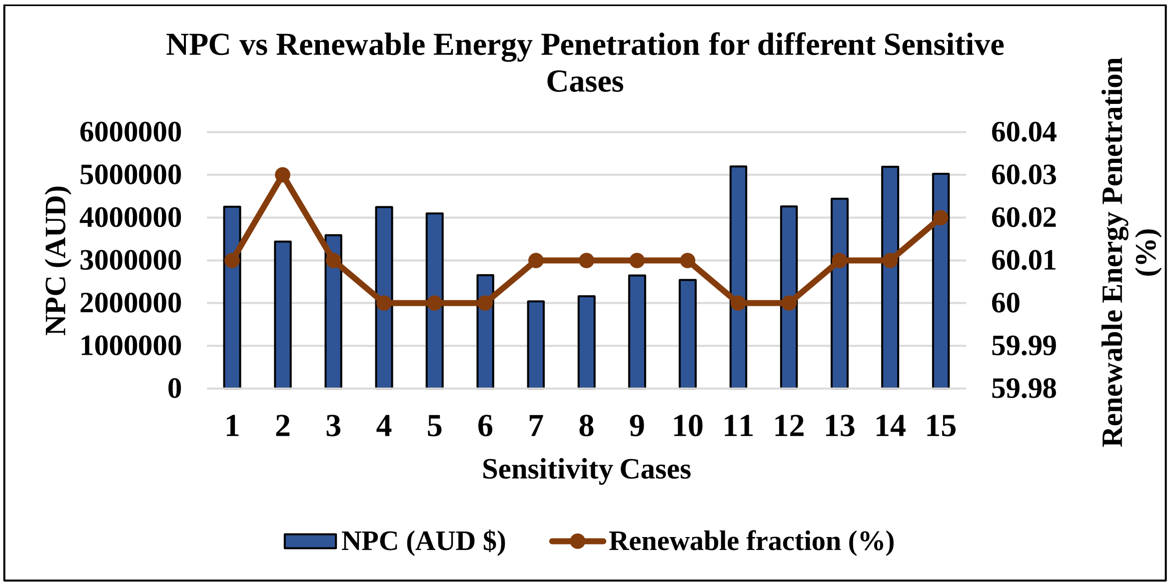


Figure 6.13 NPC and Renewable energy penetration for different sensitivity cases

6.2.2.4 Discussion of results from TBL analysis for a university building in Warrnambool

From the TBL analysis it could be concluded that if NPC is considered as the prime factor to decide the economic viability, it is understood that other than the load capacity, the acquisition cost plays a crucial part. However, HRES with smaller NPC has smaller job creations. This implies a balance between these factors is necessary to decide the best HRES as all the three factors crucial affect the community to adopt HRES. It is also observed as the market price of the HRES drops to 50% of the current price, the COE reduces at least by A$0.02/kWh for all the loads considered. The LCOE from HRES is larger than the power purchased from the electricity grid. However, the LCOE from the HRES is comparable with the grid power purchase price and it is considerably smaller than the grid purchase price. This suggests that there is a larger scope to improve on RE adoption from Australia's perspective. However, the capital cost of the HRES plays a critical role in easy RE adoption. Hence there is a necessity for further rebates to be provided to aid in RE adoption. Other than financial challenges, the much prevalent are the constant changes in energy policies, this one of the biggest challenges or hurdles for any university like building to adopt from RE. The constant revision of FiTs, which makes the tariffs to drop to a very low marginal value, is another demotivating factor for RE adoption. However, there is a constant drive by energy utility companies to initiate in RE adoption which is considered an important factor to weigh. This study clearly examines the possible HRES adoption and its impacts by performing TBL for a university building in Warrnambool, Australia. There is definitely a compromise between the least CO_2 emitted system and the cost of HRES system. This critical relationship between the economic environmental and social factors has been thoroughly studied for different options and the results are critically examined.

6.3 Sensitivity Analysis of HRES using iHOGA software

This section of study includes how the sensitivity factors like the average wind speed, inflation rate. Considering the stochastic behaviour of the RE and the inflation rate having a significant variation especially in a developing country like India, this analysis has been done. The impact on the economic outlook for Aralvaimozhi and Warrnambool case study has been done in this section using iHOGA software.

6.3.1 Aralvaimozhi

Considering the same HRES set up considered in the Section 5.3 in Chapter 5, the sensitivity analysis has been done for Aralvaimozhi community using iHOGA software. The sensitivity cases includes:

- Wind Speed: Base case of 7.18m/s
- Wind speed: Base case x Scale factor 0.95= 6.83m/s
- Wind speed: Base case x Scale factor 1.05= 7.54m/s
- Average Daily solar radiation on the surface of the PV panel: Base case 3.67kWh/m^2
- Average Daily solar radiation on the surface of the PV panel: Base case x Scale factor 0.95= 3.49kWh/m^2
- Average Daily solar radiation on the surface of the PV panel: Base case x Scale factor 1.05= 3.86kWh/m^2
- Inflation rate: Base case of 7.13%
- Inflation rate: 6%
- Inflation rate: 5%
- Inflation rate: 4%

The inflation rate considered is the range of inflation rate observed between the year 2017-2018 in India. Hence considering the above set of variables 3*3*4=36 cases by evaluating 153475 cases the results were tabulated by iHOGA software. The summary of the analysis has been presented in the Figure 6.14 and Table 6.5.

Figure 6.14 shows the variation of NPC and CO_2 emissions for 36 cases. It is observed that NPC and CO_2 emissions of the best solutions of different sensitivity cases are inversely related. As NPC increases, the corresponding values of CO_2 emissions decreases. This is prominent in sensitivity cases 5,6,8,9,12,13,14,15,16,22,25,28,33. However, when the NPC of all the sensitivity cases are considered, NPC value is maximum with the value larger than INR63,000 for sensitivity cases 17-20. Similarly, NPC value is smaller with the value less than INR1,200 for sensitivity cases 33-36.

NPC is maximum for the sensitivity case 17 with the value of INR6,372,845 while the CO_2 emission for this Case is 188,510kgCO_2/yr while the NPC is minimum for the sensitivity case 36 with the CO_2 emission of 158349.59kgCO_2/yr. Similarly, CO_2

emission is maximum of 203,437.7kgCO_2/yr for sensitivity case 17 while the CO_2 emission is minimum for Cases 33, 34 and 36 with the value of 158349.6gCO_2/yr.

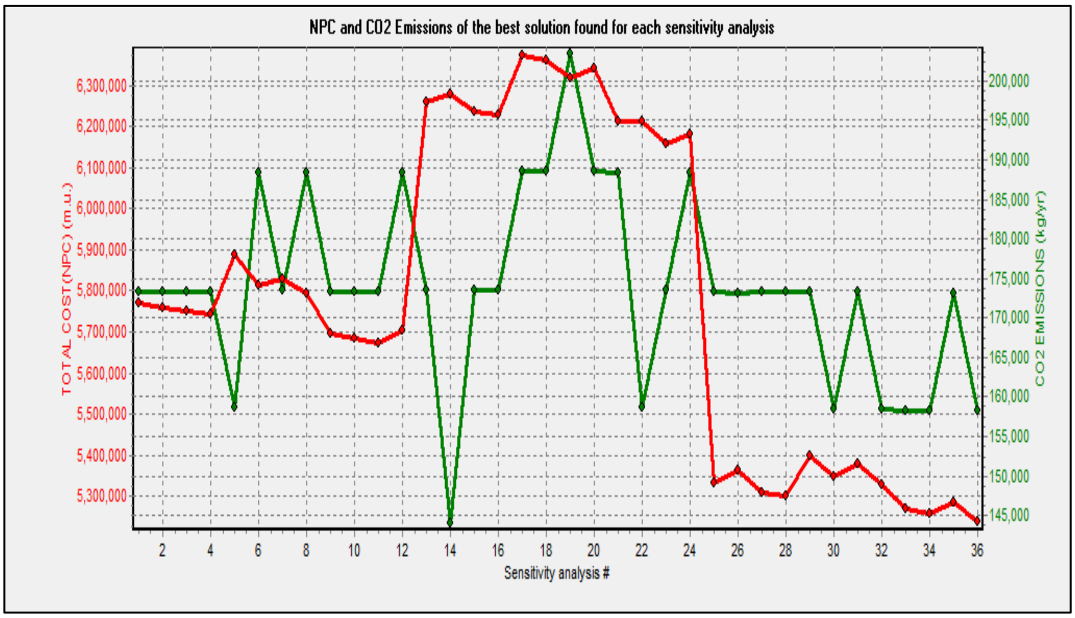


Figure 6.14 NPC and CO_2 Emission for all the sensitivity cases

From Table 6.5 it is observed that the NPC, CO_2 emissions and inflation rate of are related to each other. For any value of wind speed and average solar radiation, for a large value of inflation rate of 7.13%, NPC is larger. This is observed in cases 1, 5,9,13,17,21,29, 33. However, for sensitivity cases 25-28, the NPC is maximum when the inflation is 6%. This is due to the fact that the RE penetration of the corresponding sensitivity case is maximum compared to RE penetration for sensitivity cases 25, 27 and 28.

Considering the NPC, RE penetration and COE of the HRES, for any definite value of wind speed and average solar radiation, as the RE increases, the COE and thus the NPC value increases. However, these values NPC, RE penetration and COE also depend on the inflation rate. For a smaller value of inflation rate; the NPC and COE is smaller as observed in sensitivity cases 4,8,12,16, 28, 32, 36. Although for sensitivity cases 20 and 24, when the inflation rate is smaller, the COE is larger compared to its corresponding sensitivity cases, this is due to the larger value of RE penetration.

Table 6.5 Sensitivity results for all the cases

Sensitivity Case	Wind Speed (m/s)	Average Solar Radiation (kWh/m^2)	Inflation rate (%)	NPC (INR)	Emissions ($kgCO_2/yr$)	Renewable Energy Penetration (%)	COE (INR/kWh)
1	7.19	3.68	7.13	5771766.5	173412.7	70.25	5.75
2	7.19	3.68	6	5760257.5	173412.7	70.25	5.74
3	7.19	3.68	5	5750479	173412.7	70.25	5.73
4	7.19	3.68	4	5741111	173412.7	70.25	5.72
5	7.19	3.49	7.13	5887117.5	158741.59	70.05	5.86
6	7.19	3.49	6	5812730	188360	70.01	5.79
7	7.19	3.49	5	5829707.5	173441.2	70.26	5.81
8	7.19	3.49	4	5793620	188360	70.01	5.77
9	7.19	3.86	7.13	5694222	173392.2	70.2	5.67
10	7.19	3.86	6	5682725	173392.2	70.2	5.66
11	7.19	3.86	5	5672956	173392.2	70.2	5.65
12	7.19	3.86	4	5704333	188281.7	70.19	5.68
13	6.83	3.68	7.13	6258676.5	173626.3	70.04	6.23
14	6.83	3.68	6	6277680.5	144028.5	70.09	6.25
15	6.83	3.68	5	6237284	173626.3	70.04	6.21

16	6.83	3.68	4	6227872	173626.3	70.04	6.2
17	6.83	3.49	7.13	6372845.5	188510.09	70.22	6.35
18	6.83	3.49	6	6361290	188510.09	70.22	6.34
19	6.83	3.49	5	6319663.5	203437.7	70.01	6.29
20	6.83	3.49	4	6342071	188510.09	70.22	6.32
21	6.83	3.86	7.13	6213299	188446.09	70.22	6.19
22	6.83	3.86	6	6211990.5	158743.09	70.04	6.19
23	6.83	3.86	5	6156026	173586.7	70.07	6.13
24	6.83	3.86	4	6182584	188446.09	70.22	6.16
25	7.54	3.68	7.13	5331573	173281.5	70.02	5.31
26	7.54	3.68	6	5363691.5	173208.5	70.44	5.34
27	7.54	3.68	5	5310391	173281.5	70.02	5.29
28	7.54	3.68	4	5301066.5	173281.5	70.02	5.28
29	7.54	3.49	7.13	5400170	173281.5	70.15	5.38
30	7.54	3.49	6	5348607.5	158441.3	70.03	5.33
31	7.54	3.49	5	5378967.5	173281.5	70.15	5.36
32	7.54	3.49	4	5329497	158441.3	70.03	5.31
33	7.54	3.86	7.13	5269023.5	158349.59	70.25	5.25

34	7.54	3.86	6	5257549.5	158349.59	70.25	5.24
35	7.54	3.86	5	5283502.5	173209.2	70.3	5.26
36	7.54	3.86	4	5238458	158349.59	70.25	5.22

Considering the wind speed, average solar radiation and RE penetration values, it is observed that, when the wind speed value is kept constant and average solar radiation value is varied, the RE penetration is negligible. This implies there is a very small impact on the RE penetration with a small variation in average solar radiation, this is observed between sensitivity cases 1 -12; 13 -24 and 25-36. When sensitivity cases 1 and 25 are compared with sensitivity case13, as the value of average wind speed decreases, the RE penetration also decreases. RE penetration is maximum of 70.26% for sensitivity case 7 and the RE penetration value is least of 70.01% for sensitivity cases 6,8 and 19.

When the inflation rate, COE and RE penetration is considered, as the inflation rate decreases the COE decreases. For a maximum and minimum values of inflation rate 7.13% and 4%, the COE is maximum in Cases 1,5,9,13,17,21,25,29 and 33 corresponding to minimum COE in Cases 4,8,12,16,20,24,28,32and 36. Thus it can be concluded that, the RE availability and inflation rate for a given location has a greater impact on the economics of the HRES.

6.3.2 Warrnambool

Considering the same HRES set up considered in the Section 5.4 in Chapter 5, the sensitivity analysis has been done for Aralvaimozhi community using iHOGA software. The sensitivity cases includes:

- Wind Speed: Base case of 5.96m/s
- Wind speed: Base case x Scale factor 0.95=5.66m/s
- Wind speed: Base case x Scale factor 1.05= 6.25m/s
- Average Daily solar radiation on the surface of the PV panel: Base case 4.11kWh/m^2
- Average Daily solar radiation on the surface of the PV panel: Base case x Scale factor 0.95= 3.91kWh/m^2
- Average Daily solar radiation on the surface of the PV panel: Base case x Scale factor 1.05= 4.32kWh/m^2
- Inflation rate: Base case of 2.1%
- Inflation rate: 1.9%
- Inflation rate: 1.8%
- Inflation rate: 1.5%

The inflation rate considered is the range of inflation rate observed between the year 2017-2018 in Australia. Hence considering the above set of variables 3*3*4=36 cases by evaluating 1189,800 cases the results were tabulated by iHOGA software. These set of results have been discussed below.

Figure 6.15 shows the variation of NPC and CO_2 emissions for 36 cases. It is observed that NPC and CO_2 emissions of the best solutions are inversely related. As NPC increases, the corresponding values of CO_2 emissions decreases. NPC is maximum for the sensitivity case 17 with the value of A$4,321,548 while the CO_2 emission for this case is 497946kgCO_2/yr. Similarly, NPC is minimum of A$4,147,372 for the sensitivity case 36 with the CO_2 emission of 461,642kgCO_2/yr. Similarly, CO_2 emission is maximum of 467,927kgCO_2/yr for sensitivity case 29 while the CO_2 emission is minimum for sensitivity case 36 with the value of 461,607kgCO_2/yr.

From Table 6.6 it is observed that the NPC, CO_2 emissions and inflation rate of are related to each other. For any value of wind speed and average solar radiation, for a large value of inflation rate of 2.1%, NPC has a larger value. This is observed in Cases 1, 5,9,13,17,21,29, 33.

Considering the NPC, RE penetration and COE of the HRES, for any definite value of wind speed and average solar radiation, there is no much of variation in COE and RE penetration. The COE and RE penetration of almost all the sensitive cases are approximately in the range of 60%. Thus, the COE for all the cases are 0.11A$/kWh. This is due to the fact that the Australian economy is stable when the variation of inflation rate is observed (when compared to India). Sensitivity case 8 has the maximum RE penetration of 60.03%.

For a smaller value of inflation rate; the NPC and RE penetration is smaller as observed in sensitivity cases 4,16,20,32,36. Although for sensitivity cases 24 and 28, when the inflation rate is smaller, the NPC is larger compared to its corresponding sensitivity cases, this is due to the larger value of RE penetration.

Considering the wind speed, average solar radiation and RE penetration values, it is observed that, when the wind speed value is kept constant and average solar radiation value is varied, the RE penetration is negligible. This implies there is a very small impact on the RE penetration with a small variation in average solar radiation, this is observed between sensitivity cases 1 -12; 13 -24 and 25-36. When sensitivity cases 1 and 25 are compared with sensitivity case 13, as the value of average wind speed decreases, the RE penetration is does not change and it remains to be 60.2%. This implies, there is no impact of wind speed on the RE penetration. However, RE penetration value id dependent on the solar radiation , as all these sensitive cases include only PV penetration and not WT. Re penetration is maximum 60.03% for sensitivity cases 8,19 and the RE penetration value is least of 60% for sensitivity cases 3-7,9,16,20,22,23,27,30-33, 35 and 36. From these discussions it can be concluded that, the RE availability and inflation rate for a given location has a greater impact on the economics of the HRES.

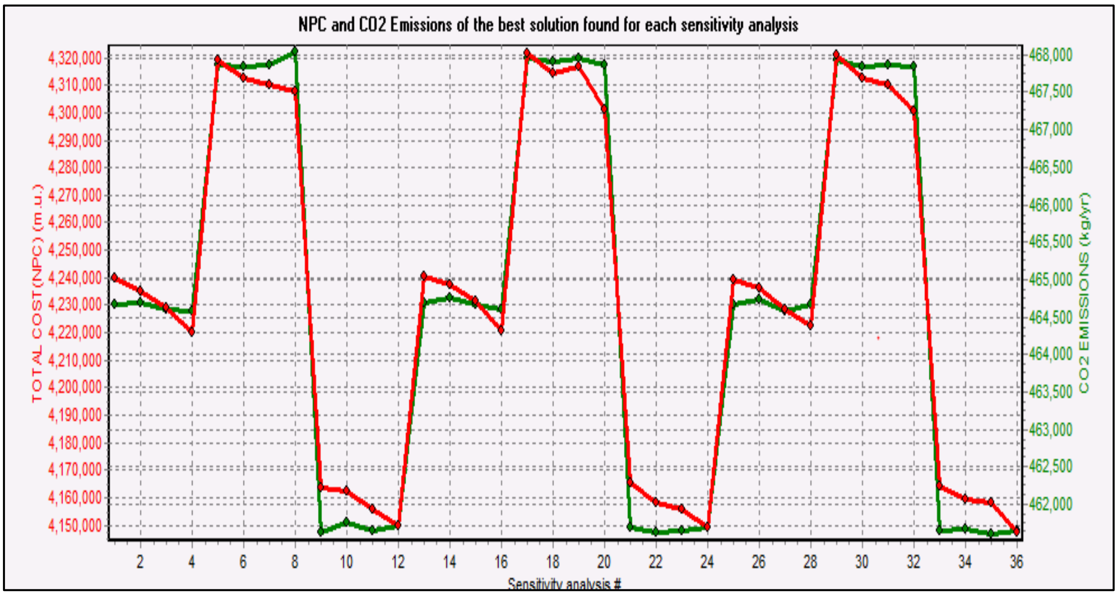


Figure 6.15 NPC and CO_2 Emission for all the sensitivity cases

6.4 Conclusion

This chapter deals with the variety of sensitivity cases that could impact the economics of the HRES. The discussion for sensitive cases included the probable changes in market price of the HRES, the load, variation in the available energy and inflation rate of the location. It is observed that, the market price and the load influence the economics of the system to a larger extent. However, when the inflation rate is considered as a variable, India, a developing country is changing constantly, this shows the growing economic gains that India is experiencing unlike Australia. There is a larger influence in the economics of the system in Indian scenario and this is very much evident from the different cases discussed for India. In contrast, Australia's economic stability is well noticed in the mostly constant inflation rate. Hence there is not much impact on the economics of the HRES. Although this chapter concentrates on the influence of these sensitivity variables, techno-economic and environmental aspect has been summarised briefly. This chapter concludes with the knowledge of the different scenarios that the two case study areas may experience, and if in case it experiences, their impacts have been clearly dealt with.

Table 6.6 Sensitivity results for all the cases

Sensitivity Case	Wind Speed (m/s)	Average Solar Radiation (kWh/m^2)	Inflation rate (%)	NPC (A$ A$)	Emissions ($kgCO_2/yr$)	Renewable Energy Penetration (%)	COE (A$/kWh)
1	5.96	4.12	2.1	4240099	464677	60.02	0.11
2	5.96	4.12	1.9	4234970.5	464694.91	60.02	0.11
3	5.96	4.12	1.8	4228849.5	464591	60	0.11
4	5.96	4.12	1.5	4219916.5	464573	60	0.11
5	5.96	3.91	2.1	4318896	467855.69	60	0.11
6	5.96	3.91	1.9	4312454	467837.19	60	0.11
7	5.96	3.91	1.8	4310003	467855.69	60	0.11
8	5.96	3.91	1.5	4307878.5	468036.59	60.03	0.11
9	5.96	4.33	2.1	4163540	461624.5	60	0.11
10	5.96	4.33	1.9	4162270.25	461759.91	60.02	0.11
11	5.96	4.33	1.8	4155907	461658.31	60.01	0.11
12	5.96	4.33	1.5	4149944	461724.5	60.02	0.11
13	5.66	4.12	2.1	4240756.5	464694.91	60.02	0.11
14	5.66	4.12	1.9	4237589.5	464745.81	60.02	0.11
15	5.66	4.12	1.8	4231453	464677	60.02	0.11
16	5.66	4.12	1.5	4220692.5	464608.31	60	0.11
17	5.66	3.91	2.1	4321548	467946.19	60.01	0.11

18	5.66	3.91	1.9	4314590	467909.81	60.01	0.11
19	5.66	3.91	1.8	4316876	467943.59	60.03	0.11
20	5.66	3.91	1.5	4301296.5	467855.69	60	0.11
21	5.66	4.33	2.1	4165621.75	461690.81	60.01	0.11
22	5.66	4.33	1.9	4157922.5	461624.5	60	0.11
23	5.66	4.33	1.8	4155599	461642	60	0.11
24	5.66	4.33	1.5	4148980.75	461690.81	60.01	0.11
25	6.26	4.12	2.1	4239436.5	464659.59	60.01	0.11
26	6.26	4.12	1.9	4236290	464731.09	60.02	0.11
27	6.26	4.12	1.8	4228368	464573	60	0.11
28	6.26	4.12	1.5	4222328.5	464659.59	60.01	0.11
29	6.26	3.91	2.1	4321211.5	467926.91	60.01	0.11
30	6.26	3.91	1.9	4312454	467837.19	60	0.11
31	6.26	3.91	1.8	4310003	467855.69	60	0.11
32	6.26	3.91	1.5	4300807	467837.19	60	0.11
33	6.26	4.33	2.1	4163998.5	461642	60	0.11
34	6.26	4.33	1.9	4159347.5	461674.31	60.01	0.11
35	6.26	4.33	1.8	4158451.75	461607.19	60	0.11
36	6.26	4.33	1.5	4147372.5	461642	60	0.11

Chapter 7

Experimental Study of a prototype HRES at Victoria University Footscray Campus: Part 1

7.1 Introduction

There are usually two ways in which RES are connected into a micro-grid to meet the desired load of a location. It is often observed that, off-grid systems are commonly used to meet the load demands in places like islands or villages [133, 134]. This is due to the complications involved in drawing energy from the grids. In these locations, a storage setup like a battery is typically used to store energy and meet the energy demand in the absence of RE. However, some literature also discusses grid connected RES [63, 135]. The battery connected to the grid system is not sighted much in the buildings or residences of countries like India and Australia. This concept of micro-grid has already been explained in Chapter 2. The current chapter discusses the practical implementation of a micro-grid setup. In the Australian scenario, South Australia's initiative to exploit the available RE using a Tesla battery bank has revolutionized the concept of RE connected to the grid through battery [136]. However, such initiatives have not been sighted as yet for the Indian scenario. Although, there are many solar and wind farms connected to the grid to exploit the available solar and wind energies.

This chapter summarises the experimental study of HRES conducted at VU Footscray Campus. The location of the campus is shown in Figure 7.1. This study is divided into three parts:

i. Preliminary study of the available resources.
ii. Detailed description of the upgraded HRES set up.
iii. Study of the HRES setup with measurements and calculations performed.

Currently, the utility grid supplies energy to the campus and helps meet its energy demands. Considering the fact of large-scale energy consumption and bulk electricity bills, this study would help to foresee the viable alternatives. This particular campus of VU was selected due to the convenience of procuring the electricity bills and thus helping in understanding the load demand.

VU Footscray Campus is the largest of the 10 campuses in the state of Victoria. This campus provides all the basic amenities for students and researchers, it provides other facilities like children's center, cafes, cafeterias, aquatic and fitness center etc. The location of the campus, the big campus terrace available and campus facing the North-South direction; all these factors make it a perfect choice for installing solar panels. The electricity bills were analyzed for one complete year (March 2015 to April 2016), this is shown in Figure 7.2.

Figure 7.1 - Schematic and Google Earth view of Victoria University, Footscray, Melbourne

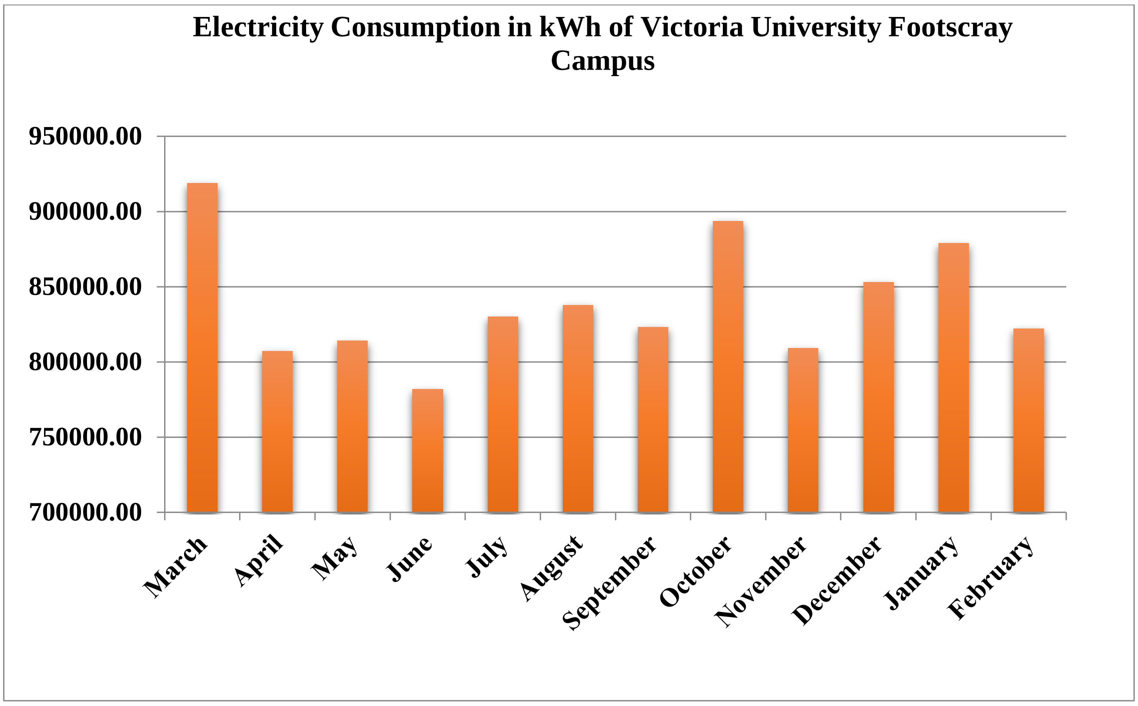


Figure 7.2 - Electricity Consumption in kWh of Victoria University, Footscray, Melbourne

In the month of March and October when student activities are maximum, there is a peak electricity consumption of 918,762.09 kWh and 893,460.7kWh respectively. However, during the summer seasons (December to March) due to the presence of air conditioner the electricity consumption is high. The average consumption of electrical energy for a year on this campus is 839,077 kWh. Hourly electricity consumption of VU on a typical day is shown in Figure 7.3. The hourly energy consumption trend provides the university working hours (9a.m to 5p.m) exactly coinciding with the peak electricity consumption on a typical day.

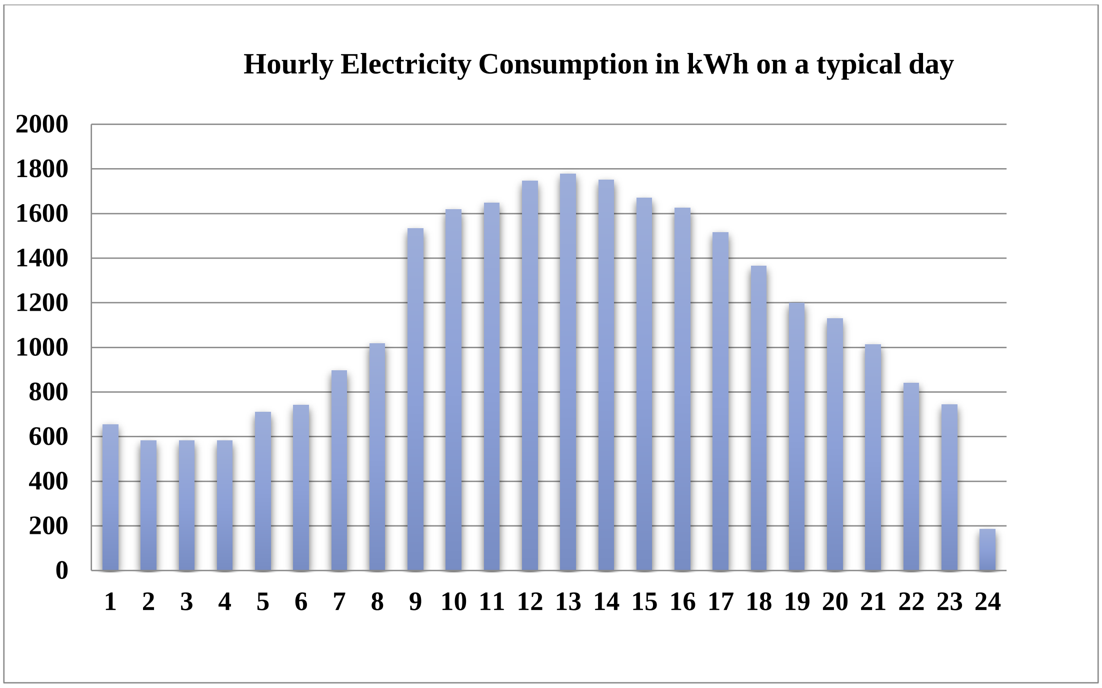


Figure 7.3 - Hourly Electricity Consumption in kWh on a typical day

7.2 Part 1: Preliminary Study of the performance of HRES system connected to the Grid

The preliminary study of HRES explained in this section considers the pre-existing PV and WT setup connected directly to the grid without battery storage facility. This HRES at VU included PV and WT intended for studying residential applications. The main factors that affect the amount of electricity generated depend primarily on the total solar radiation on the PV array and wind speed. The HRES had a PV array with an output power of 1.5kW and a wind generator with a rated output power of 3.0kW. A short note on their working and the technical specifications are introduced in this section. The detailed analysis of this configuration of the system is not relevant for the present case study and it is not presented here.

The technical specification of VU WT and PV are shown in Table 7-.1 and Table 7.2 respectively. The 1.5kW PV was connected to the VU grid through Aurora PVI-2000AU inverter shown in the Figure 7.4. The technical specification of the inverter is summarised in the Table 7.3. The WT was connected to the grid. The complete system performance can be analysed by Power-One software (from the inverter shown in Figure 7.5).

Table 7.1 Technical Specification of the WT installed at VU

Rated Power	3000W
Voltage	3 Phase, 380V
Rotor Diameter	3 m
Blade Height	3.6 m
Rotor Speed	150 m/s
Wind Energy Utilization	30 %
Rated Wind Speed	9-11 m/s
Start Up Wind	3 m/s
Survival Wind Speed	50 m/s

Table 7.2 Technical Specification of the PV 1.5kW PV installed at VU

Power Rating A.C.	1.5kW
Absolute Maximum Voltage Range (V D.C.)	0 to 600 (360 nominal)
Max. Power Tracking Window Range (V D.C.)	90 to 580 (360 nominal)
Array Configuration (Max. I D.C.=10A For Each Channel)	ONE ARRAY
NOMINAL A.C. VOLTAGE (RANGE) (V Rms)	SINGLE-PHASE 185-264
Nominal Ac Frequency (Hz)	50/60
Line Power Factor	1
MAXIMUM A.C. LINE CURRENT (A RMS)	9
Ac Current Distortion (%)	< 2.5% At Rated Power With Sine-wave Voltage
Maximum Efficiency (%)	96
TARE LOSS[Mw]	<300
Operating Ambient Temperature (°C)	-25 to +55
Enclosure Environmental Rating	IP21/NEMA 2
Relative Humidity	0-95% non-condensing
Elevation	DERATED ABOVE 6,600ft (2000m)
Audible Noise [Dba]	<30 @ 1m
Size (Height x Width x Depth) [mm]	440 x 465 x 57
Weight(kg)	6

Figure 7.4 Inverter connected to PV modules (Aurora PVI-2000AU)

Table 7.3 Technical specifications of the Aurora Inverter

Nominal Output Power	3600W
Grid Voltage Maximum Range	183 to 304 Vac
Max. Recommended Dc Power Input	4150W
Nominal Dc Power Input	3750W
Grid Frequency Nominal	60 Hz
Maximum Efficiency (%)	96.8%
Operating Ambient Temperature (°C)	-25 to +60
Casing Protection Rating	IP65/NEMA 4X
AUDIBLE NOISE (With Internal Fan On)[Dba]	<50 @ 1m
Size (Height X Width X Depth) [Mm]	787 x 325 x 208
Relative Humidity	0-100% Condensation Point
Weight(kg)	18

Figure 7.5 Inverter connected to a WT (Aurora PVI 3.6-Outd-AU-W)

The total performance of the HRES connected to the VU grid is shown in Figure 7.6. The maximum daily power produced by the whole system is less than 2kW, this means that the power output of the WT is considerably minimum.

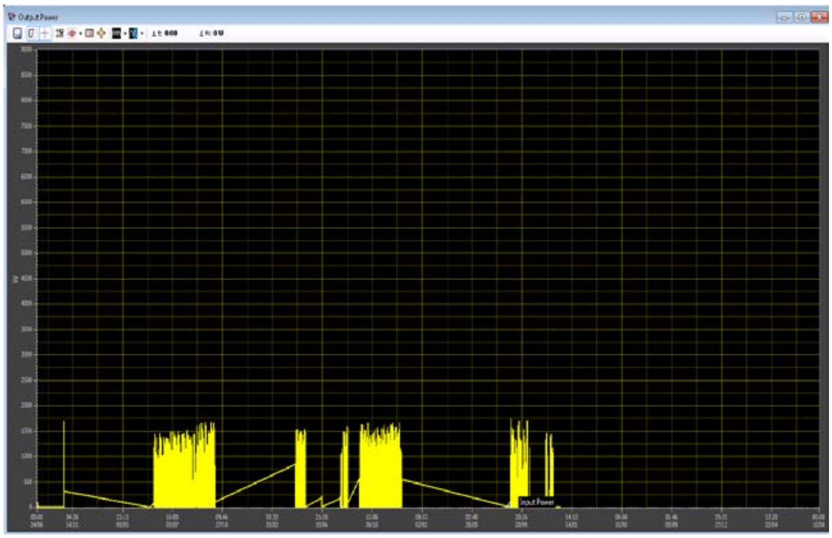


Figure 7.6 -Power output for the lifetime of the HRES system

The output power of WT and PV for the lifetime is shown in Figure 7.7 and 7.8 respectively. As understood from the earlier analysis, the output and the effciency is considerably low as compared to its technical specifications. The maximum output power of the WT has hardly touched 100W in its lifetime. The output of the PV in the lifetime matches its technical specifications. On an average, the PV output has been consitently greater than 1kW.

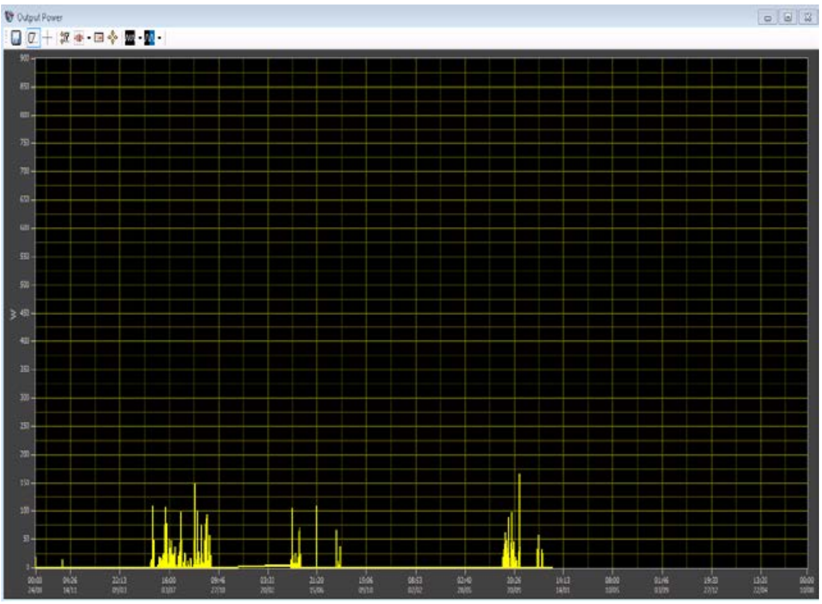


Figure 7.7 Power Output of the WT over the lifetime

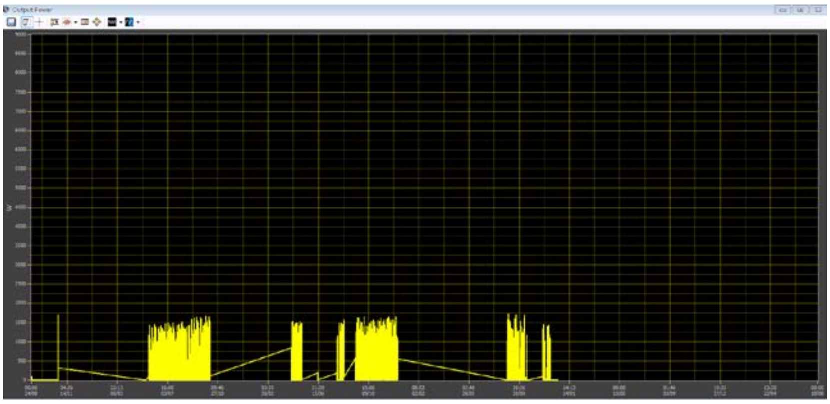


Figure 7.8 PV output Power lifetime

Figures 7.9 to Figure 7-.11 shows the HRES output for a month, and individual output of PV and WT. The output power from Figure 7.9 matches with the Figure 7.11 (the power output of the PV). However, when the power output of the WT is analysed for a month, the maximum power output reached in this duration has been approximately 130W. Thus the WT performance has been proving to be considerably low compared to its rated value.

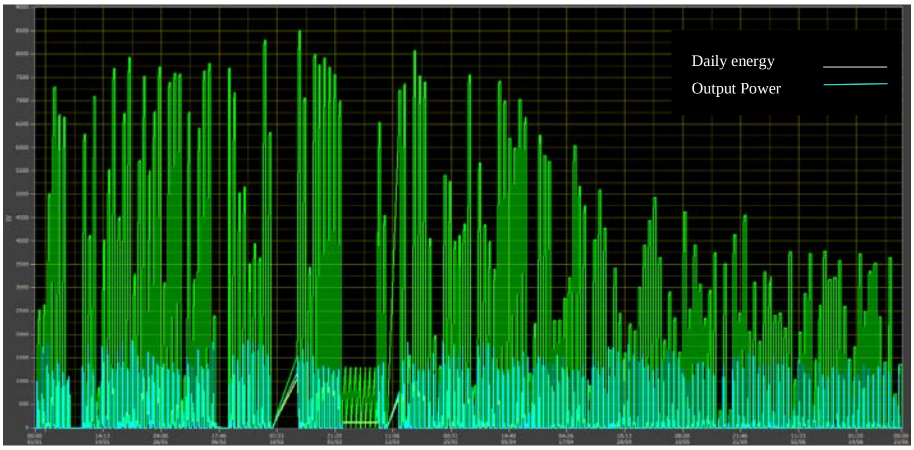


Figure 7.9 Output power and daily energy of the whole system in July, 2017

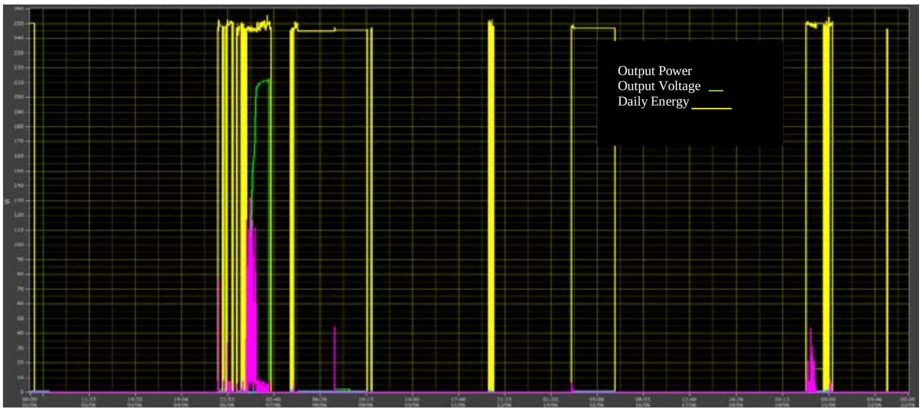


Figure 7.10 Output power for WT in July, 2017

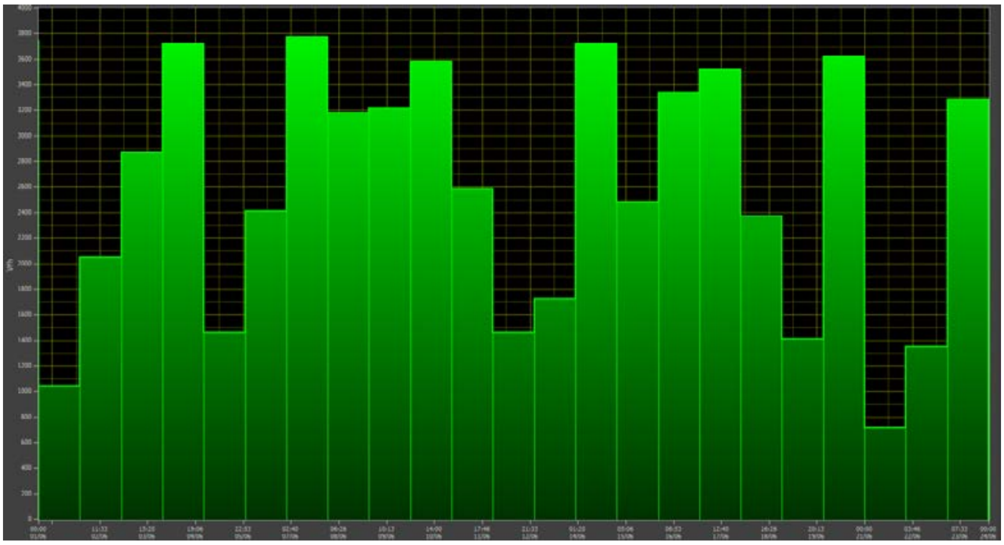


Figure 7.11 Output energy for PV array July, 2017

After extensive analysis of the graphs obtained using Power-One communicator software provided by Aurora, it could be deduced that the PV array is functioning above average and with minimal system losses, whilst the WT showed a negligible power output.

7.3 Part 2: The upgraded HRES model for the Renewable Energy Lab at VU

The HRES of VU until 2017 had the grid connected PV and WT system. The scope of the current project was to include the battery bank and load bank and thus connecting the entire setup to the grid. The existing ABB Inverters though had the grid connection compatibility, it required the voltage compatibility to introduce the battery, external load and the software to monitor the entire system. The other available off-grid unit to connect PV was obsolete and voltage incompatible. The HRES system was upgraded for the desired requirement in early 2018. It included a Schneider MPPT, Selectronic 5kW inverter and a set of new Century AGM battery bank. The existing load bank of 9kW 230V A.C. or D.C. was used. The Selectronic SP link software monitored the data which includes the Net energy used or supplied from the battery, PV output, wind power and load power. It should be noted that the PV system was upgraded from 1.5 to 2.05kW. Figure 7.12 shows the panoramic view of the Renewable Energy Lab set up. Figure 7.13 depicts the three line diagram of the newly upgraded system provided by the installer.

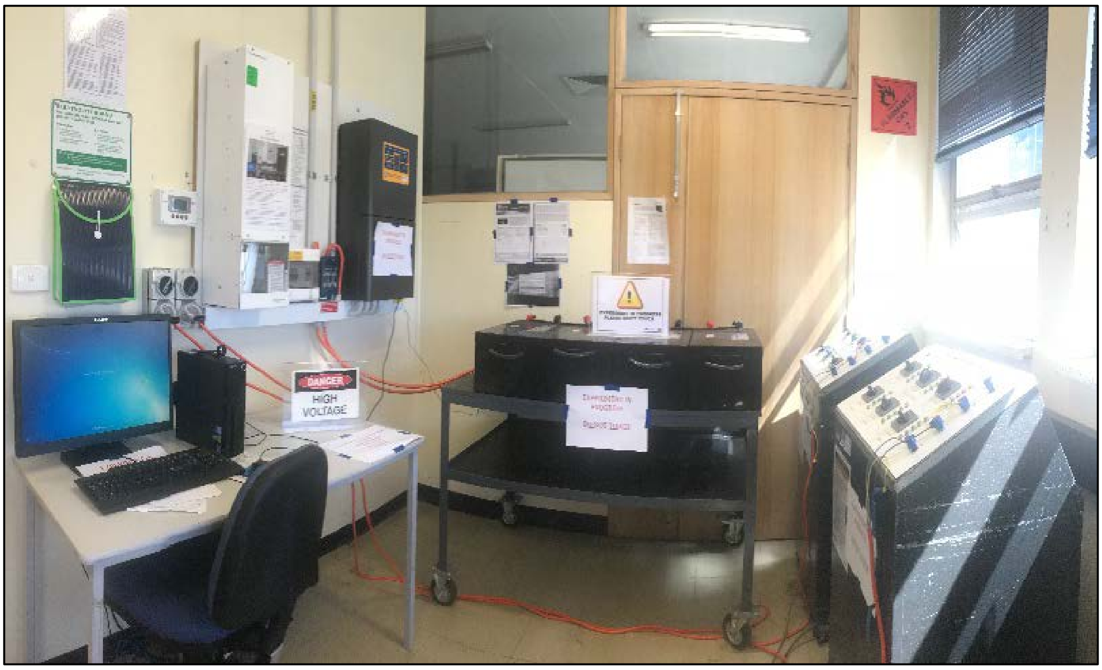


Figure 7.12 The panoramic view of the VU Renewable Laboratory setup

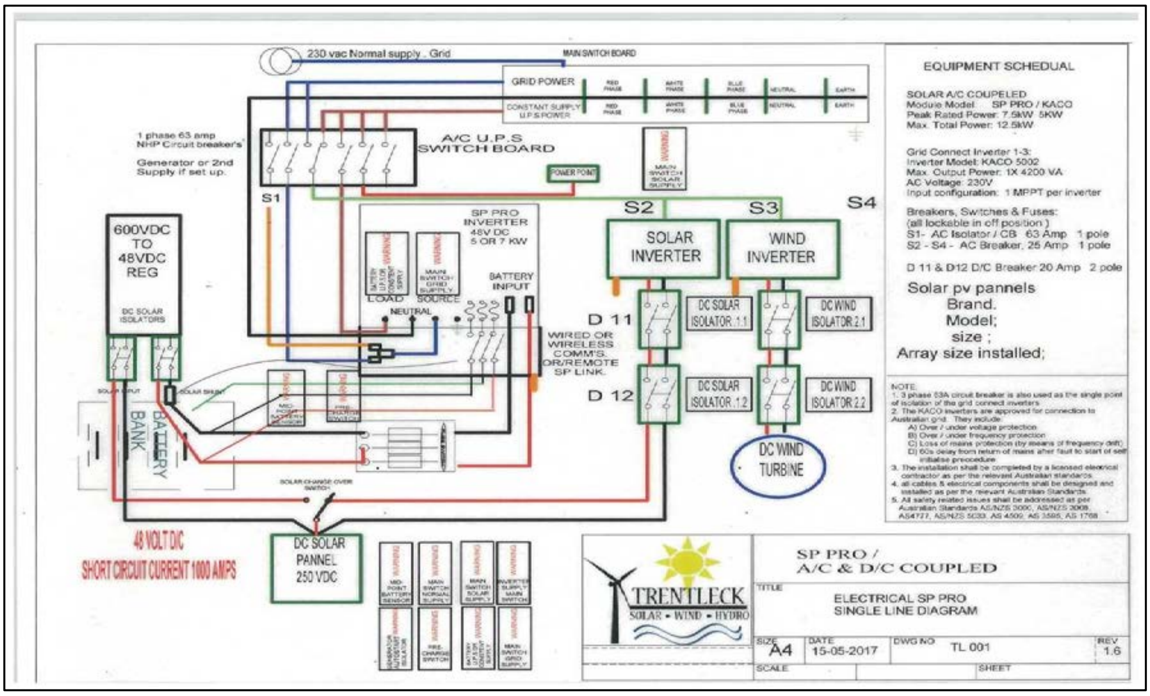


Figure 7.13 The three line diagram of the updated renewable energy system connected to the new Selectronic hybrid inverter provided by the installer, Trentleck, Australia

7.3.1 Introduction to the HRES System

The complete system except the wind turbine was updated/upgraded according to the available RES. The description of each of these components in the setup is explained below.

- Solar Panels (PV system): The solar panels were upgraded from 1.5kW to 2.05kW (275W of two panels were added to the existing 1.5kW PV) to produce enough voltage to the Selectronic inverter charger. The Figure 7.14 (a) and (b) depicts the upgraded 2.05kW PV and its location on the roof of the university building.

Figure 7.14 (a) and (b) The newly upgraded set of PV panels installed along with the pre-existing PV panels

- Wind Turbine: The 3kW rated vertical axis wind turbine is located on the terrace of the building which consists of 7 levels. The WT is shown in Figure 7.15. The rooftop is difficult to access due to its lack of safety rails along the wall.

Figure 7.15 3kW rated Wind turbine on the rooftop of Building D at VU, Footscray,Australia

❖ Conext MPPT 80 600 solar charge controller from Schneider: The Conext^{TM} MPPT 80 600 shown in Figure 7.16 (a) connects the PV array to the battery bank. It has the ability to work faster because of its usage of fewer PV strings for a larger PV array. This charge controller can be used if there is a long distance between the PV array and the charge controller. This uses a charging technology called Advanced Fast Sweep Maximum Power Point Tracking (MPPT), which helps in harnessing most of the available energy from the PV array. This works to make most of even unfavourable conditions such as partial shade. It also contains a system of display units as shown in Figure 7.16 (b) to display the PV input current and voltage and even has the option of basic and advanced settings which help in setting up the battery control voltages [137]. This Conext MPPT 80 600 is CSA certified for safety and CE marked for Low-voltage Directive (EN50178).

Figure 7.16 (a) and (b) Conext MPPT 80 600 solar charge controller and the display screen

❖ Selectronic SPMC 481 AU Inverter Charger 48 V 5kW peak: Selectronic inverter shown in Figure 7.17 (a) is a smart multi-mode inverter that helps in controlling and managing various aspects of the energy needs. The SP PRO is suitable to use for both Grid connected micro-grid and completely off-grid micro-grid purposes. It can be used in various settings such as: industrial, commercial, marine and residential. The product has been designed and manufactured in Australia. The inverter has more features than any other out of the box inverters. This inverter includes new standards for reliability, surge capacity, and power density. The SP PRO includes a built-in software SP Link software shown in Figure 7.17 (b), which helps in real-time monitoring of the data. The software also provides the facility to set and configure the system according to the user's priority. The data gets logged over time and could be retrieved, and the performance can be studied using the graphical display. SP PRO complies to the following standards: safety (Uninterruptible Power)- IEC 62040-1-1:2002/ AS 62040-1-1:2002: power converter used in PV systems: IEC 62109-1 and : IEC 62109-2; EMC (Domestic limits) EN 61000.6.3:2007; EMC (Industrial limits) EN 61000.6.4:2007; Grid connect AS 4777.2:2015; Certification- Certification of suitability CS,Ctick; Protection IP43.

Figure 7.17 (a) and (b) Hybrid 5kW Selectronic inverter and the quick display of the data from the screen when connected to the SP Link software

a. Battery storage: Four Century AGM Deep Cycle Batteries rated 12V, 270Ah each were included in the setup to provide the storage option. These batteries are prioritized to be charged by the RE (PV); when the energy from the battery drops to a specific value of SOC, the remaining energy is provided by the grid. The battery charging cycle is shown in Figure 7.18. The charging of the battery is managed by the charging system of the SP PRO inverter and priority is given to the appropriate RES and this ensures RES is used cost effectively. The battery recharges in five stages and the SP PRO monitors all the charging sources continuously. Each stage or

Charging Mode is controlled by voltage, current and time settings. Using the SP Link software the settings can be configured, however, they do not need to be updated after the initial installation. Each voltage setting is battery temperature compensated. The set values displayed do not change. The different battery charging modes are as follows [138]:Initial: At this stage, the SP PRO continues to charge the battery until the voltage increases to the point of the initial charge voltage. This voltage is maintained till such time the Bulk stage starts. At this stage, the Initial/Bulk indicator will flash.

b. Bulk : The SP PRO charges at the bulk charging current until the battery voltage rises to the bulk charge voltage, then holds this voltage for a set length of time, before starting the Absorption stage. In Bulk charge mode, the Initial/Bulk indicator will be steady ON.

c. Absorb: In the Absorption charge phase the SP PRO will charge at the absorb charge current until the absorb charge voltage is reached. Once this voltage is reached, the SP PRO will carefully monitor the rate of change of the charge current as set in the Absorb-Float transition setting. When the Absorb-Float transition setting is met, the charge cycle will switch to Float and terminate an auto start backup generator if connected. If an Equalise charge is pending, the Equalise charge cycle will now be performed. The Absorption indicator will be steady on when in the Absorption phase.

d. Float: The SP PRO holds the battery voltage at the Float level and will provide up to the float current to maintain the float voltage. The SP PRO will remain in this charge state until battery voltage falls below the Initial Return level. If the SP PRO is still connected to an A.C. Source after 24 hours of Float, the charger will transition to the Long Term Float voltage. Long Term Float voltage will allow batteries to sit at a lower voltage level indefinitely, reducing battery losses.

e. Equalise: Periodically, the SP PRO performs an equalise charge in which the battery is held at a higher voltage for a period set in the Equalise window. This will help ensure all cells within the battery bank have an equal amount of charge. The equalise indicator will be steady on when in equalise mode and will flash when an equalise is pending, that is the charger will perform an equalise after float stage is next reached.

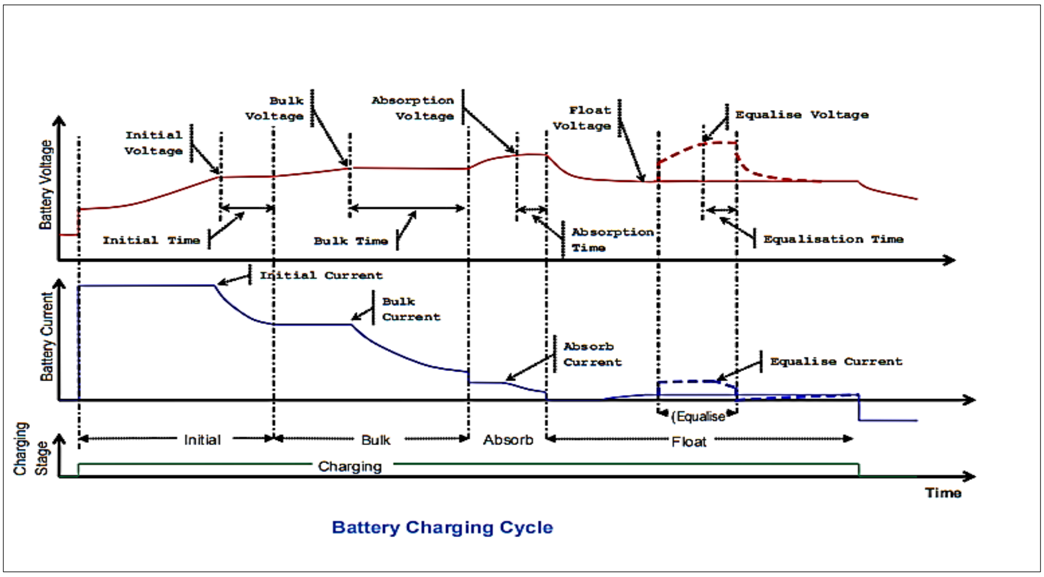


Figure 7.18 Different charging modes in the battery charging cycle [140].

❖ A.C. load bank: Rated 9kW 230V A.C. or D.C. load bank has been included in the HRES set up is shown in Figure 7-19. Power of 1.5-2kW was extracted from it. This energy of up to 2kW was met by the RE predominantly. Two of this load banks were used in this experiment.

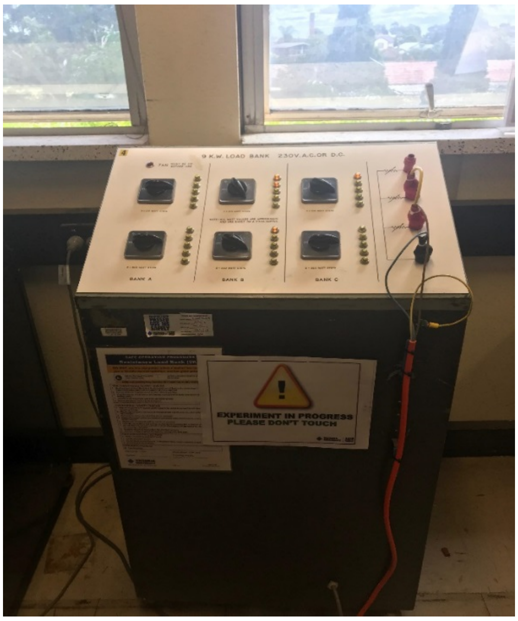


Figure 7.19 9kW 230V A.C. or D.C. load bank

7.4 Experimental analysis of HRES at VU

The HRES at VU consists of PV rated 2.05kW and 3kW (rated) vertical axis wind turbine is examined in this Section. This system was connected to the grid through a 48V 270Ah AGM batteries. The performance of each of these discrete units are described in the Sections 7.4.1 to 7.4.5.

7.4.1 Examination of Performance of solar panels

The 1.5kW solar panels which was installed earlier prior to 2015 was increased to 2.05kW capacity in 2018. The solar panels were installed on university Building D. The PV installed earlier was facing the North direction of the campus to absorb maximum sunlight. Figure 7.20 shows the performance of the PV on a typical summer day in the month of February where the availability of solar energy is maximum. The solar energy output from PV gradually increases during the day by 8a.m and produces maximum power between 11:00a.m to 2:30p.m and the power gradually subsides as the sun sets. Maximum power of 1.6kW is harnessed from the PV on a typical summer day like this. This examination clearly suggests that, harnessing solar energy using PV depends on the availability of the sun. Since the data was collected in the month of February, maximum energy has been harnessed from the available sunlight.

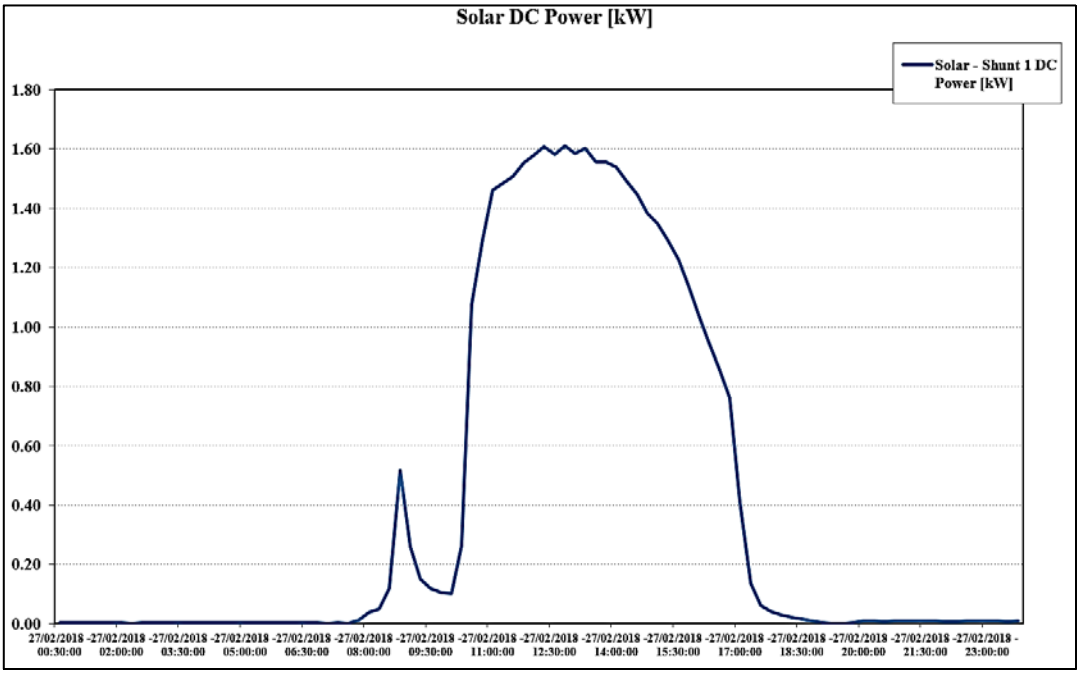


Figure 7.20 PV output recorded in the VU Renewable Energy lab with the updated PV panels

The PV output on 27.2.2018 was plotted using the available data, and is as shown in Figure 7.20. It is observed that, for a summer month like February, the PV output gradually has increased to a maximum of nearly 500W by 9:00a.m, however due to the occurrence of clouds, the output dropped to less than 200W by 10:30a.m. While there was gradual increase in the output of the PV, with a clear sky aiding the maximum utilisation of the sunlight, producing nearly 1.6kW of maximum power by noon. The total accumulated output energy from the PV by the end of the day was 9.6kWh. This is shown in Figure 7.21.

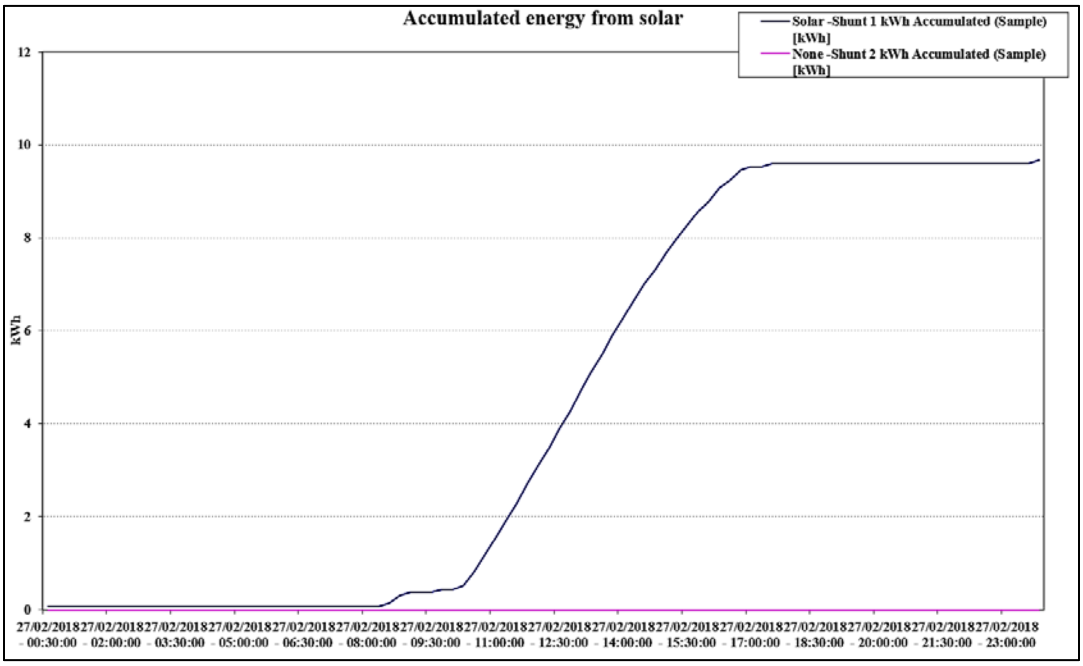


Figure 7.21 Accumulated energy from the PV panels on a day

7.4.2 Examination of Performance of Wind Turbine

From the history of WT output presented in Section 7.2, it is observed that the output of the WT from the recent past has been meagre. Hence, to understand the output of the WT as compared to its, specifications (shown in Section 7.2), a small experiment was conducted. To further validate these experimental values, the WT was assessed by an electrical contractor.

- WT Output assessment conducted using Anemometer.

An anemometer was used to note the Cut-in wind speed of the turbine blades. The instantaneous output voltage and current were measured from the output terminals of the wind turbine which was connected to the inverter earlier (discussed in Section 7.2). The power output of the WT was calculated as shown in the Table 7.4.

It can be noted that, the 3kW rated WT at the speed of 9-11m/s, have a rated conversion efficiency of 30%. This implies that, when the wind speed is 9-11m/s, the output of the WT should be 900W. From the calculated values shown in Table 7.4, the output of the WT has not crossed 100W. This can also be validated from the output of the WT being as low as 100W from the history of its output power discussed in Section 7.2 earlier.

Table 7.4 Power Output Calculations from the Wind Turbine

Wind velocity (v) m/s	V_{out} (V)	I_{out} (A)	Power output of WT (W)
1.88	247	0	0
1.9	241	0	0
3.6	207	0	0
4.83	255	0.2	51
5.38	250	0.1	25
5.7	261	0.4	104.4
6.08	256	0.2	51.2
6.86	263	0.5	131.5
7.07	262	0.5	131
7.73	261	0.4	104.4
8.06	260	0.4	104
8.71	261	0.4	104.4
9.16	261	0.4	104.4
10.98	261	0.4	104.4
11.4	261	0.4	104.4

- Assessment of WT Electrical Tests conducted by the electrical contractor

There were a set of assessments carried out on the existing WT at VU

1. Electrical Tests :
    a. Voltage specifications test: The tests conducted indicate that it is rated at 380V 3phase. Voltages tested and were within tolerances at the time of testing and at medium wind speeds.
    b. Wattage output from the Turbine: Specifications indicate that it is rated at 3000W at 9-11m/s with a startup speed of 3m/s. No wind graph was provided to indicate expected output at wind speed between 3m/s and 9m/s. Under our testing the highest wattage measured was approx. 550W, at high wind speeds.
    c. Insulation resistance test: Insulation to earth of all conductors between each active and earth show they are of sound condition. Mechanical Checks Termination circuit breaker at termination points were all checked and were

OK. Both A.C. and D.C. termination points at ABB Inverter checked and all were OK. Voltage drop estimated due to the length of cable to the ABB Inverter indicated that there would be a reasonably high voltage drop. This would equate to voltage drop and a loss of output wattage.

2. Mechanical / Structural Assessment:
   a. Mounting method: Turbine tower is Dynabolted to the concrete roof and 4 guidewires to reduce out of balance wobble. There is no method of lowering or raising the turbine to provide maintenance or to gain access to the turbines electric motor. Turnbuckles for tensioning of guidewires were found to be under the roof tin in a non-accessible location and exiting through a decktite. The turbine was found to be severely out of balance due to its poor design. Observation of severe wobble in the turbine even under moderate wind conditions. This has and caused excessive strain and wear and tear on the guidewires and turnbuckles which lead to one turnbuckle being broken inside the roof and one guidewire to be damaged and sheared through 95% of the 18mm guidewire. This damage could probably be the result of incorrect installation and inferior quality turnbuckles.
   b. Further examination suggested resulted in existing turnbuckles inside the roof to be broken. Hence a set of turnbuckles were replaced as shown in Figure 7.22.

Figure 7.22 (a) and (b) The newly replaced Turnbuckles in the wind turbine at Victoria University

The professional assessment regarding the sub-optimal output of this turbine is that, due to its location and the poor quality of materials used in its construction and that no maintenance has been or is able to be carried out which would lead to deterioration of moving parts and magnets, therefore it is not capable of producing the amount of power that it is rated for.

- Further WT Data Assessment

  From the understanding of the new HRES connection, though WT is connected to the micro-grid laboratory setup, the data acquired from the system validates the negligible output from the WT. This data shown in Figure 7.23 was collected on a cloudy and windy day (4.7.2018).

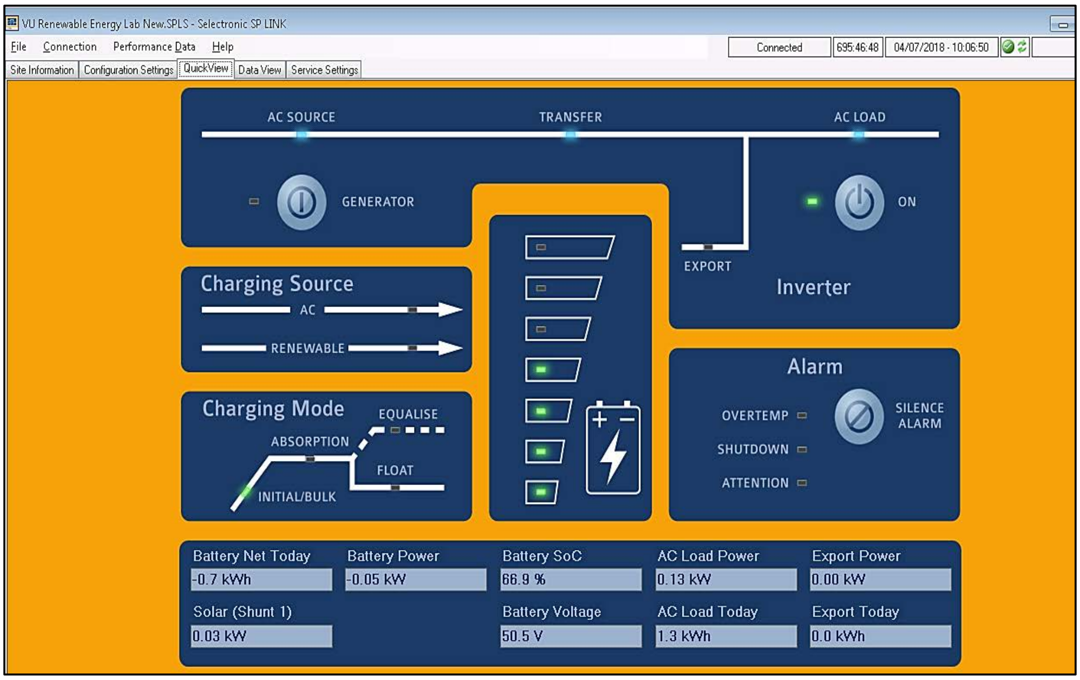


Figure 7.23 The Quick View Data of the energy harnessed from the HRES on a windy day on 4.7.2018

Since the PV output being as low as 30W, the battery discharged the power of 50W to meet the inverter load of 130W. From the technical specifications of Selectronic inverter, its efficiency is 96%. This implies, for the 125W output considering the losses from the converter, the output from the WT is 45W as shown in Table 7.5.

Table 7.5 The WT output Calculations

	PV	Battery	Wind	Total
Power Output (W)	30	50	45	125
Converter Output = 130W				
Converter Losses (96% efficiency)= 125*0.04 = 5W				

Thus, on considering all the tests conducted, it is validated that the WT produces very negligible output. This could be due to its electrical and mechanical failure. The output of the WT was considered to be negligible.

7.4.3 Examination of Batteries charging by the Renewable Energy Source with the presence of the external load.

The primary requirement from the micro-grid setup is that the battery should be charged from RES only. If the RES does not produce enough power, the battery could be charged by the grid energy. The configuration settings in the SP link software of the inverter provides an option to prioritize the source for battery charging option. This was set to RE only as highlighted in the Figure 7.24. When the battery was set to charge mainly by the available RE, the grid support was disconnected to see how the charged battery along with the available RE supported the 2kW load. This was done by enabling the Grid Disconnect as shown in the Figure 7.24.

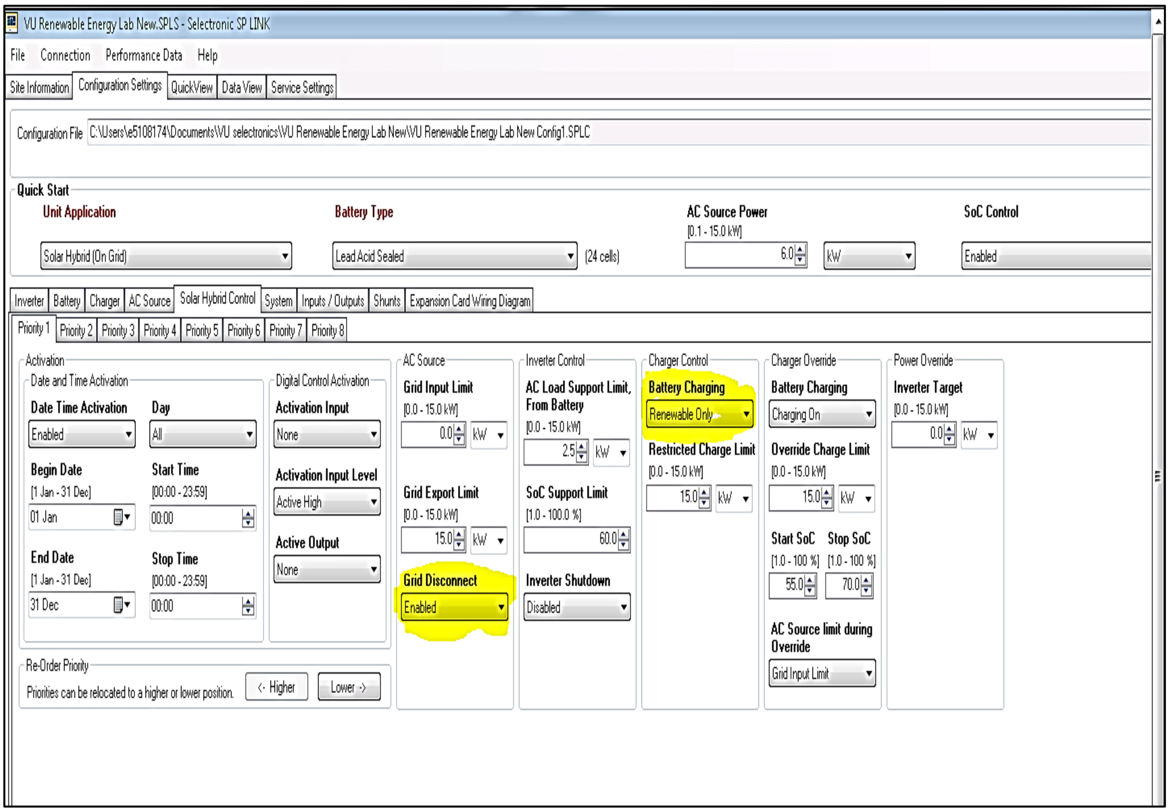


Figure 7.24 Snapshot of Configuration Settings in the Selectronics Inverter

An A.C. load of 2kW was set in the morning around 9:15a.m. The weather in Melbourne varies drastically and hence a proper sunny day was spotted to perform this experiment. The load was kept constant until 4:00p.m, beyond which an alarm to shut down the system due to the drop in voltage to a set minimum value. Hence, the load was disconnected at this stage. The output was recorded using the SP link software. Figure 7.-25 shows the performance data of the HRES system. This illustrates the battery charging and discharging the power during the experiment. At the start of the experiment before the load was switched on, the SOC of the battery was read to be 85.7%. Until the load was connected to the system, the available power from the PV was used to charge the batteries. This was confirmed by the export power to be zero and the increasing values of battery voltage and current values from Figure 7.26. The trend shows the A.C. load power superimposing the Battery charge power. When the external load was disconnected, the SOC of the battery dropped to 62.3% as shown in Figure 7.27.

The temperatures of the transformer, battery and heatsink are shown in the Figure 7.28. The temperature of the battery is about 30^{0}C (which is precisely in the charging temperature range of the battery provided by the company). The heatsink temperature has reached the maximum of 50^0C which is similar to the highest temperature reached by the transformer. On this day, about 10kWh of accumulated input D.C. energy and 16.8kWh of output D.C. accumulated energy has been noted. When battery energy is considered, 20.6kWh of energy is the total accumulated input to the battery while 34.6kWh was the battery output energy accumulated for that day.

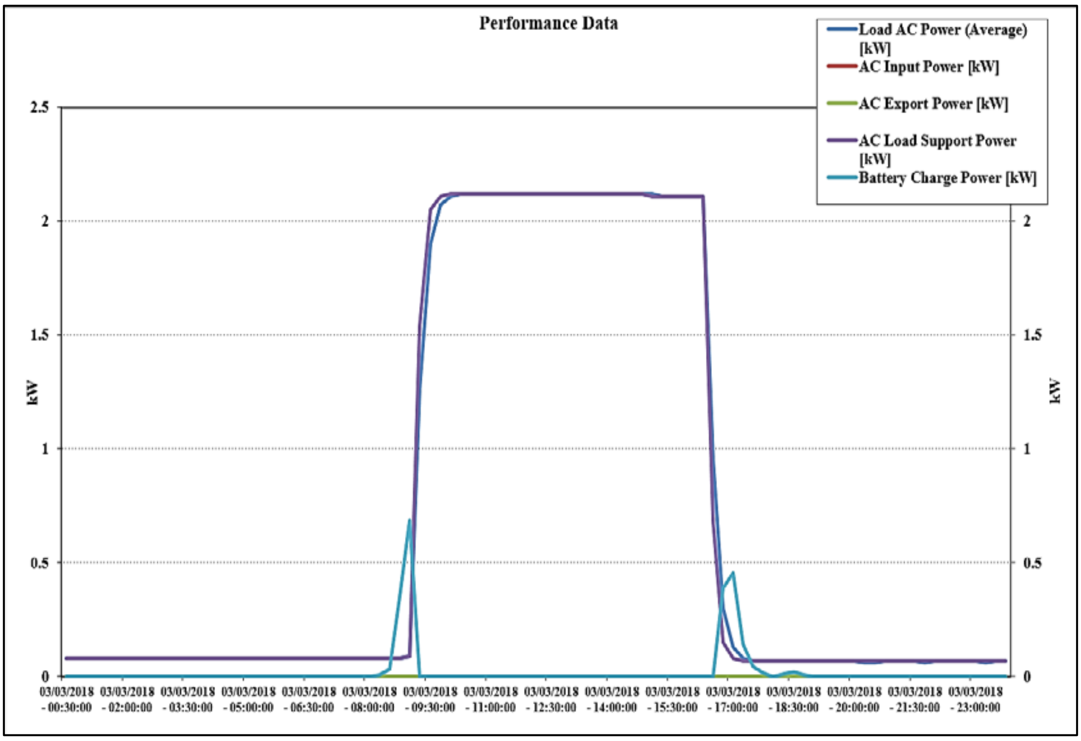


Figure 7.25 Performance Data plot showcasing different current flows on 3.3.2018

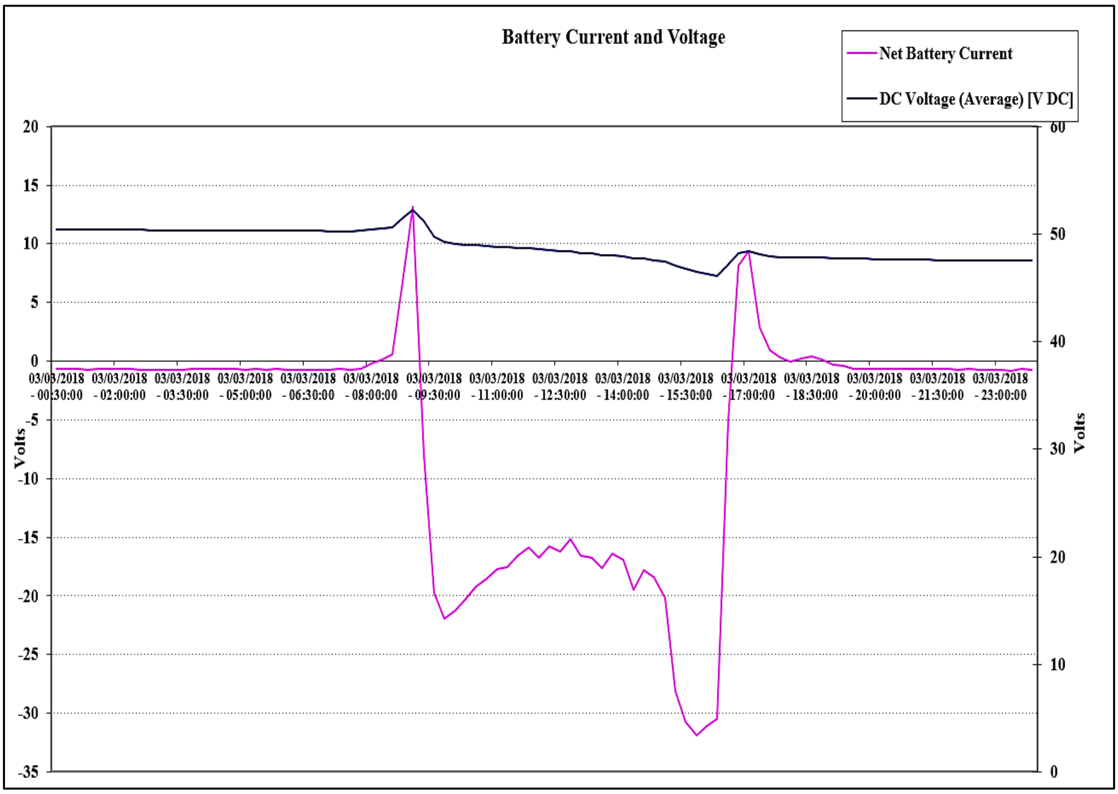


Figure 7.26 Battery Current and Voltage on 3.3.2018

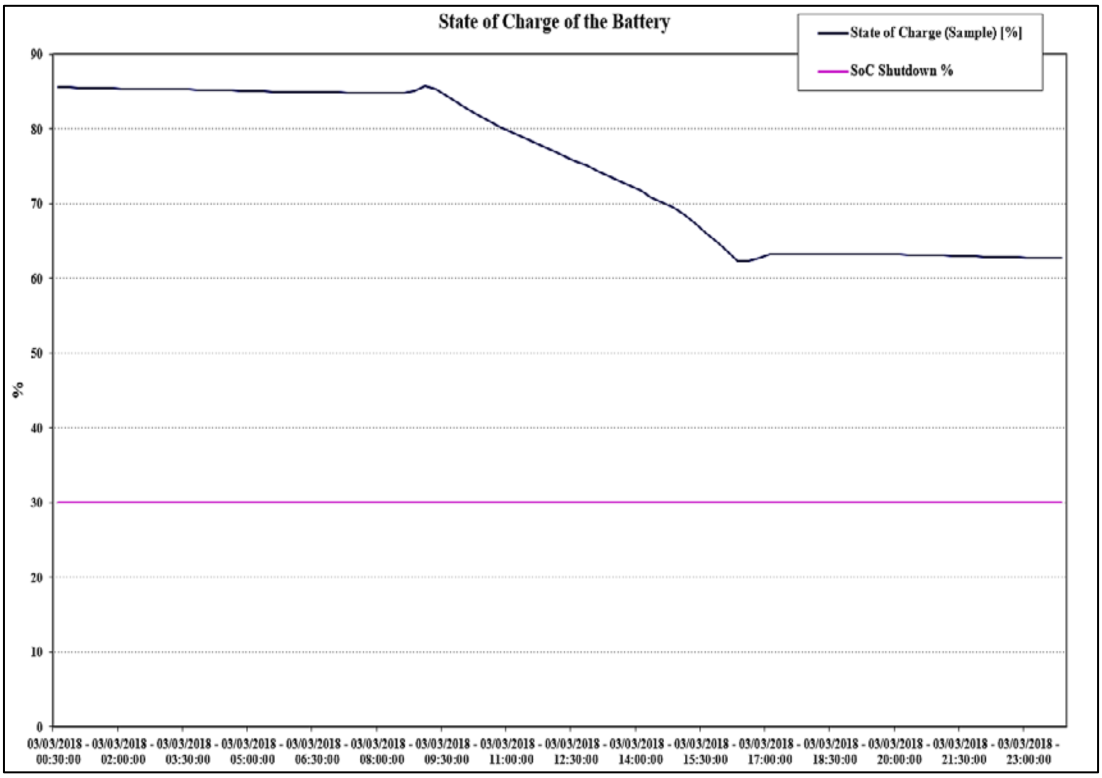


Figure 7.27 SOC of the Batteries

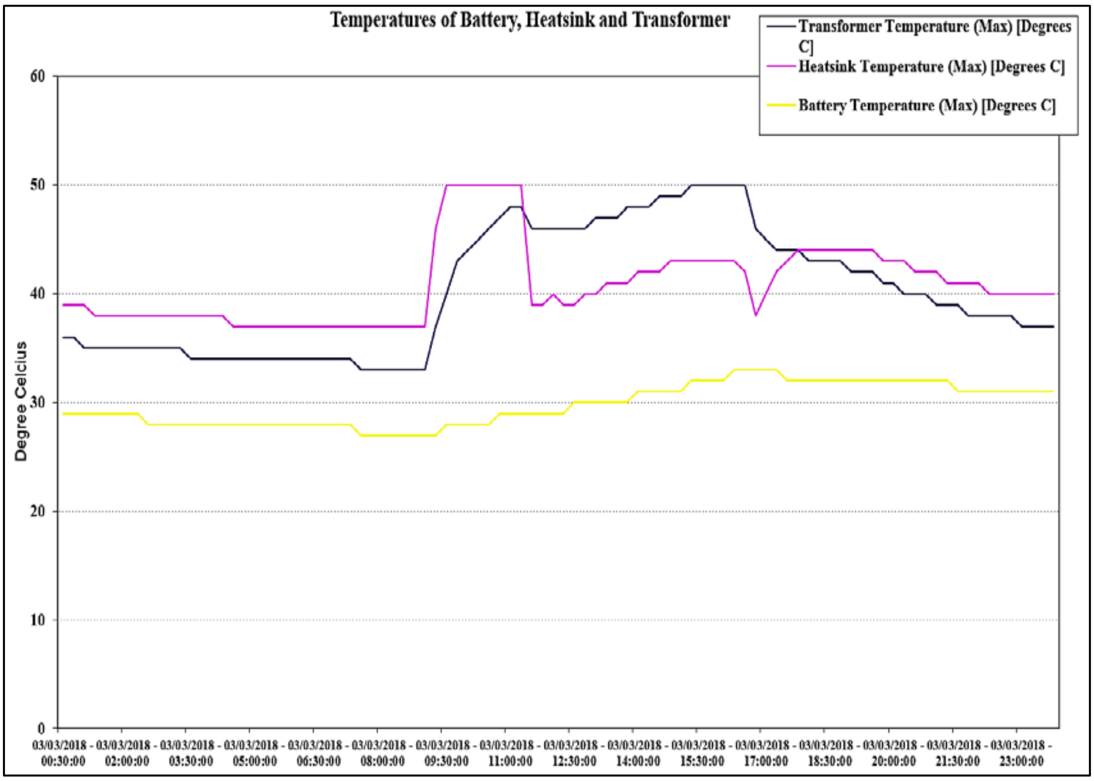


Figure 7.28 Temperatures of Battery, Heatsink and Transformer of the system

7.4.4 Examination of export power after charging the batteries in the absence of an external load

This examination was performed to understand the power export to the grid. In case of excess RE availability (from PV), after charging the batteries to optimum limit, the excess energy has to be exported into the grid in the absence of the load. To examine this scenario, the external load of 2kW was disconnected and the batteries were left to charge by the RES. The charging of the batteries not only depends on the amount of power discharged from it on the previous day, it also depends on the climatic condition of the given location. The excess is the availability of RE to requirement, more energy can be exported to the grid. Here, the presence of grid is not only to supply energy when there is an energy deficit from the RE or energy from the battery, the grid acts as a dump load when there is excess RE available after meeting the load. When a certain amount of energy is fed to the grid, the user/owner of the system is eligible for FiTs which is already dealt in Chapter 4.

Figure 7.29 illustrates the power exported by the system on 21.4.2018. It is observed that, approximately a maximum of 250W has been exported to the micro-grid system. It is also observed that this power has been exported to the grid when the PV output was maximum during the day. This experiment confirms that the excess RE energy has been exported to the grid. The maximum export power from the grid also depends on the SOC of the battery (set by the user); as the RE has been prioritised to charge the battery and then to export the excess power to the grid in the absence of external load. Table 7.6 shows the Daily summary data provided by the software. The data shown in the Table 7.6 illustrates that a total of 36kWh has been exported to the grid on this day. Currently, the FiTs in Victoria is 0.11A$/kWh.

The total revenue gained on exporting this power to the grid= 36 * 0.11A$

=A$4/day.

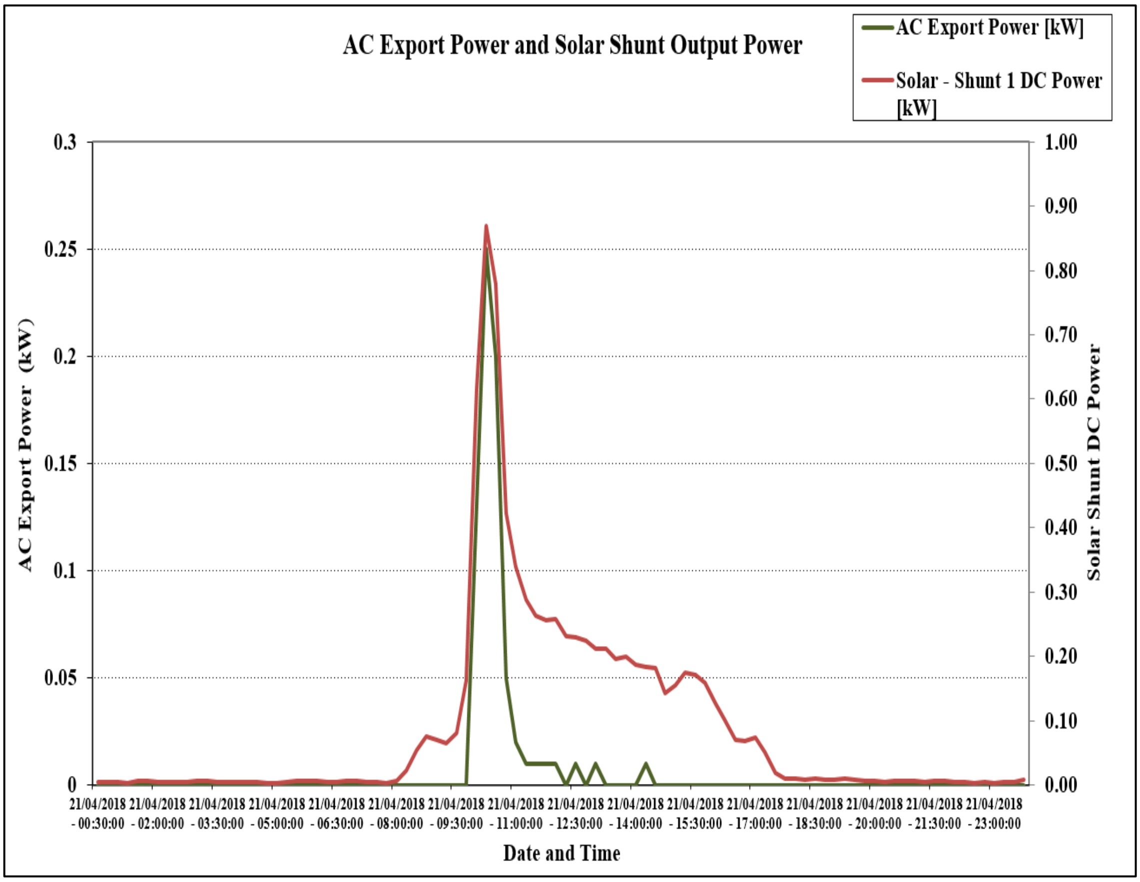


Figure 7.29 A.C. export and Solar shunt Output Power on 21.4.2018

The System Performance data was plotted to analyse the power output of the individual component in the system. This is shown in Figure 7.29. The graph plotted shows the power output of the PV, A.C. export power and A.C. charge power. The performance data plot illustrates that, the PV output is maximum between 9:30a.m and 5:00p.m. In this duration, only between 9:30a.m to 2:00p.m the RE has been exported. The rest of the RE from PV has been used to charge the battery. This is evident from the Battery charge voltage and current graph shown in Figure 7.30. From the daily summary data it can be confirmed that 52.1kWh has been used to charge the battery, while the battery output of 57.3kWh is the energy used by the load (internal load of the inverter).

Table 7.6 Summary of the Data on 21.4.2018

Date/Time Stamp [dd/MM/yyyy]	21/04/2018
D.C. Input Total Accumulated (Sample) [kWh]	2.2
D.C. Output Total Accumulated (Sample) [kWh]	2.1
Battery In Total Accumulated (Sample) [kWh]	52.1
Battery Out Total Accumulated (Sample) [kWh]	57.2
A.C. Input kWh Total Accumulated (Sample) [kWh]	98.6
A.C. Load kWh Total Accumulated (Sample) [kWh]	256.9
Shunt 1 kWh Total Accumulated (Sample) [kWh]	-123.6
Shunt 2 kWh Total Accumulated (Sample) [kWh]	0
A.C. In Hours Total Accumulated (Sample) [Hours]	1346.47
A.C. Export kWh Total Accumulated (Sample) [kWh]	36
Inverter D.C. kWh Total Accumulated (Sample) [kWh]	165.6
Modulation Hours (Sample) [Hours]	1370.53
Battery Charge Efficiency Index (Sample) [Units]	1.018

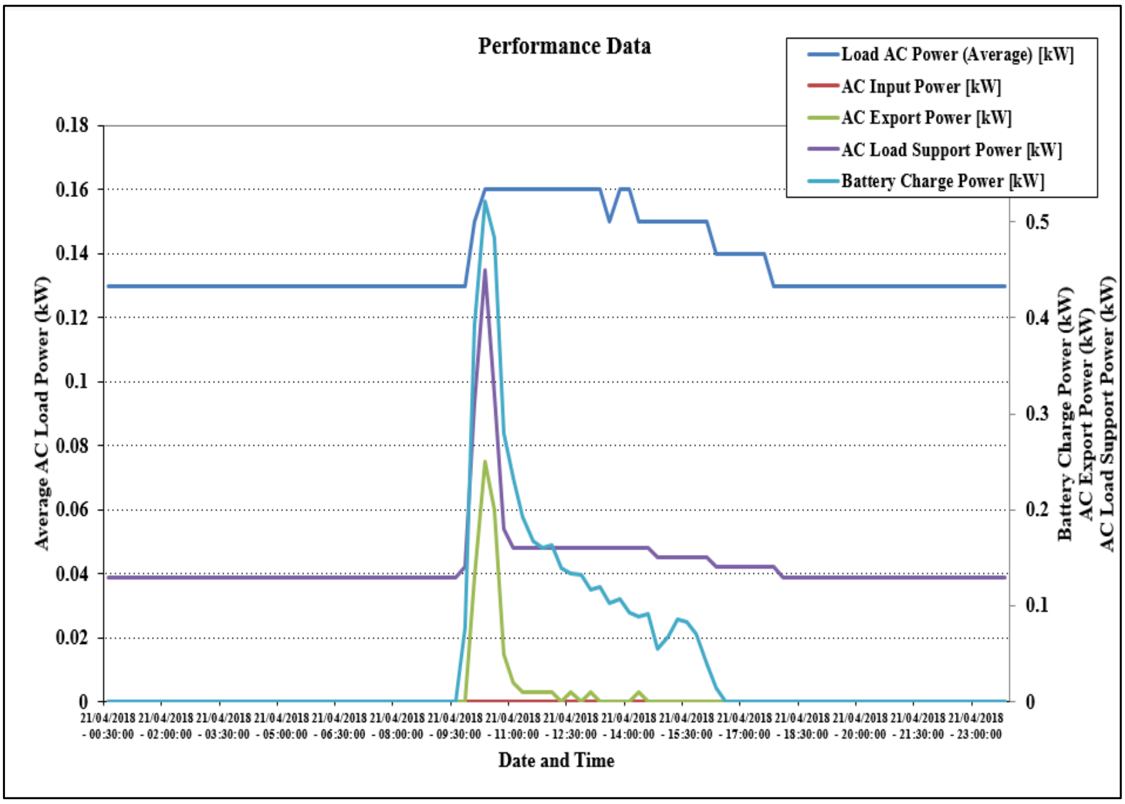


Figure 7.30 Performance Data showcasing the different Current Flows in the micro-grid system

7.4.5 Study of grid reliability when HRES, load and storage batteries connected through Selectronic Hybrid inverter.

In Sections 3.3.1 and 3.3.2 from Chapter 3, it was understood the two ways HRES are typically connected to a micro-grid, is either by grid connected mode or stand-alone mode. The experiment discussed in this section examines the reliability of the grid. The HRES system is connected to the battery storage unit and external load through the hybrid inverter is prioritized to charge the battery first and then to meet the load. If the RE is in excess or in the absence of the load (after the battery is completely charged) will be exported to the main grid. However, when the SOC of the batteries drops below 60%, and when the RE is not sufficient to meet the load, the grid supplies the power to charge the battery (and maintain SOC in the range of 60-70% and meet small value of the load. In the absence of the grid, the load would drain the battery power which will reduce the lifespan of the battery. Hence, grid presence is necessary for a scenario when the SOC of the battery drops to a minimal level and RE availability is minimal. The grid charges the battery until it reaches SOC of 70% and further it disconnects (the maximum SOC of the battery to be charged by the grid is capped at 70%).

Figure 7.31 shows the Performance data highlighting load power and A.C. grid input power when the experiment was conducted on 9.5.2018. A constant 2kW external load was set around 10:30a.m. PV and battery was unable to meet the load beyond 2:00p.m. As the SOC of the battery dropped below 60%, the grid started to support the load by supplying power to charge the battery and meet the load. After the grid started to charge the battery, the external load was turned off. This is seen from the A.C. average load power decreasing while the A.C. input power started to increase. This is also shown in the screenshot of the Quick View screen from the SP link software in Figure 7.32. Though it could be seen that approximately 6kW of power was initially supplied, as soon as the battery SOC dropped below 60%. This value has not been registered in the Performance plot. This is due to the fact that the 6kW power supplied by the grid was momentary and was the power supplied by the grid, it gradually attenuated until the SOC of the battery reached 70% as shown in Figure 7.33. In this time, the voltage decreased to 49V from 53V (due to discharge of power to load) as shown in Figure 7.34.

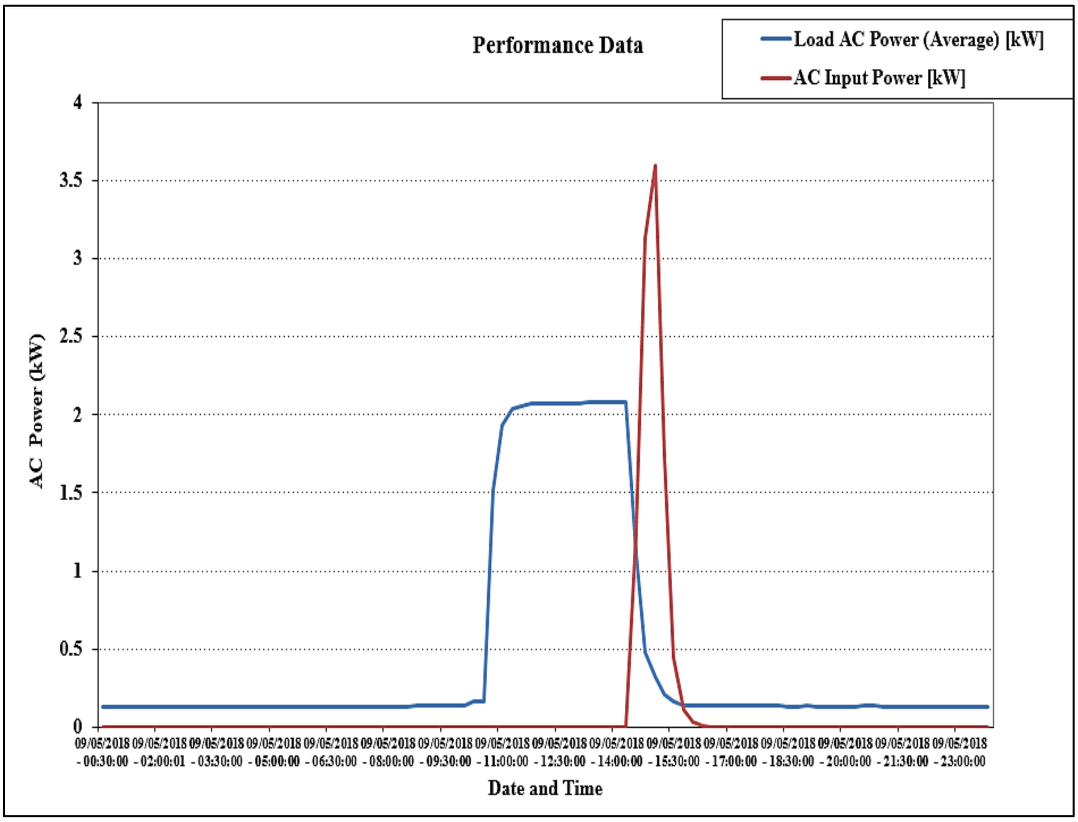


Figure 7.31 The Performance Data showcasing the A.C. load power and A.C. power from the grid 9.5.2018

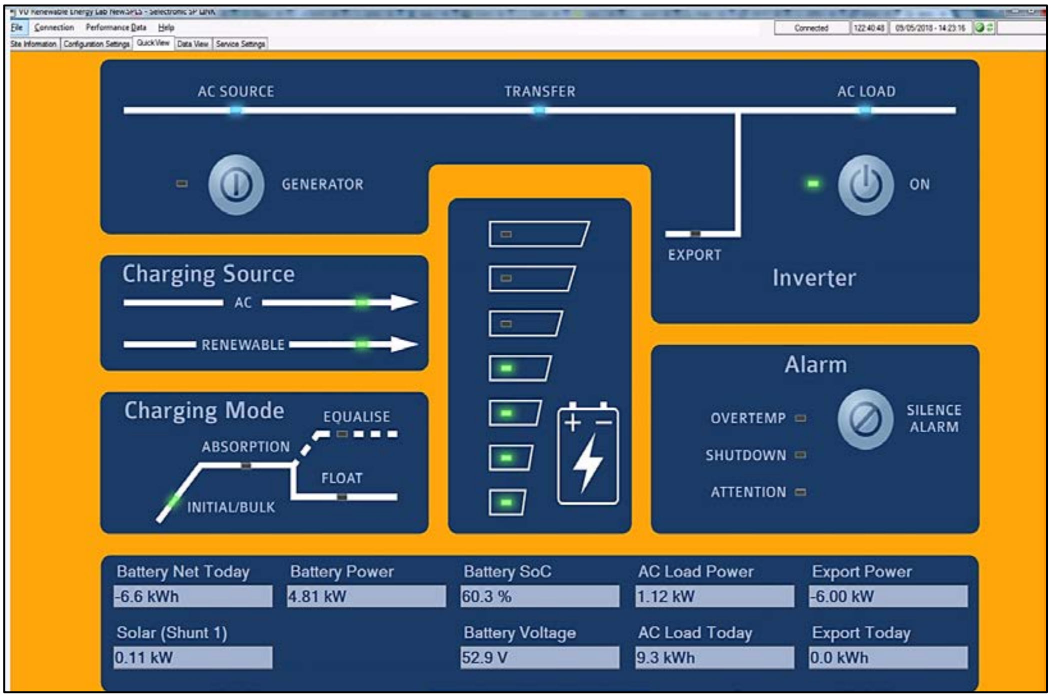


Figure 7.32 Quick View screen of the software highlighting the A.C. grid soaring in power to charge the batteries (on 9.5.201

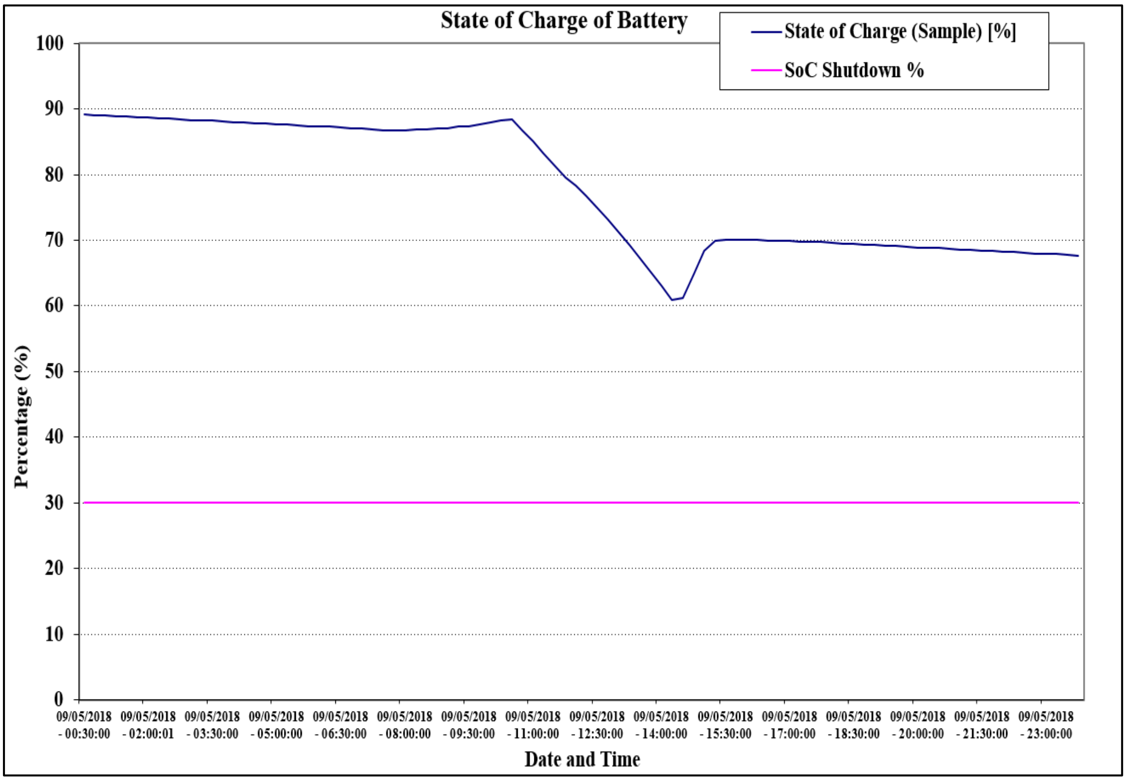


Figure 7.33 SOC of Battery

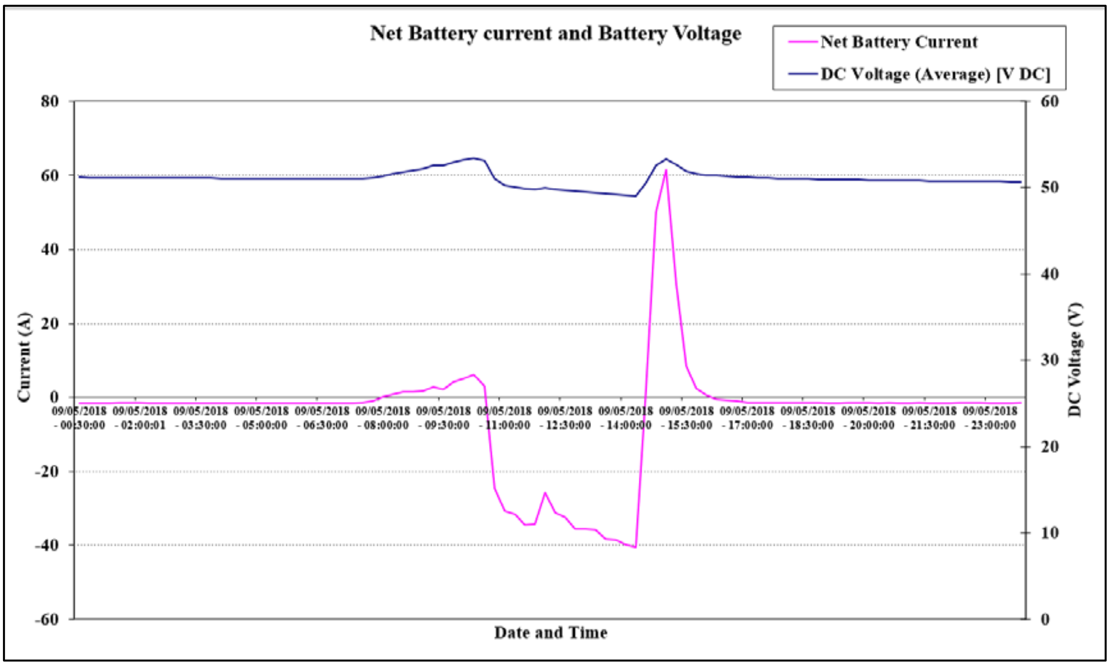


Figure 7.34 D.C. Voltage and Net Battery Current Flow on 9.5.2018

7.5 Experimental study of HRES without external load

This study was conducted on 25.7.2018 to understand the total energy consumption by the system (inverter) without any external load being connected and understand the performance of the HRES connected to the VU micro-grid. The description of the performance of the HRES when the experiment is conducted is explained in Table 7.7.

On the day the experiment was performed the maximum output from PV was by 11:00a.m of 0.76kW and the PV output gradually reduced after 5:00p.m. PV charged the battery at every instant of time, while the battery voltage and current reached a maximum value of 57.14V and current 11.62A respectively. Due to the presence of internal load from the inverter, there was approximately 3.45kWh of internal load from the system by the end of the day, while solar shunt accumulated 2.66kWh and battery output of 1.11kWh by the end of the day.

This experiment mainly suggests the performance of individual components of the micro-grid. It can be noted that, Selectronic inverter has the scope to provide the current, voltage, power output, energy accumulated and temperatures data of the system configuration. It also helps in analysis of the data for every 15 min interval for a particular day. It is also understood that there is some amount of internal load of maximum 0.2kW present in the system, and this value is included along with the external load value in the further experiments discussed in this chapter further.

Table 7.7 Daily event description for the experiment conducted without external load

Date	Experiment Conducted	Event Schedule	Daily Event description and HRES performance interpretations from the Performance graphs
25.07.2018 (on a winter day)	Experiment to understand the total energy consumption by the system (inverter) without an external load.	No external load conducted. HRES is connected to the grid through the battery throughout the day.	➢ *PV output power:* • Until 9.30a.m: below 0.2kW. • At 11:00a.m: gradually increases to approximately 0.76kW. • By 2:45p.m: gradually decreases to 0.15kW. • By 5:00p.m: further reduces to 0.1kW. PV charges the battery as observed in Performance Data in Figure 7.35. ➢ *A.C. load power (Average Power):* • It is initiated by the system of approximately 0.14kW (when the PV output is negligible. • It reaches a peak value of 0.19kW when PV output is maximum. • Accumulated PV energy at the end of the day is approximately 2.5kWh. • The power output from PV meets both load and charges the battery at every interval of time as observed in Power Output Data from the Figure 7.36. ➢ *Battery voltage and Battery current :*

			From Figure 7.37- • Early hour of the day: 51V, (PV output is NIL in this interval) • Battery current is a negative value according to Figure 7.37. • When PV converts the incident solar energy into useful power: it charges the battery. • At 11:00a.m: Battery voltage reaches a peak value of 57.14V and current 11.62A. (This corresponds to the PV output being maximum at that time). • After 3:00p.m: The battery voltage and current steeply reduces. ➢ *SOC of the batteries*: From Figure 7.38, • Early hours of the day: the SOC of the battery was 76.1%. • During the mid-day: Reaches a maximum 80.4%. • End of the day: gradually reduced to 78%. The battery SOC is directly dependent on the performance of the battery to support the load. The battery shutdown voltage was set to SOC of 30%. ➢ *D.C. currents, Accumulated Energy at the end of the day and temperatures of transformer, batteries and heatsink:* From Figures 7.39, 7-.40 and 7.41,

			• D.C. currents shows the shunt current (PV current) and inverter current. • The Solar shunt current exactly follows the PV output shown in Performance data in Figure 7.34. • At 8:00a.m: Solar shunt current increases from 0.5A • By noon: Solar shunt current increases to 13.4A • By 5:00pm: gradually reduces to 0.33A. The inverter consumes some amount of power and thus the current is negative. The maximum solar shunt current of -1.9A during noon. • Approximately 3.45kWh of internal load from the system. • By the end of the day: solar shunt accumulated 2.66kWh and battery output of 1.11kWh. This implies that the battery and PV output was sufficient to meet a load of a minimum of 3.5kWh even on a day in winter when the PV output is considerably low. • Temperatures of the transformer, batteries and heatsink: Temperatures have been maintained under 35^{0}C. • The maximum temperature of: Heatsink : 33^{0}C by the evening, Transformer temperature: 29^{0}C and Battery temperature: 19^{0}C.

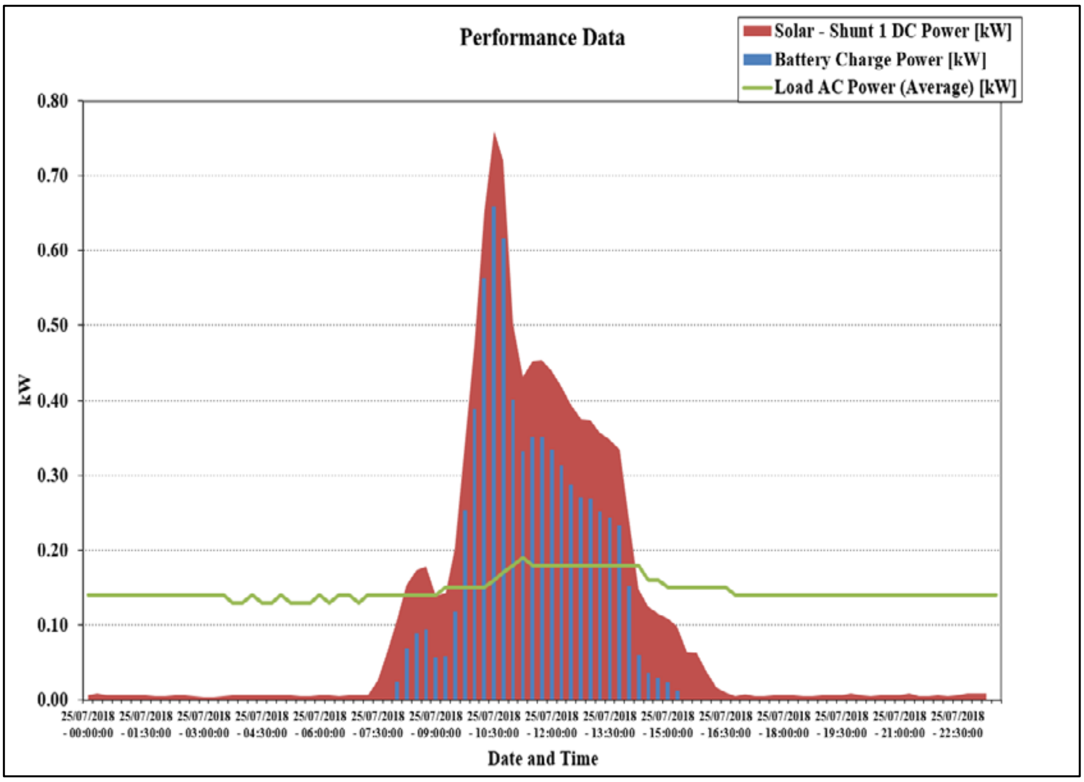


Figure 7.35 Performance Data highlighting the performance of PV, battery and Load

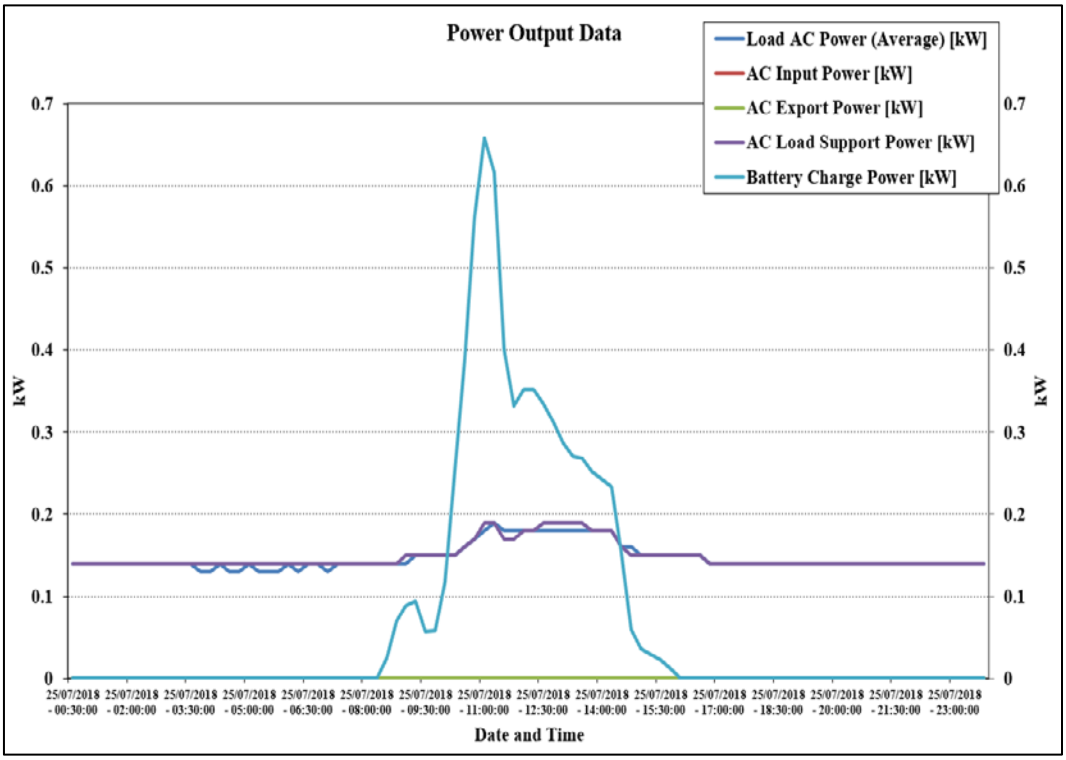


Figure 7.36 Power Output Data of all the components in the micro-grid

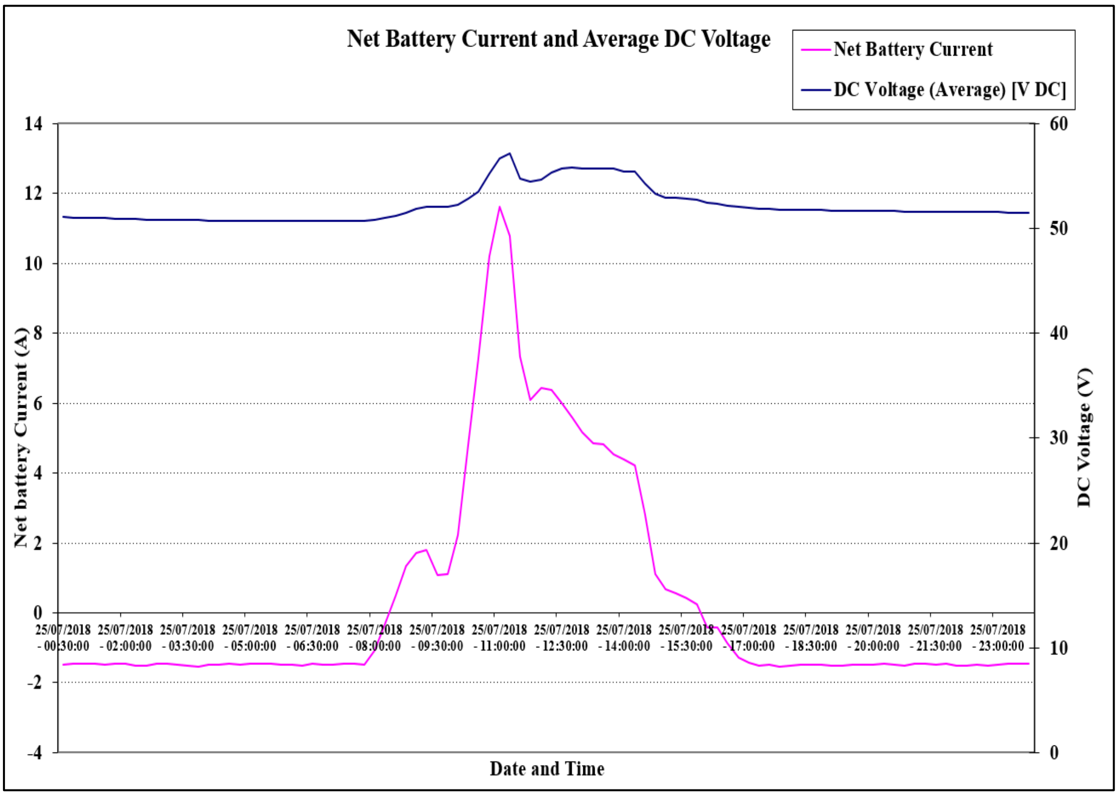


Figure 7.37 Net Battery Current and D.C. Voltage

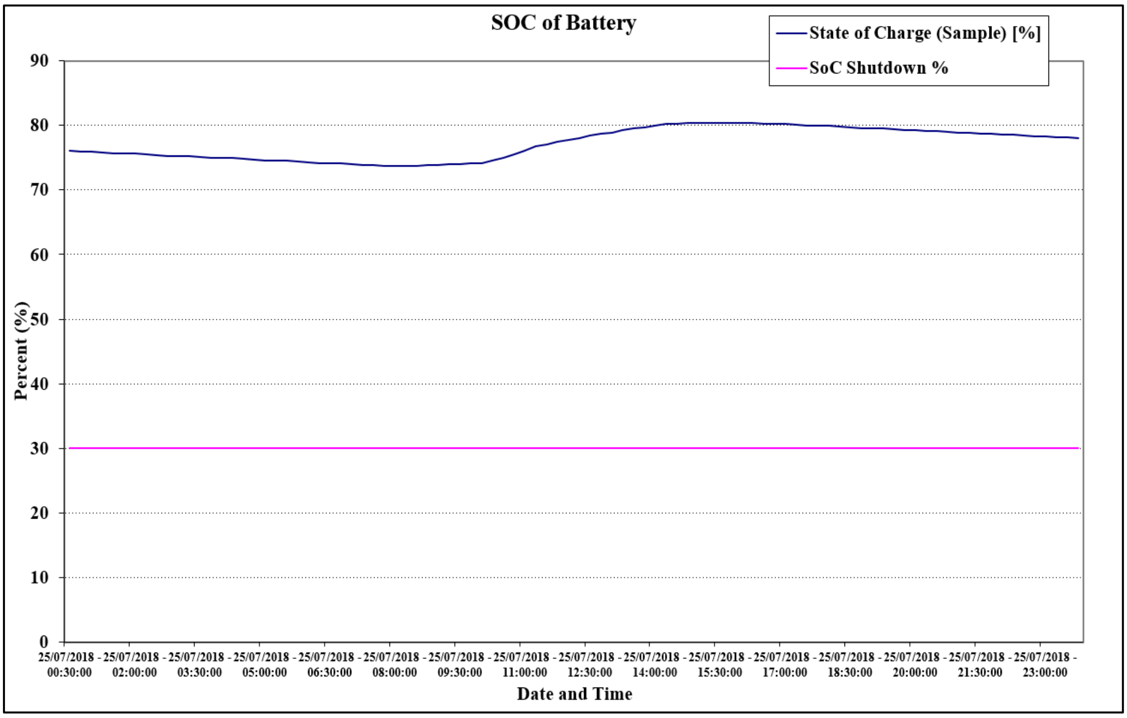


Figure 7.38 SOC of the Battery

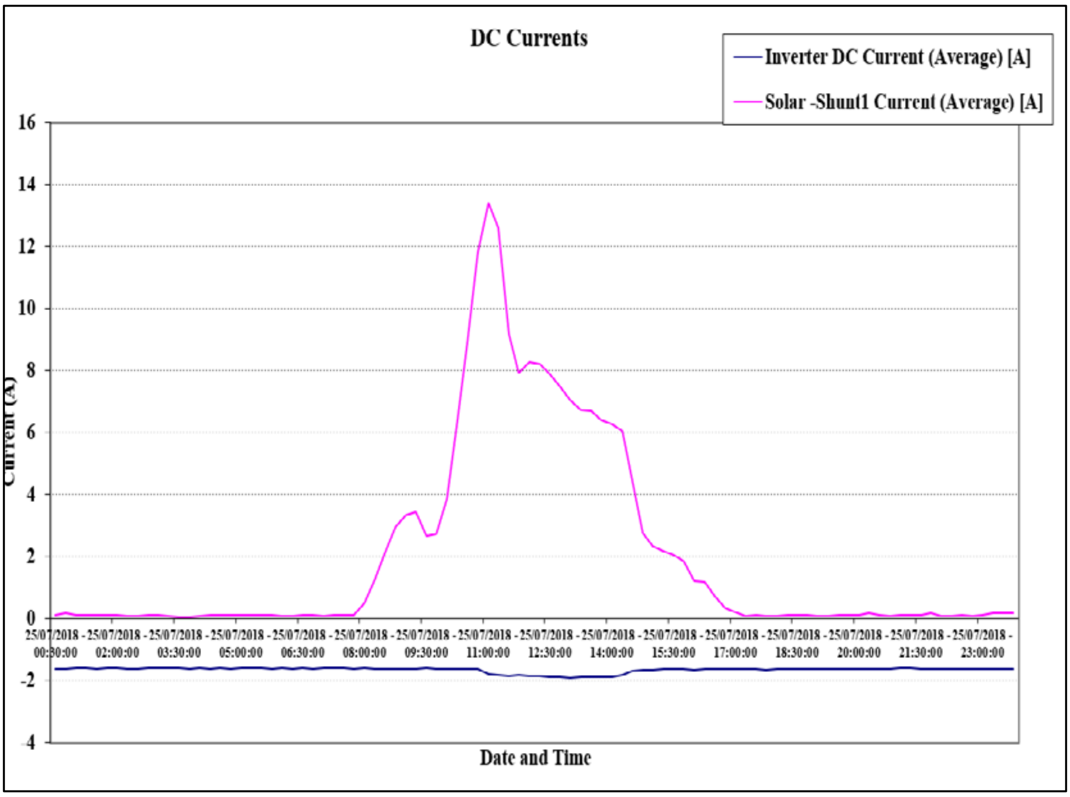


Figure 7.39 D.C. Current Flow in the micro-grid

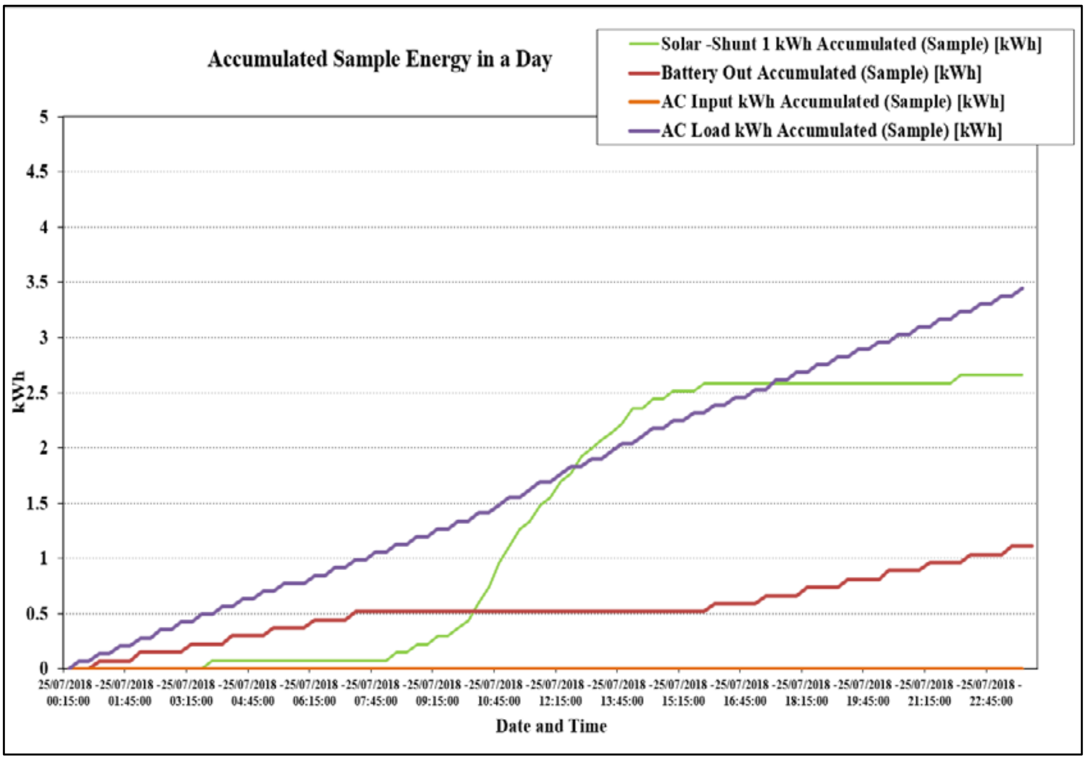


Figure 7.40 Accumulated Energy in a Day

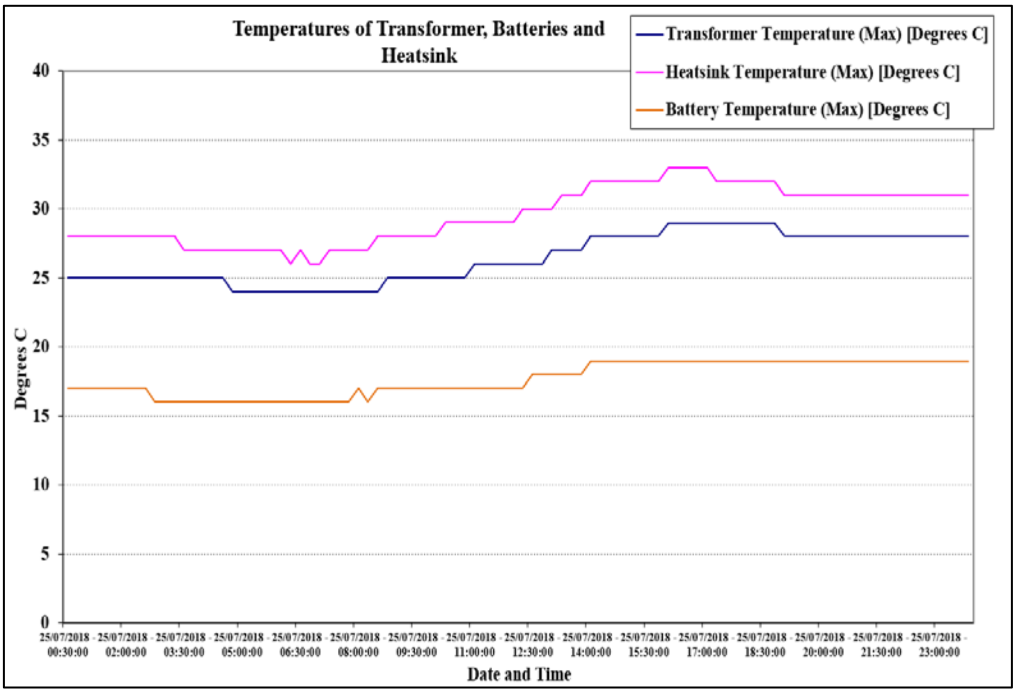


Figure 7.41 Temperatures of Transformer, Batteries and Heatsink

7.6 Experimental Study of HRES when connected to the micro-grid through the load.

Section 7.4 discussed the detailed working of every component according to the priority set. This shows the flexibility of the micro-grid setup. In this part of the section the same HRES setup along with an external load bank rated 9kW with 230V A.C. has also been considered. This Section 7.6 is further divided into two parts:

- Connecting constant load and
- Variable load.

Thus, the reliability of the external grid along with the HRES, battery and the presence of load in the micro-grid setup have been discussed. The study conducted examine the working of the HRES set up for different load options and finally considering a constant load running for a definite time. The analysis explores the possibilities of the HRES system connected to a Selectronic inverter with a set of battery bank.

The principle of the experiment performed is shown in Figure 7.42. The real-time data plotted for the solar power output from the PV installed in the university and average energy consumption of a house in Footscray (data procured from the energy distributor) were plotted. The energy consumption of the house shows that the energy consumption is comparatively low between 7:30a.m and 5:00p.m, whilst PV just starts to produce power by early 7:00a.m. During the day it is observed that the load is much smaller than the available RE (Solar Energy). Nonetheless, this excess energy after meeting the load in this duration can be used to charge the batteries. Thus, the charged batteries can be further discharged to reach the load in the absence of RE. In case, if the batteries and the available RE are unable to reach the load demand at any instant, the grid can supply the power. This micro-grid model more flexible and reliable from the consumer's outlook.

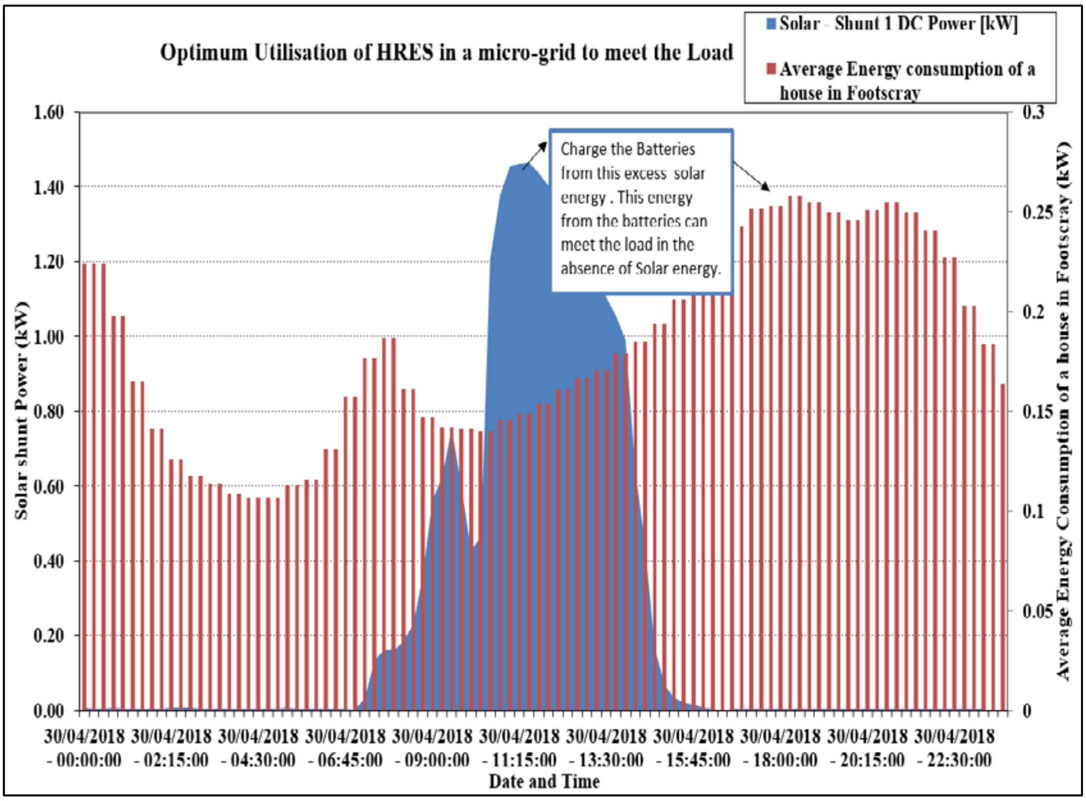


Figure 7.42 Optimum Utilisation of HRES in a micro-grid to meet the load.

Considering the maximum utilisation of PV by connecting an external load, the experiment was performed. It is seen from the experiments that, as soon as the SOC of the battery declined below 60%, the grid starts to export power to charge the battery. The experiments conducted has been divided into two phases:

a) Phase 1-The initial battery size consisted of 4 numbers each of 12V 270Ah capacity each and the experiments were conducted (to be described in Section 7.6.1). The micro-grid setup for the experiment is shown in Figure 7.12.
b) Phase 2- An additional 4 numbers of the same 12V 270 Ah each were connected to provide 48V and 270Ah (will be discussed in Chapter 8).

7.6.1 Phase-1 of the experiment with constant and variable load

Phase-1 of the experiment considers the experiment performed with the initial 4 batteries setup. Two experiments were performed using this setup considering:

i. The external load kept equivalent to PV output
ii. 2kW of total load kept constant.

7.6.1.1 External load value equal to Power output of PV.

This experiment was conducted by keeping the external load value almost equivalent to the power output of PV. This was done to maintain the SOC of the battery, while PV solely supply the power to the load. Figure 7.43 shows the Quick View screen shot from the SP link software. It is observed that on 30.4.2018 when this experiment was conducted, the power output from the PV was 1.29kW at about 12:49p.m. The external load was kept equivalent to the PV output of 1.29kW. This is seen in A.C. Load Power in Quick View screen of the software. Throughout the experiment SOC of the battery was maintained at 80.5% and battery voltage to be 52.4V. The description of the performance of the HRES when the experiment is conducted is explained in Table 7.8.

On the day the experiment was performed the maximum output from PV was by 11:00a.m of 1.47kW and the PV output gradually reduced after 3:30p.m. The energy from sun was not uniformly incident, this was due to the shadowing effect from the clouds. Hence, the PV output reduced at 10:30a.m. The output from PV was used to meet the load (the value of load was kept equivalent to the output of the PV. With the available PV output the battery was charged when the load was disconnected. The battery voltage and current reached a maximum value of 56.52V and 11.62A respectively. Due to the presence external load, there was approximately 8kWh is the total A.C. load on that day, while the internal load from the system was 3.45kWh. The total PV output and accumulated battery output energy was 2.66kWh and 1.11kWh respectively.

Table 7.8 Daily event description for the experiment conducted with the value of external load equivalent to PV output power for Phase 1 experiment

Date	Experimental Description	Event Schedule	Daily Event description and HRES performance interpretations from the Performance graphs
30.4.2018	Experiment to understand the HRES performance in the presence of an external load.	An external load with the value equivalent to PV output was connected to the HRES at 10:.30a.m and was disconnected around 4:30p.m.	➢ *PV output power:* • Before external load connection at 10:30a.m: PV power charges the batteries as shown in the battery charge power plot in the Performance Data of the HRES system Figure 7.44. • PV output power at: 8:00a.m : 0.14kW 10:a.m : Increases to 0.76kW 10.30a.m:Due to the shadow effect of the cloud, the PV output considerably reduces to 0.43kW 12p.m: PV output increased to a maximum of 1.47kW and By 3:30p.m: PV output gradually decreased to a minimum of 0.07kW. Between 10.30a.m to 3:30p.m: PV output was maximum, this is validated from the Solar Shunt power output from the Figure 7.45. ➢ *Battery Voltage, Battery current and Battery SOC:* From Figures 7.45 and 7.46, • At 10:00 a.m.: Battery voltage reach a maximum of 56.52V Battery current reaches maximum of 11.62A. The SOC in this duration was approximately 80%. ➢ *A.C. Load Power:* • The Load A.C. Power (Average) and A.C. Load Support Power plots superimpose on one another precisely, this confirms the external load was kept equal to the PV output power. ➢ *Accumulated energy of the battery output, solar output:*

			From Figure 7.47, • 8kWh is the total A.C. load on that day, • 6.5kWh is the total PV output and • 1.5kWh is the accumulated battery output by the end of the day. This implies, for a house 8kWh, the load can be met by the PV and battery if the PV output is similar to 30.4.2018. ➢ *Battery voltages and D.C. currents:* • As the output of the external load was kept equal to PV output power, the battery voltage was maintained to a constant value. • Between 8:30a.m to 2:00p.m: PV charges the battery. This is visible form the increasing battery voltages and D.C. current from the plots as shown in Figure 7.48 and Figure 7.49 respectively. • The average D.C. voltage and D.C. currents were maximum of 56.4V and 25.5A respectively. ➢ *Temperatures of batteries, transformer and heatsink:* • Temperatures increases during the day when the PV is producing enough power to the system and to charge the batteries as shown in Figure 7.50. • The battery temperature is maintained below 30^{0}C, which is the optimum value. • The maximum temperatures of: Transformer: 41^{0}C and Heatsink: 49^{0}C.

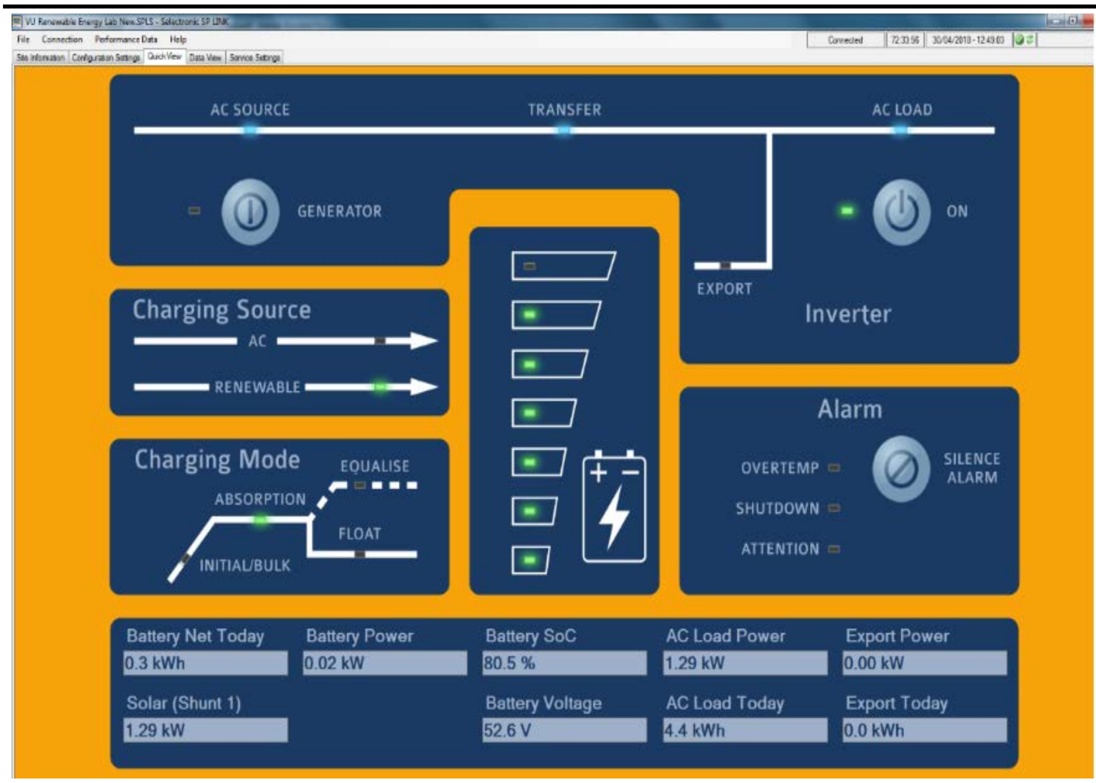


Figure 7.43 Screenshot of the Quick View screen of SP Link software

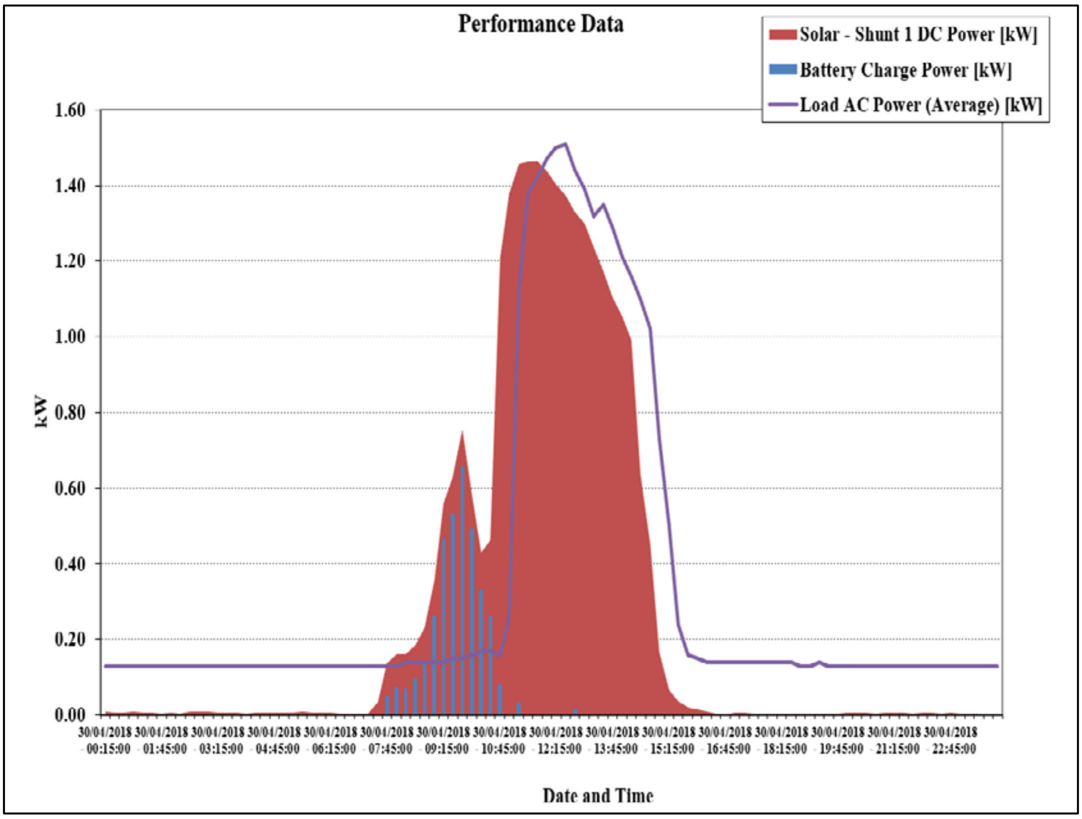


Figure 7.44 Performance Data highlighting the Performance of PV, Battery and Load

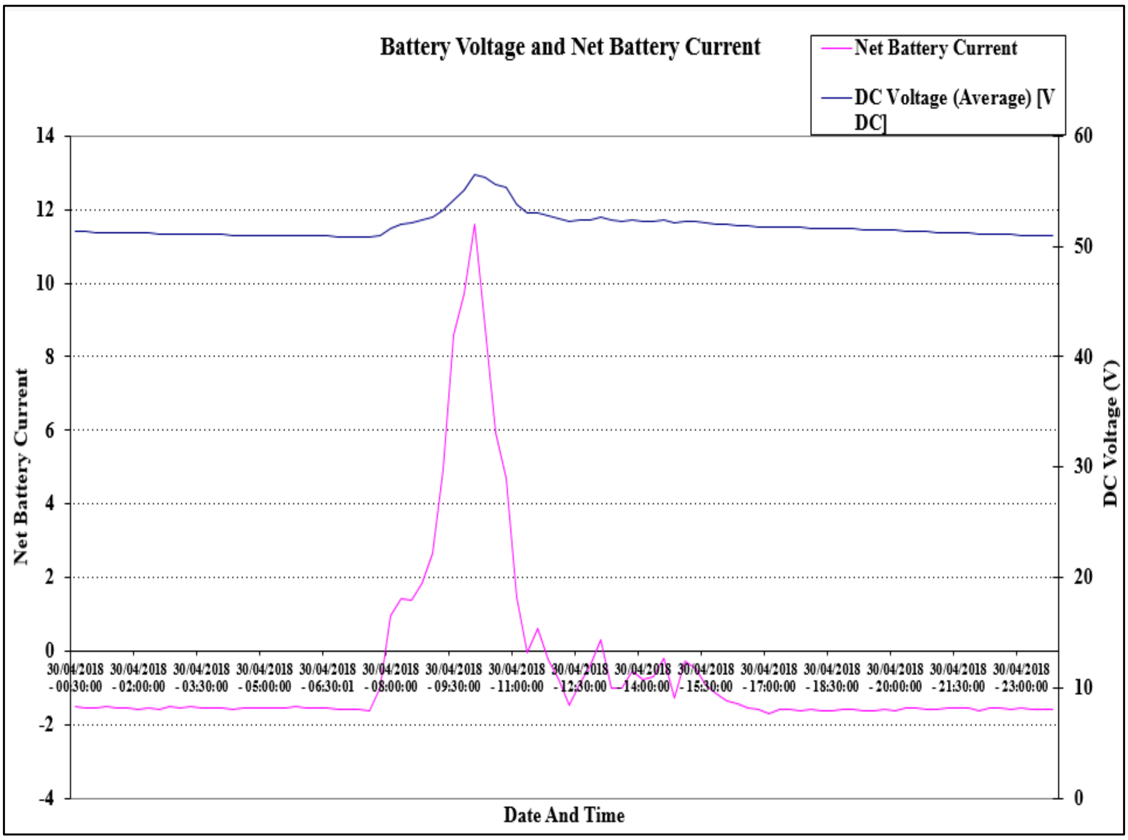


Figure 7.45 Battery Voltage and Net Battery Current of the system on 30.4.2018

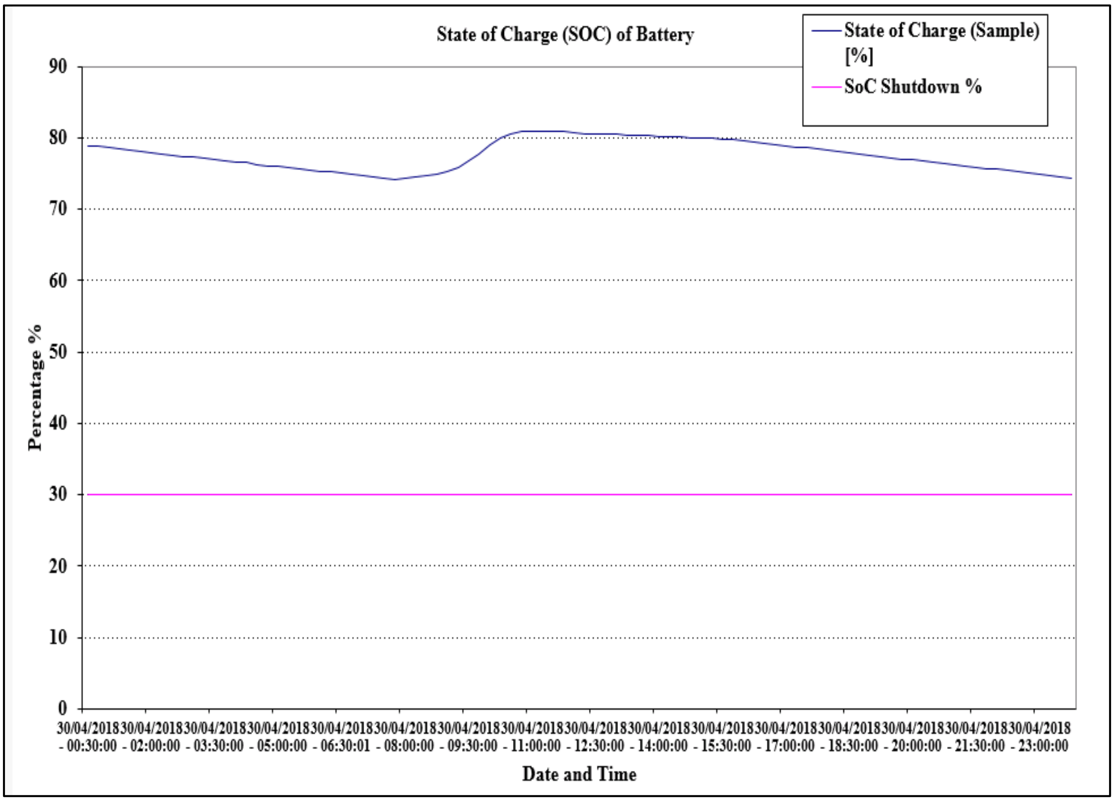


Figure 7.46 SOC of the Battery

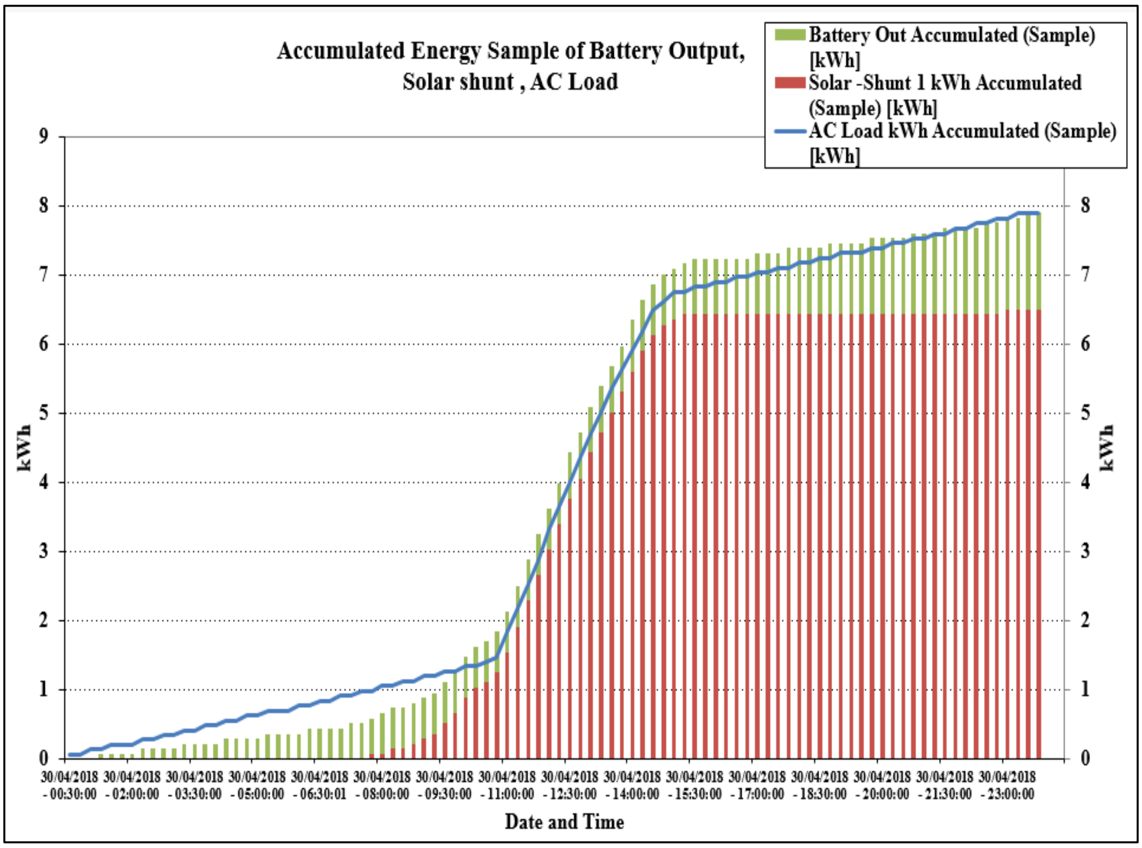


Figure 7.47 Accumulated energy of PV, Battery, Load till the end of the day

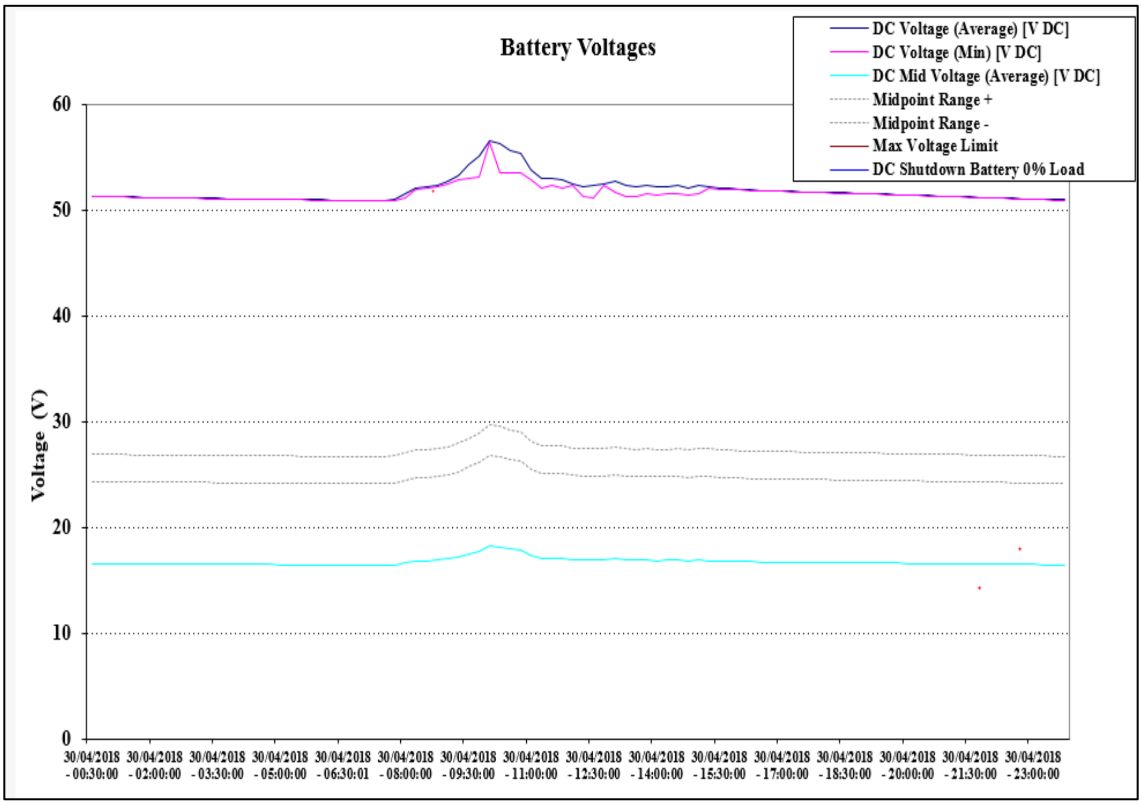


Figure 7.48 Battery Voltages on 30.4.2018

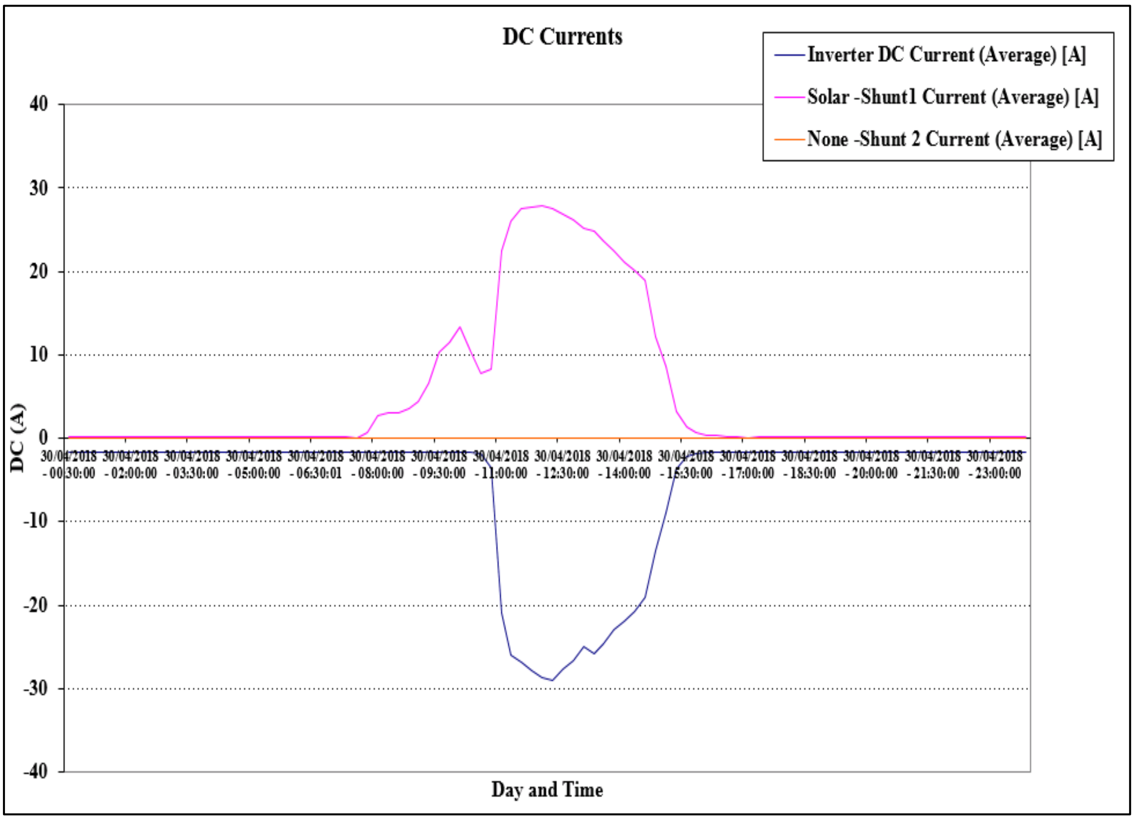


Figure 7.49 D.C. Current flow on 30.4.2018

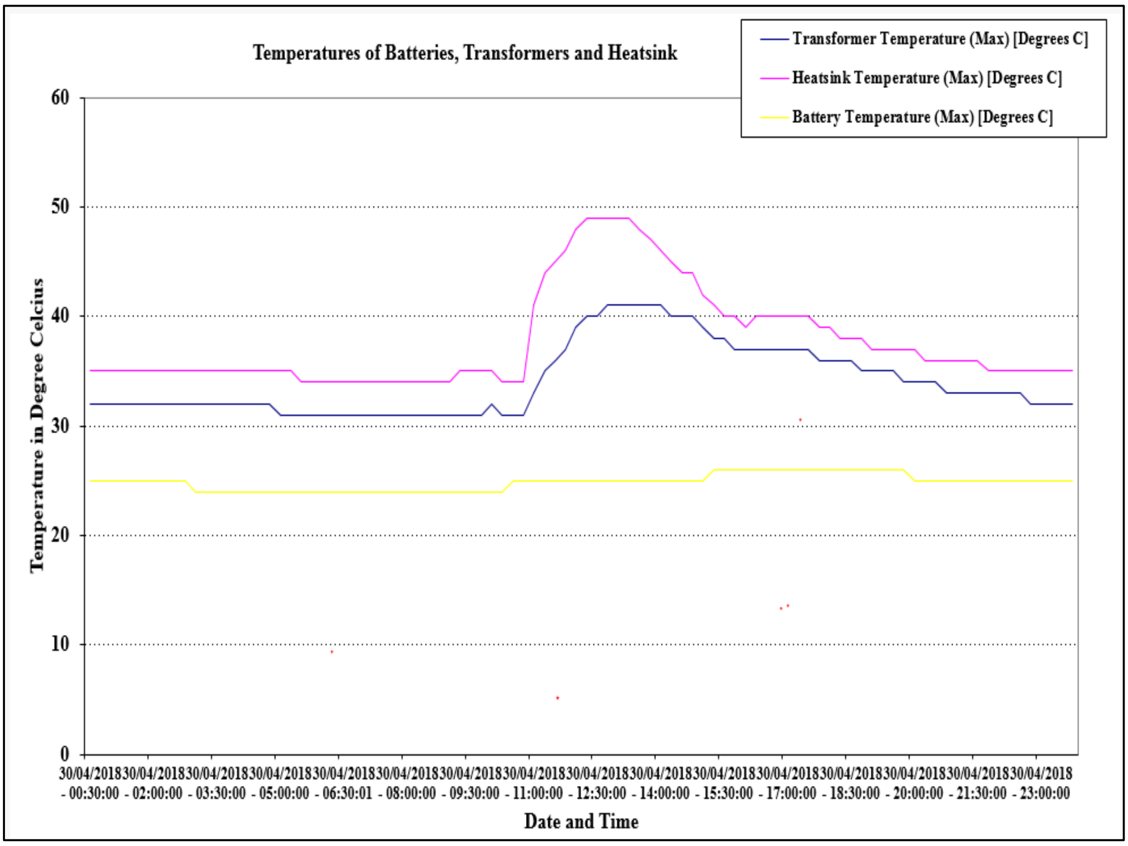


Figure 7.50 Temperatures of Batteries, Transformer and Heatsink

7.6.1.2 Load was kept constant of 2kW

In this experiment, the load was kept to a constant value of 2kW. The 2kW is the PV capacity at VU, and hence 2kW load was used to perform this experiment. The Quick View data screen of the SP link software is shown in Figure 7.51. The description of the performance of the HRES when the experiment is conducted is explained in Table 7.9. The Performance data of the HRES in the micro-grid is shown in Figure 7.52. The performance data illustrates the performance of the battery load and the load support during the day.

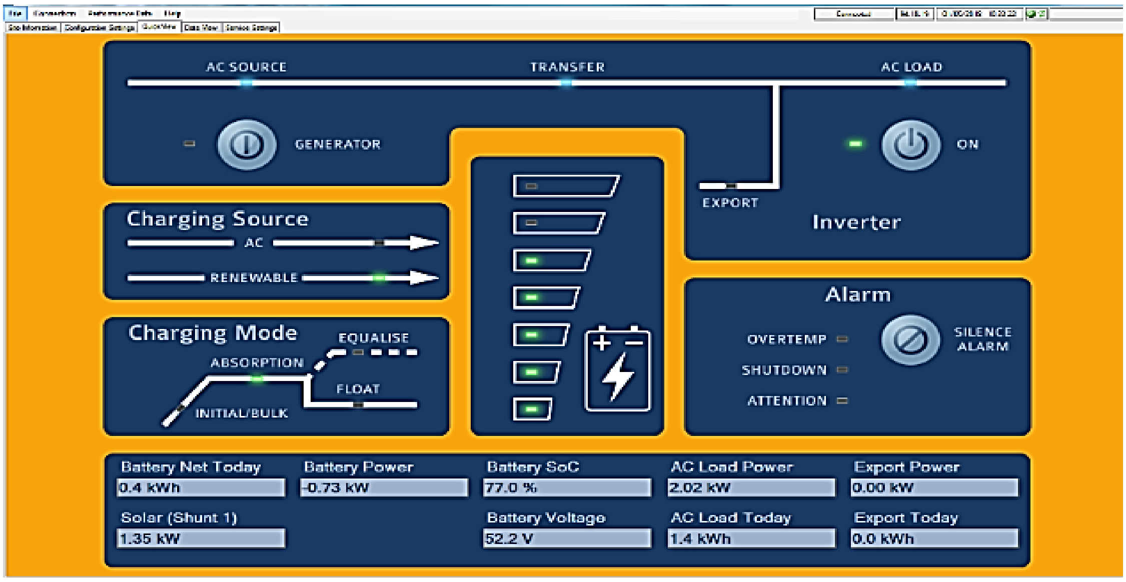


Figure 7.51 Quick View Screen of the Software

On the day the experiment was performed the maximum output from PV was by 12:00p.m of 1.49kW and the PV output gradually reduced after 4:00p.m. A constant 2kW load was connected to the system at 10:30a.m. At any instant of time, the A.C. load was met by the battery and PV output. This was until the SOC of the battery was approximately 60%, when the SOC of the battery reduced to 60%, the A.C. grid charged the battery and until the battery SOC reached 70%. With the available PV output and the battery power, the external 2kW A.C. load was met until about 3:00pm. The battery voltage and current reached a maximum value of 57V and 15.94A respectively before the external load was connected at 10:30a.m. Due to the presence external load, there was approximately 9.79kWh on that day, while 3.4kWh is the total PV output and6.65kWh is the accumulated battery output by the end of the day.

Table 7.9 Daily event description for the experiment conducted with the value of external load 2kW for Phase 1 experiment

<table>
<tr><th>Date</th><th>Experimental Description</th><th>Event Schedule</th><th>Daily Event description and HRES performance interpretations from the Performance graphs</th></tr>
<tr><td>1.5.2018</td><td>Experiment to understand the HRES performance in the presence of an external load.</td><td>An external load with the value of 2kW was connected to the HRES at 10:30a.m.
At 1.30p.m, when the PV output gradually reduced, the SOC of the battery reached below 60%. Grid supplied enough power to charge the batteries. (At this instant of time, the load was reduced to 1kW as the current from the grid surged in). The external load was disconnected around 3:00p.m.

(PV output was not high enough to meet the 2kW load, thus batteries discharged some power at every instant of time to meet the 2kW load along with the PV)</td><td>➢ PV output power:
From Figure 7.52,
PV convers incident solar energy into useful energy from 7:00a.m until 10:30a.m (until load is connected). This is shown as battery charge power plot shown in the Performance data plot.
PV output power at :
8:00a.m : 0.11kW
12:00pm: 1.49kW
2:30p.m:0.84kW
4:30p.m: 0.02kW
➢ A.C. Load Power:
2.02kW of the load that was set, at 10:30a.m, was met by PV and the battery. As the battery SOC reduced to 60%, the external load was set to 1kW. The grid supplied power to charge the battery and also meet the load. This is observed in Average A.C. load curve from Figure 7-.52.
➢ Battery Voltage, Battery current and Battery SOC:
From Figure 7.53,
Battery voltage at:
Start of the day:50V,
10:29a.m: maximum value of 57V (before an external load of 2kW load was connected) ,
1:15p.m: minimum battery voltage of 49.7V (Grid exported power to charge the battery when the SOC reduced to 60%),
3:00p.m:51.9V
End of the day: 50.67V</td></tr>
</table>

			• Battery current at: Start of the day:0.43A, 10:29 am:15.94A, 1:15p.m:-16.87A(negative value of current illustrates the battery discharging the power) 3:00:p.m:-0.4A End of the day:-1.6A From Figure 7.53, • SOC of the battery at: Start of the day: 73.9% 10:29a.m: 76.9% 1:15p.m: 61.4% 3:00p.m: 70% End of the day:63.4% ➢ *Accumulated energy of the battery output, solar output:* From Figure 7.55, • 9.79kWh is the total A.C. load on that day, • 3.4kWh is the total PV output and • 6.65kWh is the accumulated battery output by the end of the day. This implies, with PV, battery and A.C. grid, the micro-grid has the capacity to meet a load of approximately 10kWh. ➢ *Temperatures of batteries, transformer and heatsink:* From Figure 7.56, • The maximum temperature reached by: Transformers: 48^0C, Heatsink: 50^0C, Batteries: 28^0C

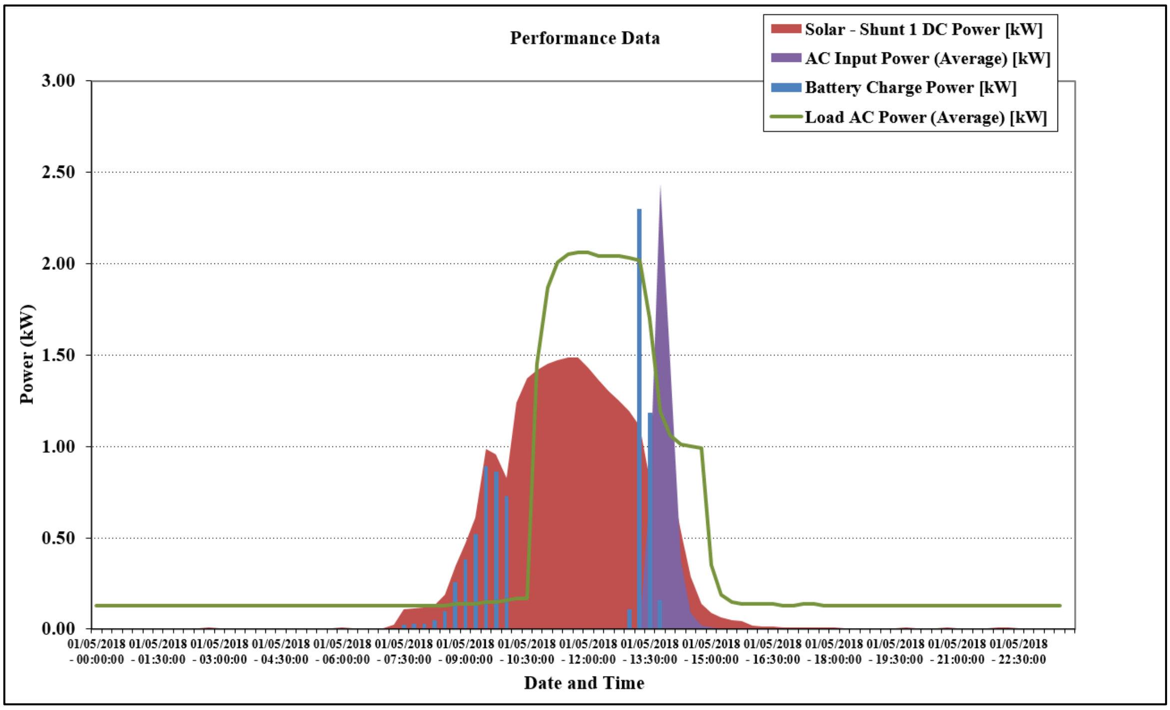


Figure 7.52 Performance Data showcasing the Performance of PV, Load, Battery and A.C. grid on 1.5.2018

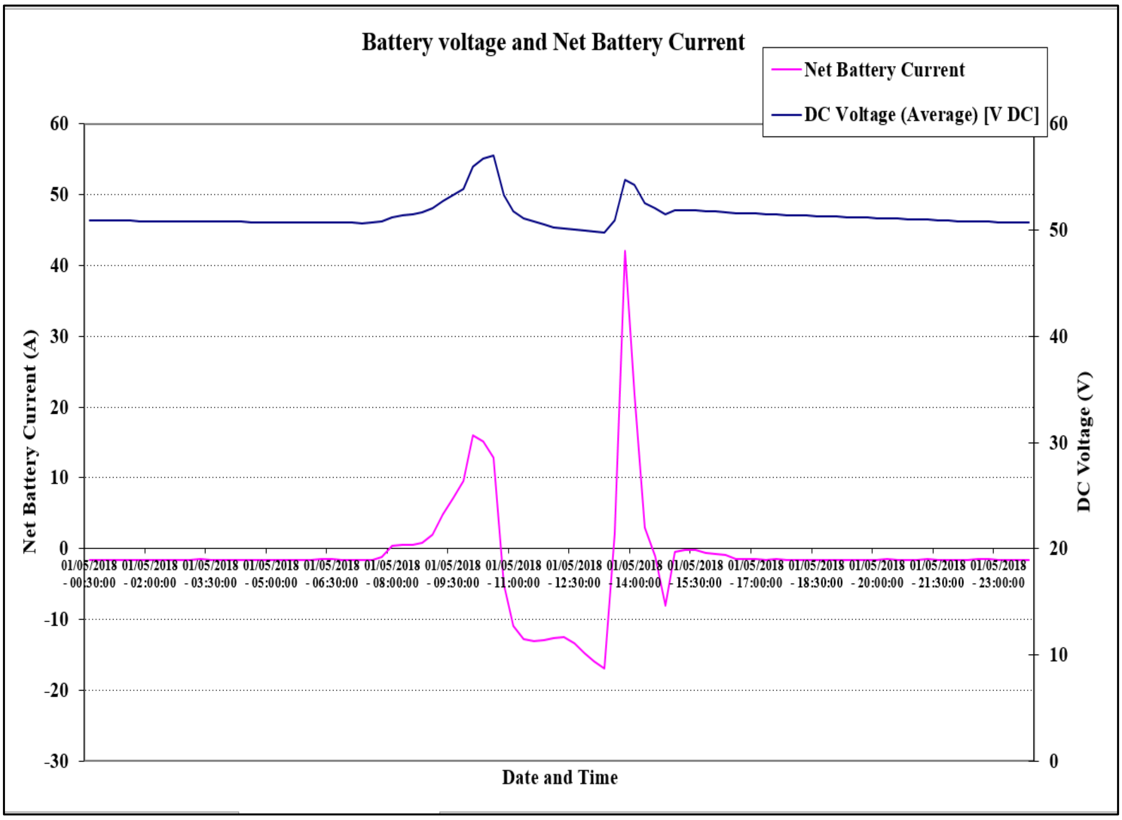


Figure 7.53 Battery Voltage and Net Current readings

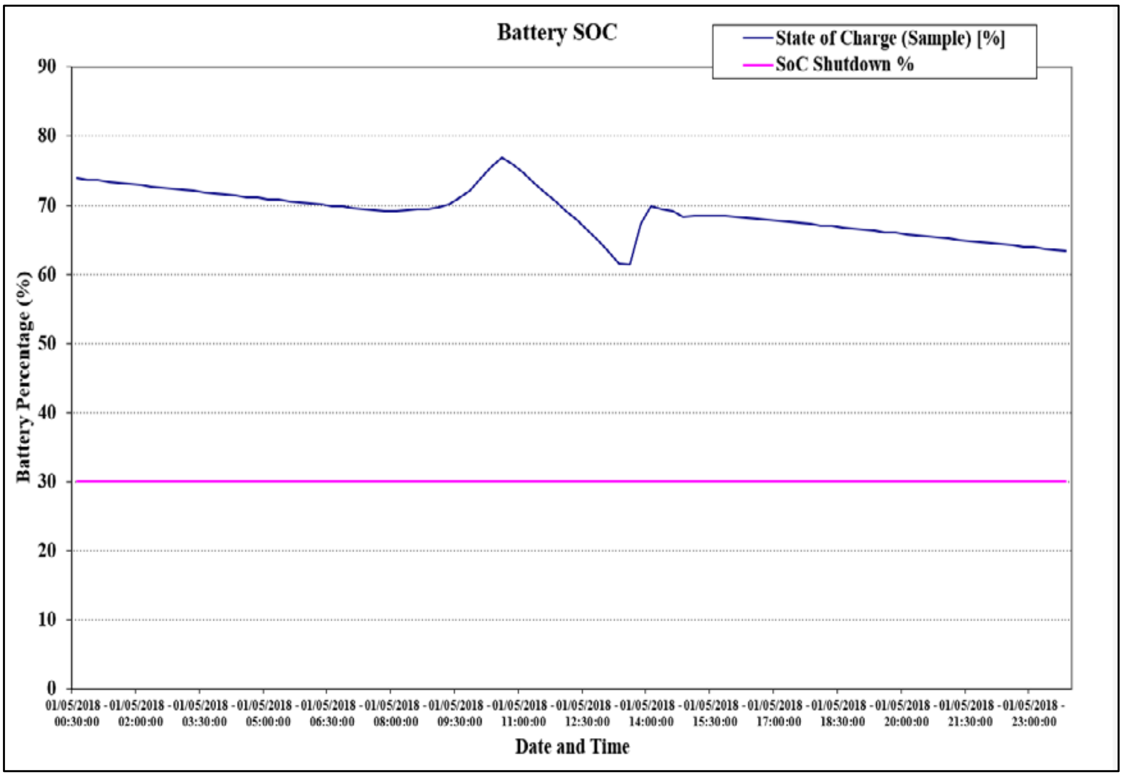


Figure 7.54 Battery SOC performance

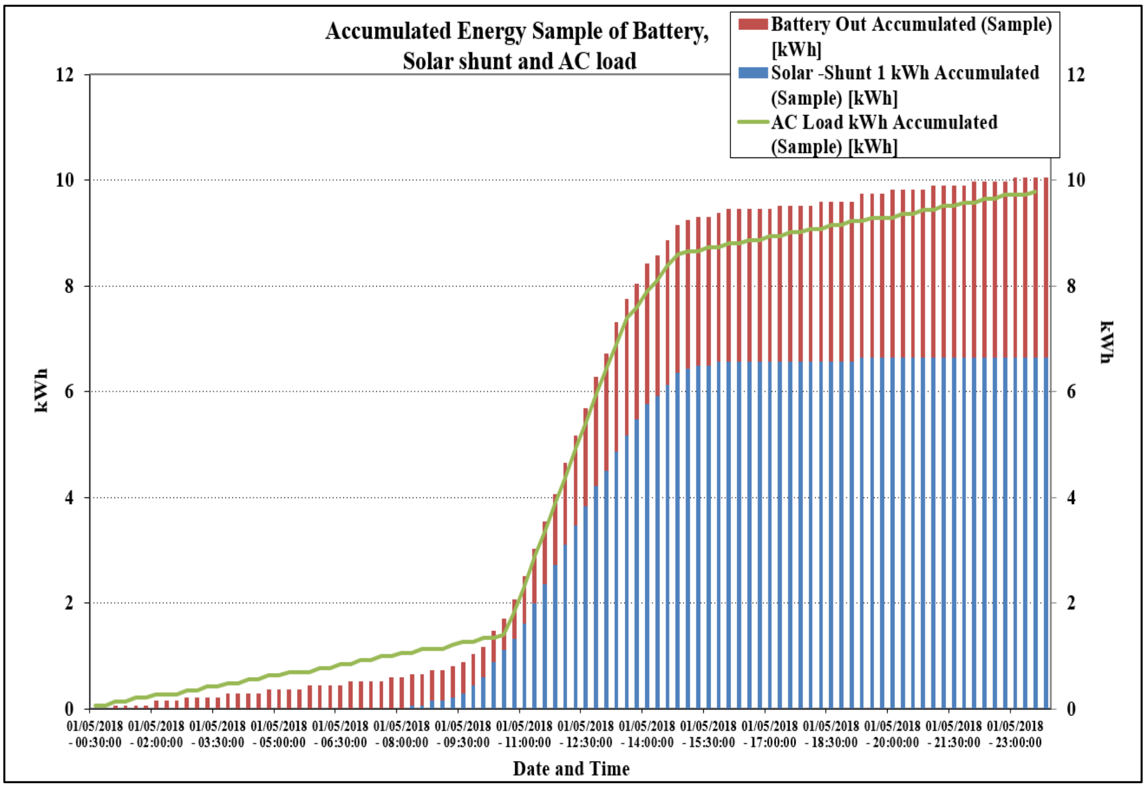


Figure 7.55 Accumulated Energy of Battery, PV (Solar Shunt) and A.C. Load for the Day (on 1.5.2016)

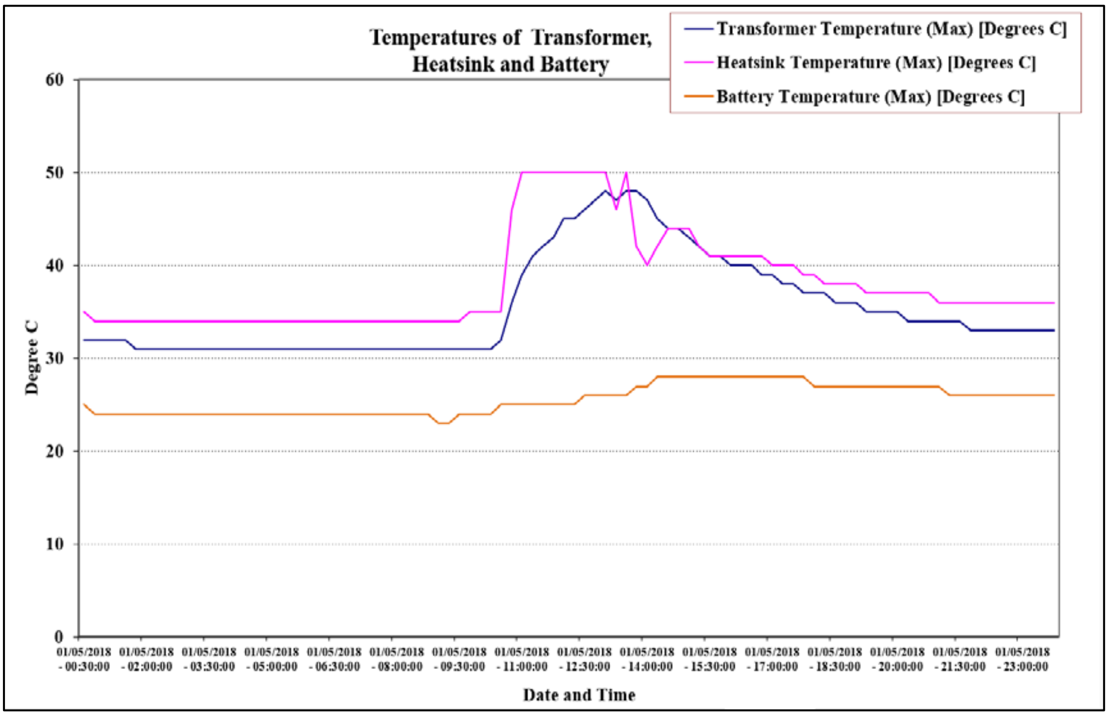


Figure 7.56 Temperatures of Transformer, Heatsink and Battery

This experiment helps in understanding the system performance and competence of each of these units to meet any load if available of this kind. It also helps in understanding the reliance of individual system units and the whole micro-grid in general for further studies. This experiment helps in analysing the battery and PV performance to efficiently meet a particular load size. This experiment was performed to understand the reliability and performance of the every component in the micro-grid to meet the load. It is observed that, at every instant of time, PV, battery and grid supported the external load that was set. The accumulated load at the end of the day which was met by the micro-grid system was equivalent to the average energy consumption of a house in the Footscray locality during the day. The battery capacity was though considerably low, the presence of external grid aided in meeting the load and maintaining the SOC of the battery. To further reduce the dependency of external load, an additional 4 set of same batteries were connected so that the Ah of the battery was doubled whilst the battery voltage was kept at 48V. With the upgraded battery storage system, similar experiments were performed. This is explained in Chapter 8 as Phase -2 of the experiment.

7.7 Conclusion

This chapter discusses in detail the available HRES at VU and its performance with the newly upgraded setup. The individual system performance was examined to understand the competence and reliance. Further, to study the performance of HRES connected to the grid through battery was conducted. Batteries of 4 numbers each of 12V 270Ah were used in the Phase-1 of the experiment. However Phase -2 of the experiment consisting of an additional 4 more batteries of same rating have been used and the results are discussed in Chapter 8, which is a continuation of Chapter 7.

Chapter 8

Experimental Study of a prototype HRES at Victoria University Footscray Campus: Part 2

8.1 Introduction

Chapter 7 discussed the various experiments performed to understand the VU micro-grid setup. This included the performance of PV, WT, grid, battery storage system. As a first part, Chapter 7 included the initial battery size consisting of 4 numbers each of 12V 270Ah capacity each and the experiments were conducted. Chapter 8 is the continuation of Chapter 7 (hence named Part 2) consists of the Phase 2 experiments and summarising the overall performance of HRES connected to VU micro-grid. In this chapter, the micro-grid setup consists of the same HRES discussed in Chapter 7 with an additional 4 numbers of the same 12V 270 Ah each were connected to provide 48V and 270Ah. As a continuation to the previous chapter, this chapter describes the various experiment conducted to study the HRES performance when connected to VU micro-grid.

8.2 Phase-2 of the experiment with constant and variable load

In Section 7.6.1, the micro-grid system designed for VU initially consisted of 4 sets of batteries (Phase-1 of experiments discussed consisted of these initial 4 batteries setup). On 4.5.2018, four new Century AGM batteries (aiding to additional discharge of power to the load) each of rating 12V, 270Ah were added of the existing model. The panoramic view of the VU renewable energy lab with the upgraded battery system is shown in Figure 8.1. This increased the Ah to 540Ah; the upgraded 8 batteries were connected with four of each batteries in series and two such strings connected in parallel resulting in 48V. Like Phase-1, two experiments were performed with constant and variable loads. The performance of the newly upgraded VU micro-grid will be discussed in this section.

8.2.1.1 External load value equal to Power output of PV.

This experiment was conducted by keeping the external load value almost equivalent to the output power of PV. This was done to maintain the SOC of the battery and PV solely supply the power to the load. Figure 8.2 shows the Quick View screen shot from the SP link software. It is observed that on 8.5.2018, when this experiment was conducted. The power output from the PV was 1.29kW at about 12:49p.m. The external load was kept equivalent to the PV output of 1.21kW. This is A.C. Load Power in Quick View screen of the software. Throughout the experiment SOC of the battery was maintained around 92% and battery voltage to be 53V. The description of the performance of the HRES when the experiment is conducted is explained in Table 8.1.

Figure 8.1 The panoramic view of the Victoria University Renewable Energy lab with the upgraded battery system

On the day the experiment was performed the maximum output from PV was by noon of 1.28kW and the PV output gradually reduced after 3:30p.m. Due to the overcast day, there was considerable variation in the PV output observed. This confirms the solar availability window narrowing with the seasonal variation in Melbourne. The output from PV was used to meet the load (the value of load was kept equivalent to the output of the PV). With the available PV output the battery was charged when the load was disconnected. The battery voltage and current reached a maximum value of 55.2V and 15.65A respectively. Due to the presence external load, there was approximately 6.41kWh is the total A.C. load on that. The total PV output and accumulated battery output energy was 4.87kWh and 1.55kWh respectively.

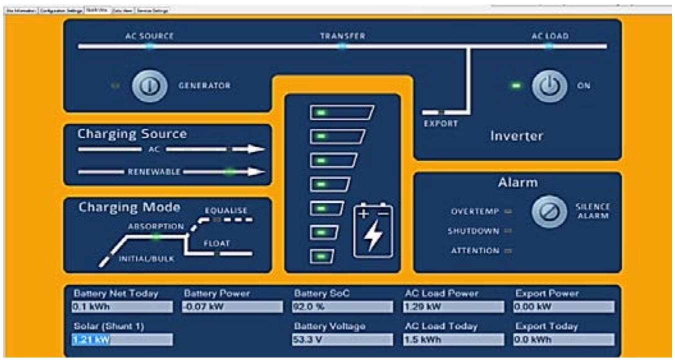


Figure 8.2 Quick View Screen of the SP Link software showing the live performance of the system

Table 8.1: Daily event description for the experiment conducted with the value of external load equivalent to PV output power for Phase 2 experiment

Date	Experimental Description	Event Schedule	Daily Event description and HRES performance interpretations from the Performance graphs
8.5.2018	Experiment to understand the HRES performance in the presence of an external load.	An external load with the value equivalent to PV output was connected to the HRES at 10:.30a.m and was disconnected at 3:15p.m.	➢ *PV output power:* From Figure 8.3, • Between 8:00a.m and 10:30a.m: PV output power was used to charge the batteries • At 10:30a.m.: the external load was connected at, • At 3:15p.m: the external load was disconnected and • Between 10:30a.m and 3:30p.m: PV output was maximum. • PV output power: At 8:15a.m: Gradually increases from 0.15kW. At 10:00 am: PV output is 0.360kW. At 10:30a.m: PV output peaked to 1.06kW By 11.45a.m: PV output reduced to 0.37kW By noon: PV output was maximum of 1.28kW. At 3:00p.m: PV output reduced to a minimum value of 0.1kW. • Due to the overcast day, there was considerable variation in the PV output observed. This confirms the solar availability window narrowing with the seasonal variation in Melbourne. ➢ *The Load A.C. Power (Average) and A.C. Load Support Power* • The Load A.C. Power (Average) and A.C. Load Support Power plots mostly superimpose on one another (not exactly though, as the PV output was drastically varying due to the overcast weather). This confirms the external load was kept almost equal to the PV output power. ➢ *Battery Voltage, Battery current and Battery SOC:* • From Figures 8.4 and 8-.5, At 10:15a.m: Battery voltage reach a maximum of: 55.2V Maximum battery current: 15.65A. Maximum battery SOC: approximately 91.5%.

			A.C. Load Power: • The Load A.C. Power (Average) and A.C. Load Support Power plots superimpose on one another precisely, this confirms the external load was kept equal to the PV output power. ➢ *Accumulated energy of the battery output, solar output:* From Figure 8.6, • Total A.C. load on that day : 6.41kWh • Total PV output: 4.87kWh. • Accumulated battery output: 1.55kWh. • Figure 7-62 implies, for a typical house having energy consumption approximately about 6kWh, the load can be met by the PV and battery if the solar output is similar to 8.5.2018. ➢ *Battery voltages and D.C. currents:* From Figures 8.7 and 8.-8 • Between 8:30a.m to 2:00p.m: the battery was charged by the PV, this is visible form the increasing battery voltages and D.C. current from the plots. • Maximum average D.C. voltage: 55.21V • Maximum net D.C. current:15.65A ➢ *Temperatures of batteries, transformer and heatsink*: From Figure 8.-9, • Battery temperature: maintained below 25^0C, which is the optimum value. • The maximum value of temperature of transformer:37^0C • The maximum value of temperature of heatsink: 44^0C.

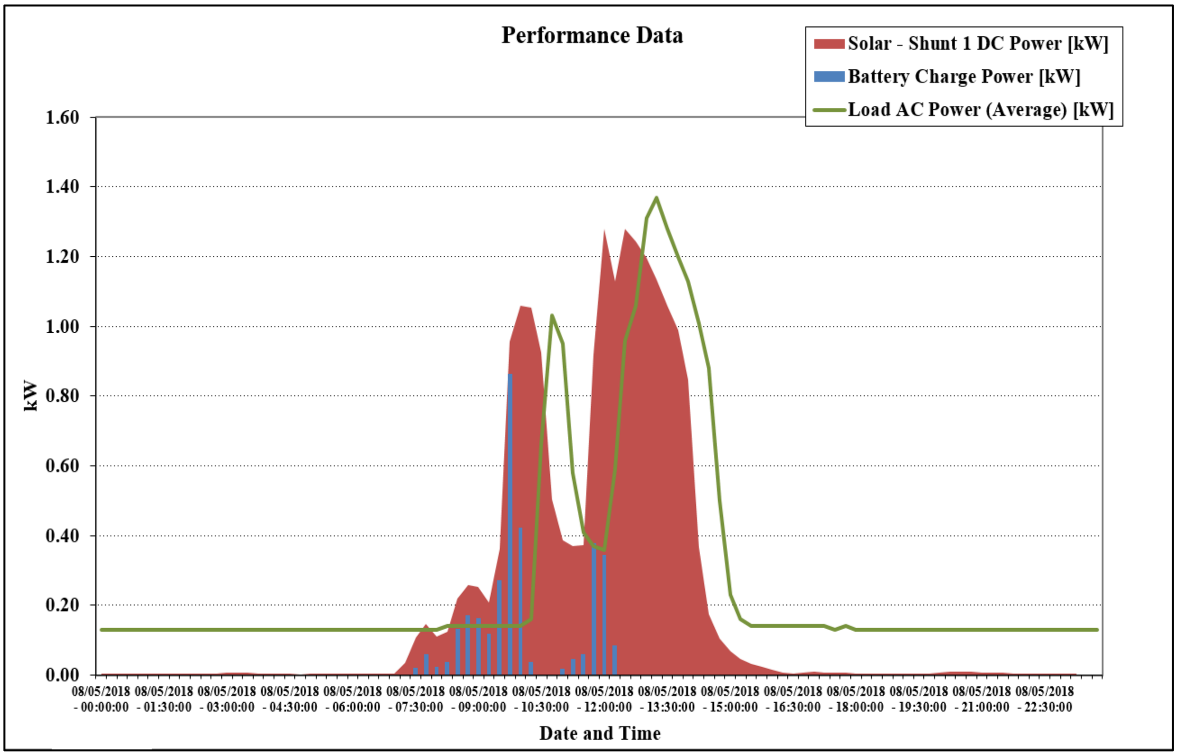


Figure 8.3 Performance Data of the system on 8.5.2018

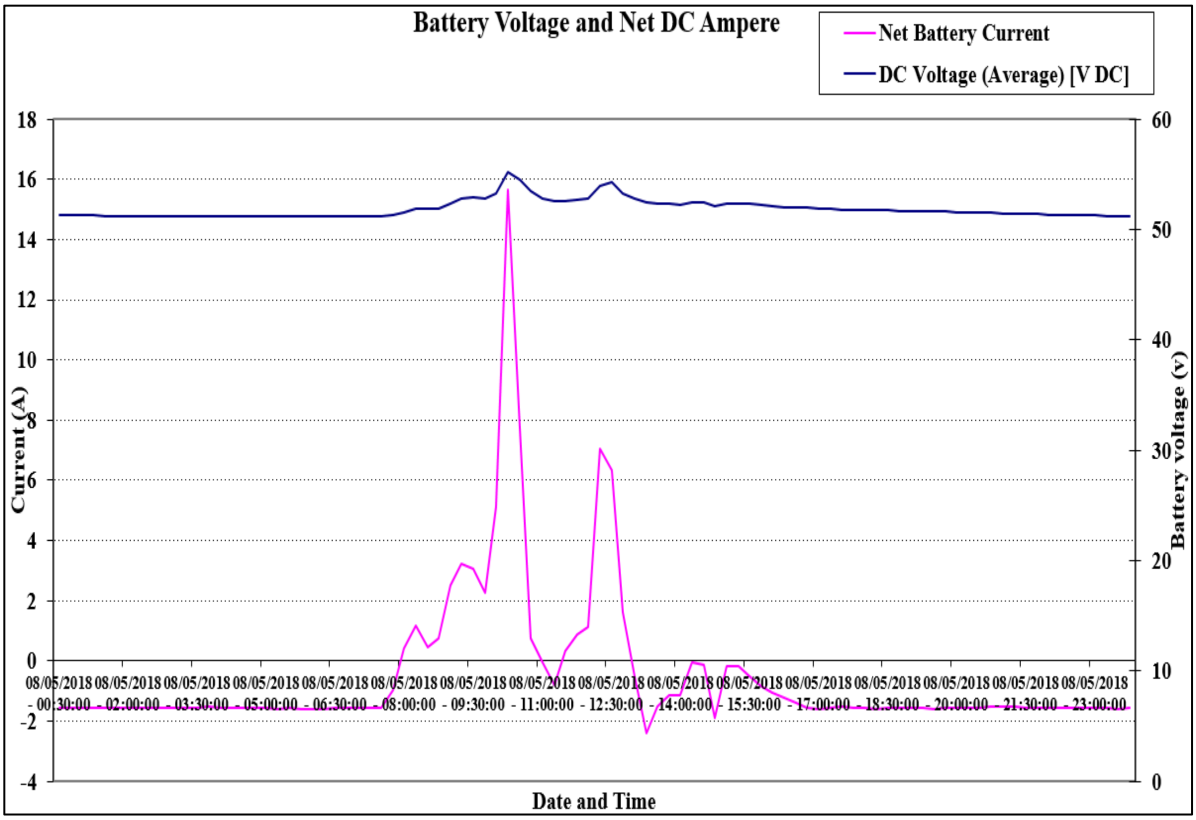


Figure 8.4 Battery Voltage and Net Battery Current Values

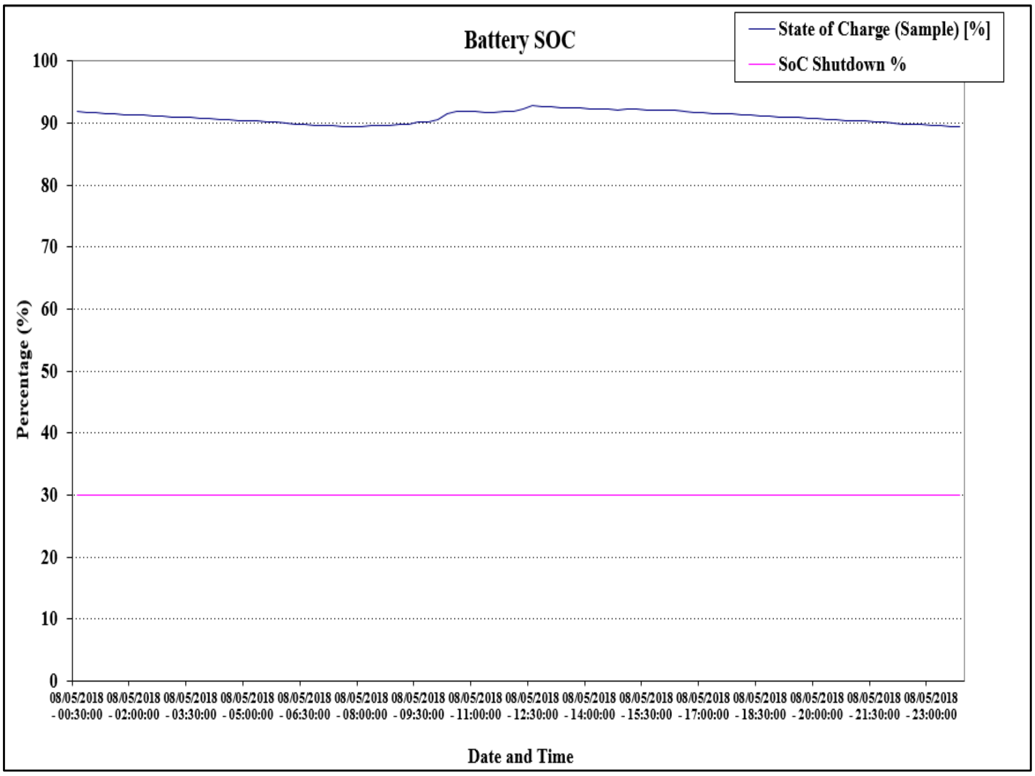


Figure 8.5 Battery SOC readings

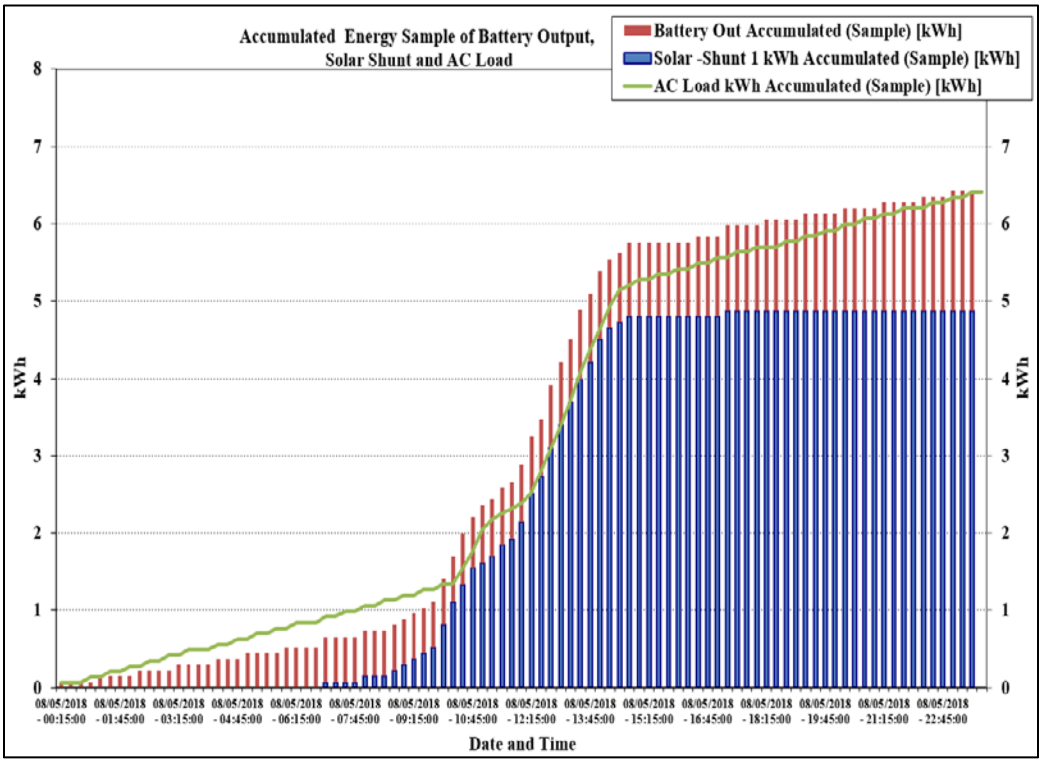


Figure 8.6 Accumulated energy of Battery, PV (Solar shunt) and A.C. Load for the day (on 8.5.2018)

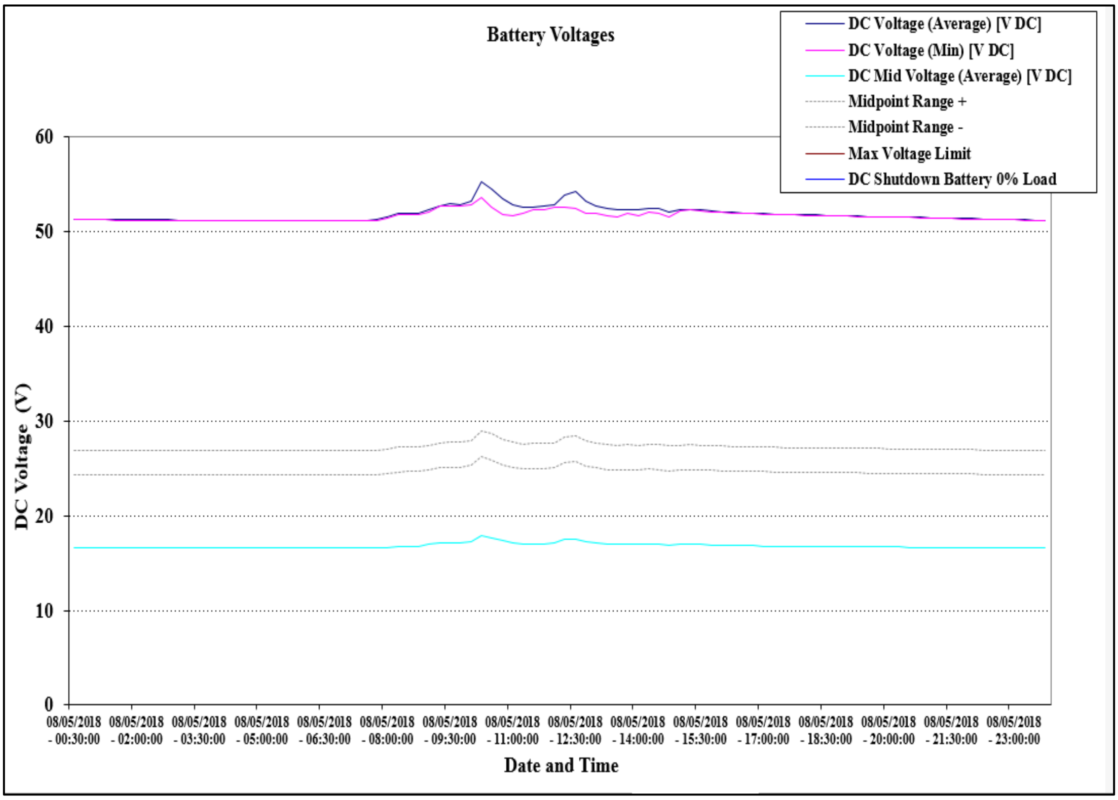


Figure 8.7 Battery Voltages with reference

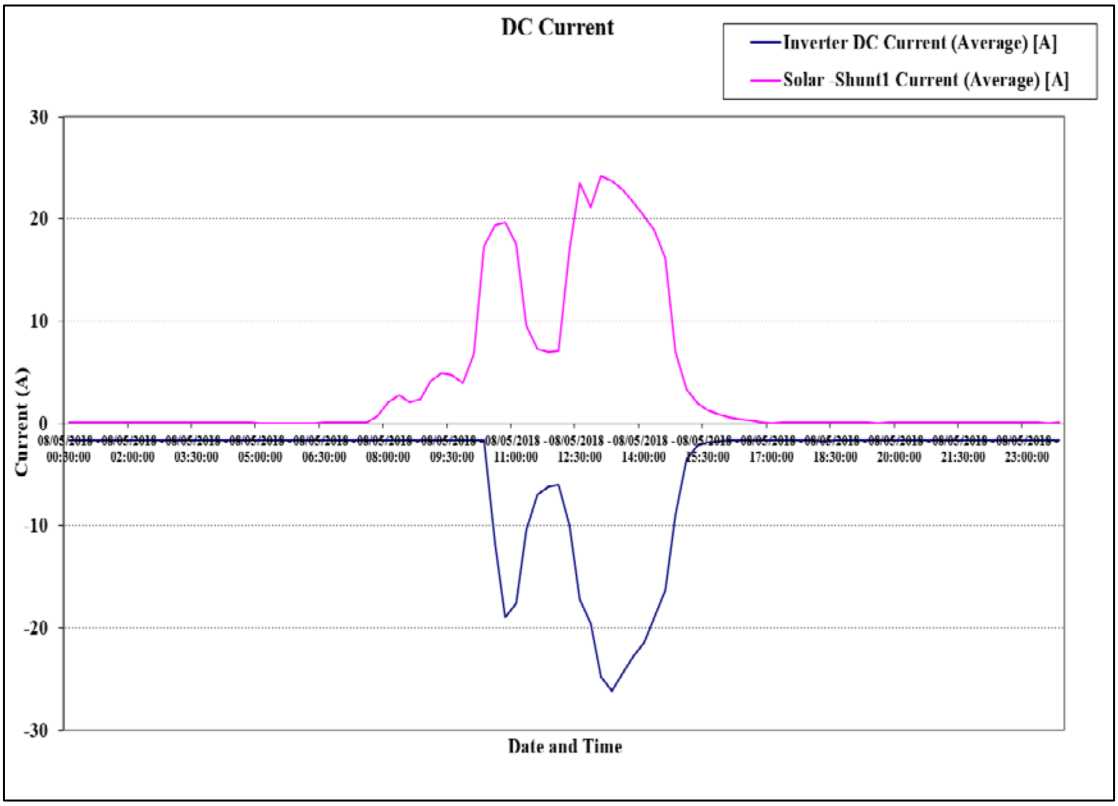


Figure 8.8 D.C. Currents of the system to the pre-set reference voltages

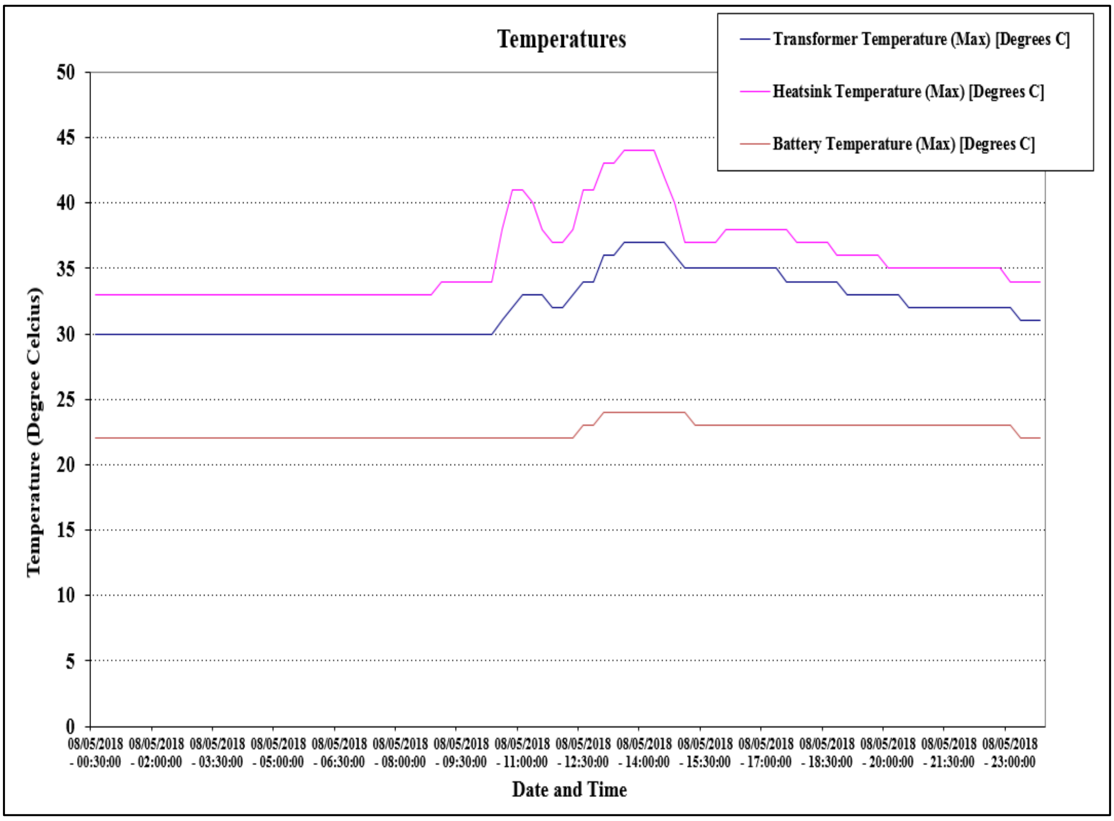


Figure 8.9 Temperatures of Transformer, Heatsink and Battery

8.2.1.2 For Constant load of approx. 2kW

In this experiment, the load was kept to a constant value of 2kW. 2kW is the PV capacity at VU, and hence 2kW load was used to perform this experiment with the updated storage setup in the micro-grid.

8.2.1.2.1 Worst case scenario: when the PV output was considerably low

In this experiment, the worst case scenario of the micro-grid performance is discussed when the availability of solar energy was very low due to overcast weather. It can be noticed from the Quick View screen of the SP Link software that, the PV output is lower than 0.5kW to supply enough power to charge the battery or meet the load. This can be noted from the power output of the Shunt (PV) in Figure 8.10. The description of the performance of the HRES when the experiment is conducted is explained in Table 8.2.

On the day the experiment was performed the maximum output from PV was by 12:00p.m of 1.49kW and the PV output gradually reduced after 4:00p.m. A constant 2kW load was connected to the system. At any instant of time, the A.C. load was met by the battery and PV output. This was until the SOC of the battery was approximately 60%, when the SOC of the battery reduced to 60%, the A.C. grid charged the battery and until the battery SOC reached 70%. With the available PV output and the battery power, the external 2kW A.C. load was met until about 3:00pm. The battery voltage maximum value of 53.4V before the external load was connected at 10:30a.m while the current reached a maximum of 61.48A. Due to the presence external load, there was approximately 10.7kWh of total A.C. load on that day. 2.51kWh is the total PV output and 7.68kWh is the accumulated battery output by the end of the day. Since the PV output was considerably low during the day, this experiment was considered as the worst case scenario to understand the working of HRES at VU micro-grid.

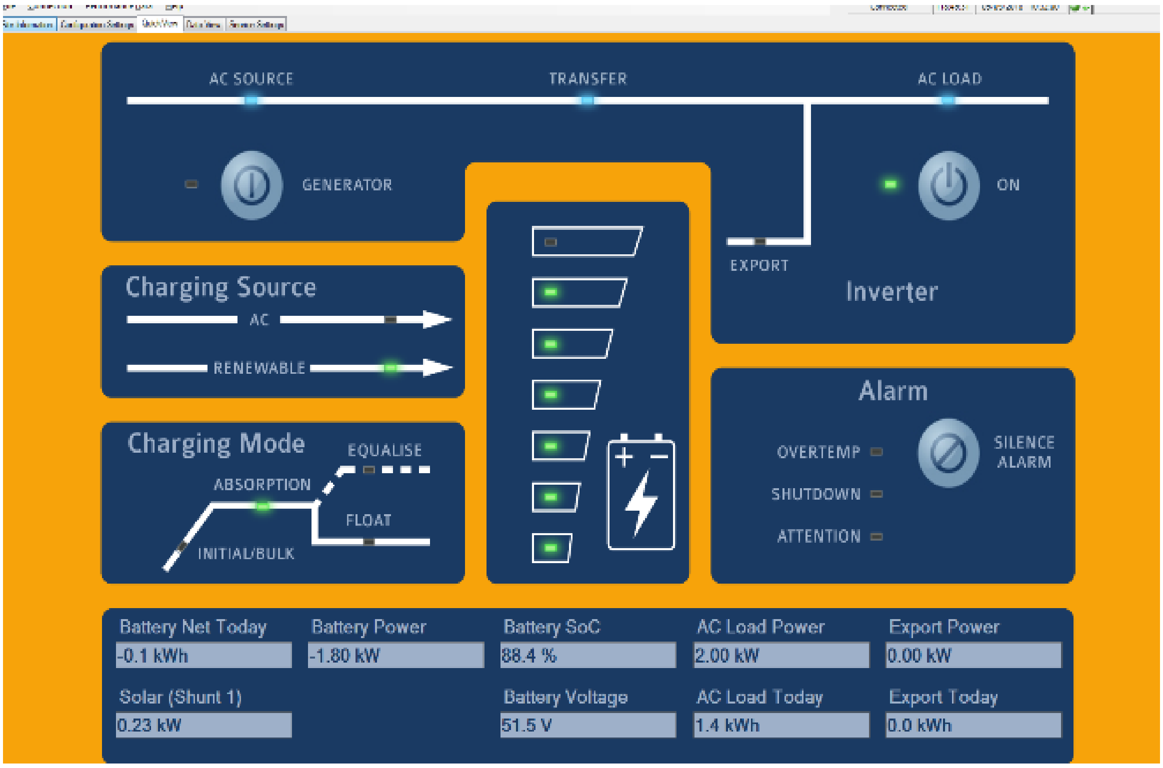


Figure 8.10 Quick View Screen of the SP Link software showing the live performance of the system

Table 8.2 Daily event description for the experiment conducted with the value of external load 2kW for Phase 2 experiment (Worst case scenario)

Date	Experimental Description	Event Schedule	Daily Event description and HRES performance interpretations from the Performance graphs
9.5.2018	Experiment to understand the HRES performance in the presence of an external load.	An external load with the value of 2kW was connected to the HRES at 10:32a.m.The external load was disconnected around 3:00p.m. (PV output was low due to overcast day, hence this experiment has been considered as experiment conducted for the worst case scenario. Battery discharged some power (until SOC reaches 60%) at every instant of time to meet the 2kW load along with the PV)	➢ *PV output power:* From Figure 8.11, • PV convers incident solar energy into useful energy from 7:00a.m until 10:32a.m (until load is connected). This is shown as battery charge power plot shown in the Performance data plot. • PV output power at : 8:00a.m : 0.1kW 12:00pm: 0.84kW 1:30p.m:0.26kW 4:30p.m: 0.04kW ➢ *A.C. Load Power:* • 2.0kW of the load that was set, at 10:30a.m, was met by PV and the battery. As the battery SOC reduced to 60%, the grid supplied power to charge the battery and also meet the load. This is observed in Average A.C. load curve from Figure 8.11. ➢ *Battery Voltage, Battery current and Battery SOC:* From Figures 8.12, • Battery voltage at: Start of the day:51.1V, 10:15a.m: maximum value of 53.44V , 2:15p.m: Minimum battery voltage of 49V (Grid exported power to charge the battery when the SOC reduced to 60%), 3:00p.m:53.3V End of the day: 50.68V

			• Battery current at: Start of the day:-1.55A, 10:15 am:6.17A, 2:15p.m:-40.54A(negative value of current illustrates the battery discharging the power) 3:00:p.m:61.48A End of the day:-1.51A From Figure 8.13, • SOC of the battery at: Start of the day: 89.2% 10:15a.m: 88.3% 2:15p.m: 60.9% 3:00p.m: 68.4% End of the day:67.8% ➢ *Accumulated energy of the battery output, solar output:* From Figure 8.14, • 10.7kWh is the total A.C. load on that day, • 2.51kWh is the total PV output and • 7.68kWh is the accumulated battery by the end of the day. This implies, with PV, battery and A.C. grid, the micro-grid has the capacity to meet a load of approximately 11kWh. ➢ *Temperatures of batteries, transformer and heatsink:* From Figure 8.15, • The maximum temperature reached by: Transformers: 64^0C, Heatsink: 54^0C, Batteries: 23^0C

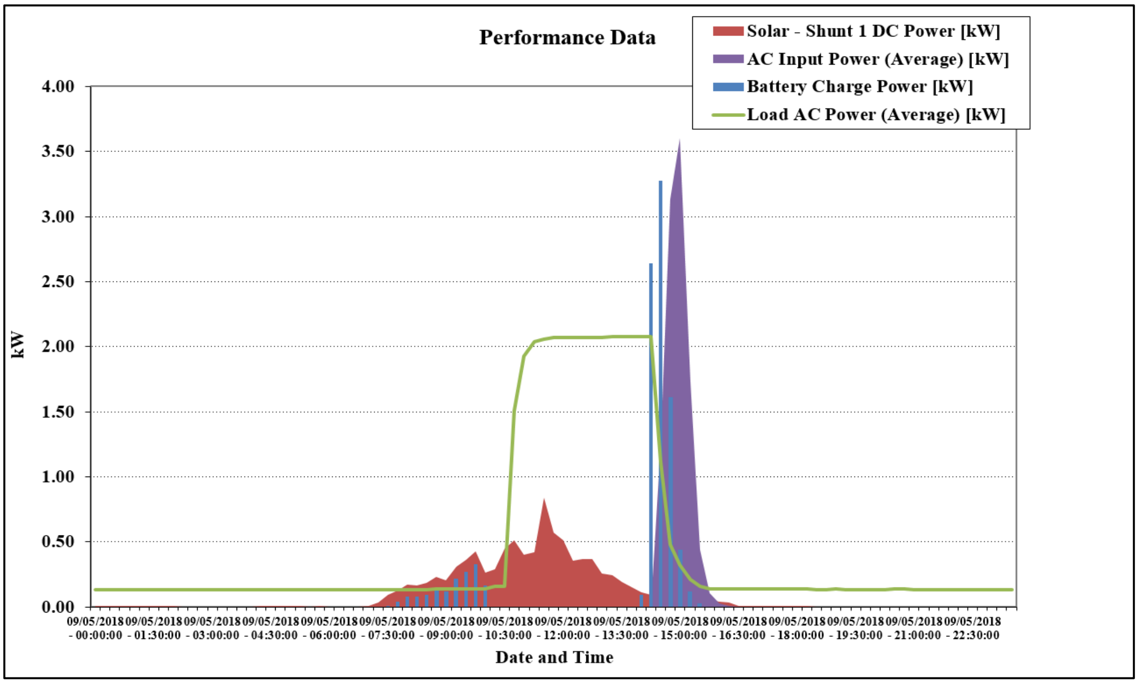


Figure 8.11 Performance Data highlighting the Performance of PV, Battery and Load on 9.5.2018

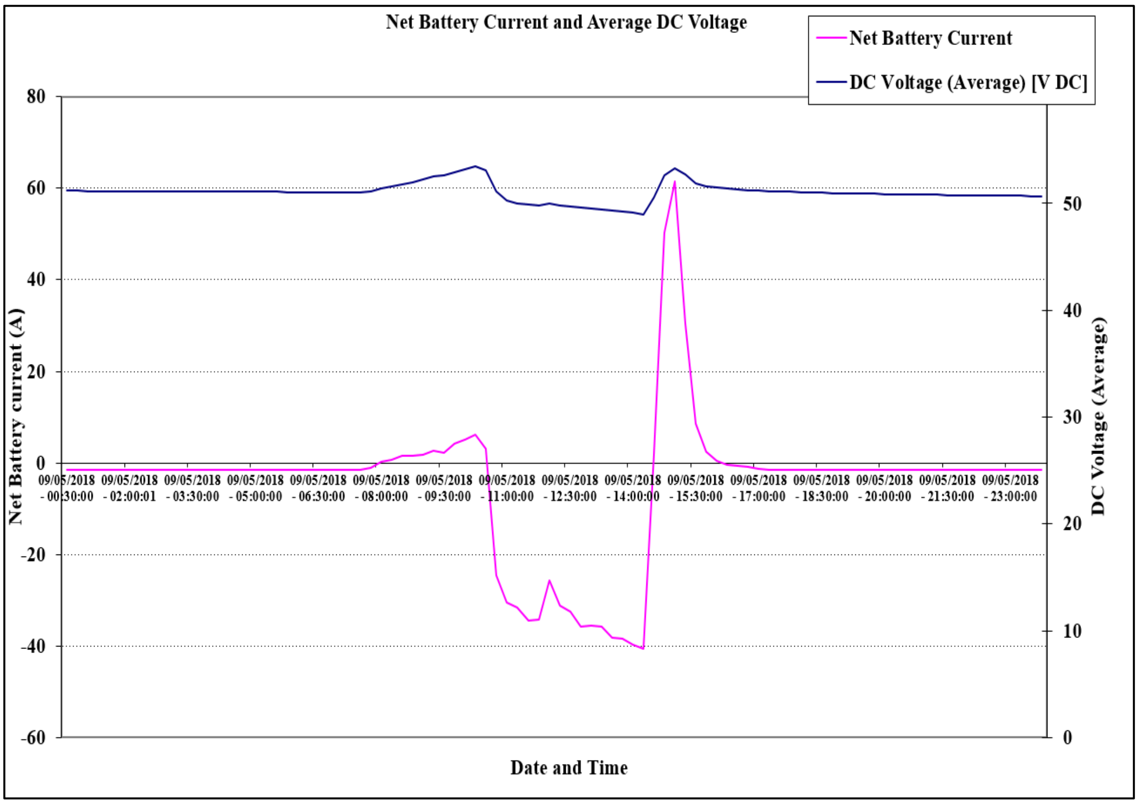


Figure 8.12 Battery Voltage and Net Battery Current of the system

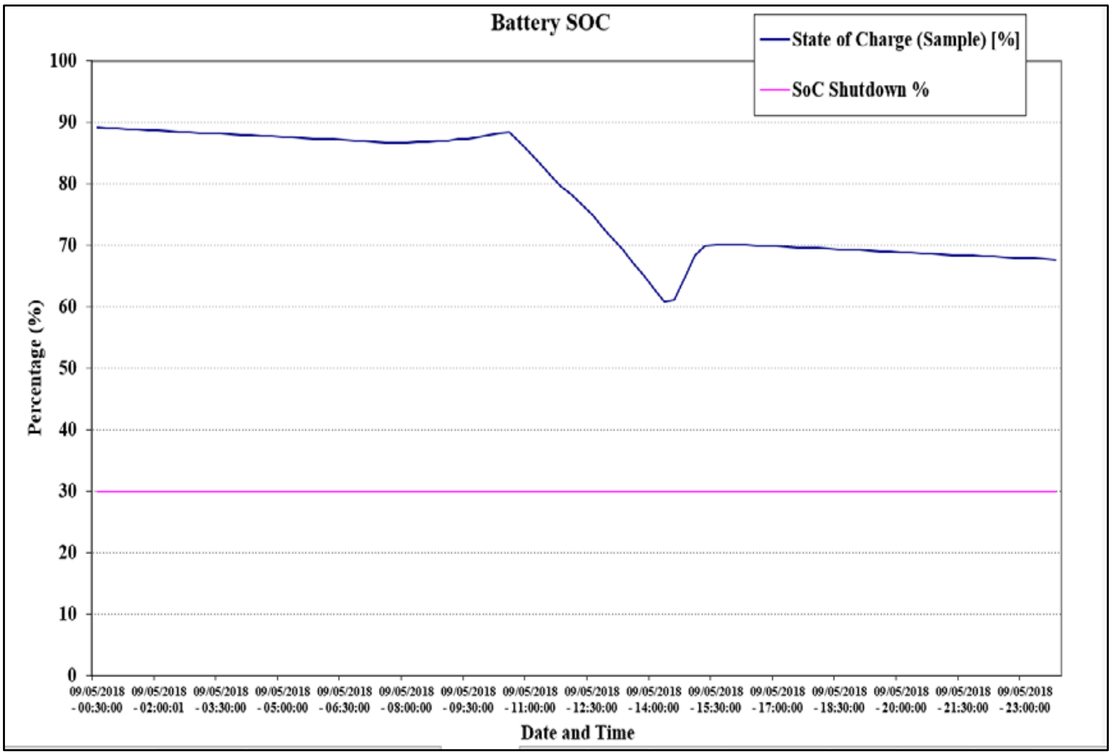


Figure 8.13 SOC of the Battery

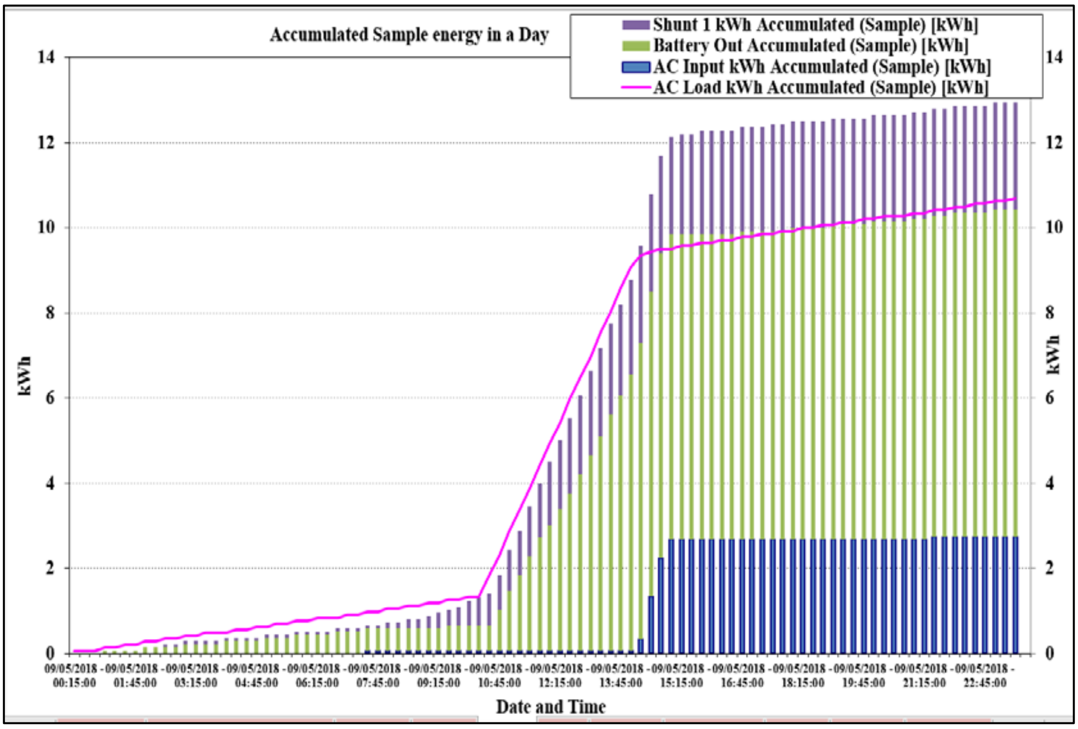


Figure 8.14 Accumulated energy of Battery, PV (Solar shunt) and A.C. Load for the day (on 9.5.2018)

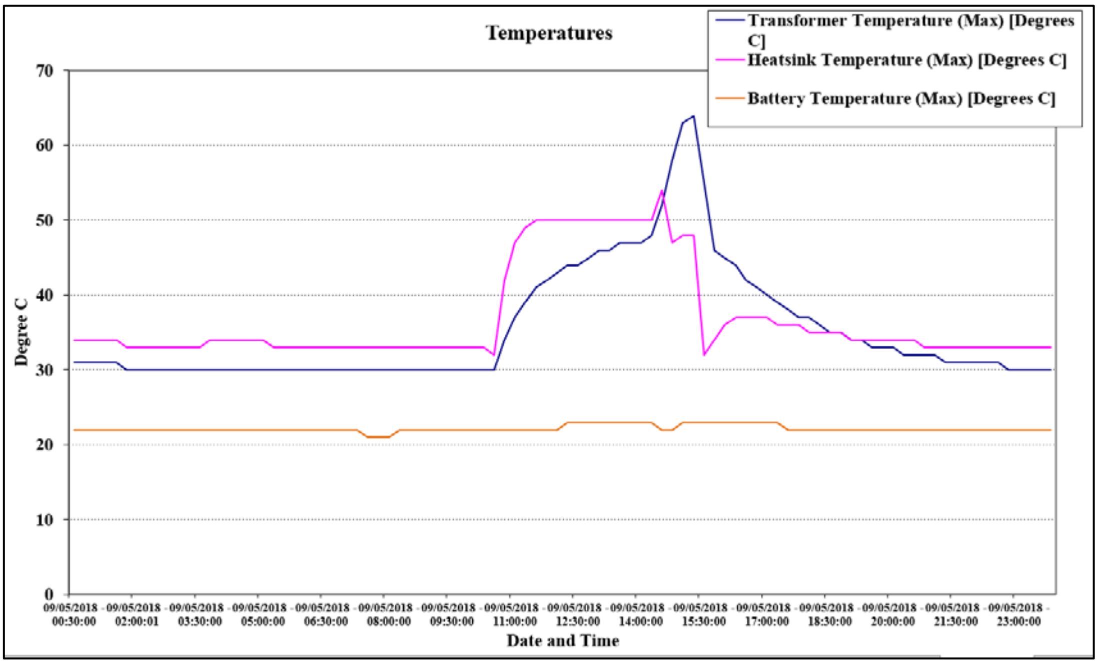


Figure 8.15 Temperatures of Transformer, Heatsink and Battery

8.2.1.2.2 Best Case Scenario: when the PV output is normal

The experiment in this section considers the study of micro-grid performance on a normal day in the month June (winter). This experiment was performed on 19.6.2018. The PV output was better compared to the previous scenario considered in Section 7.6.2.2.1. The battery was charged to 93% before the load was connected. Figure 8.16 and Figure 8.17 are the screen shots of Quick View screen of the software. This helps in comparing the data before the load was connected and just before the load was switched off. The description of the performance of the HRES when the experiment is conducted is explained in Table 8.3.

Considering the fact that the experiment was performed in the month of June (winter month), the maximum PV output during the day was 1.3kW by the noon. The output was not enough to meet the 2kW load. Thus batteries discharged some power at every instant of time to meet the 2kW load along with the PV. Around 10:30a.m when the load was connected, it is observed that, the solar output was 0.5kW. The SOC of battery was large to meet the 2kW load, this is evident from the Quick View screen from the Figure 8.16. The negative value of battery power in the Quick View screen relates to the battery discharging power to the meet the load as the PV output was insufficient. Thus, the SOC of the battery reached below 60%, the grid produced enough power to charge the batteries. At this instant of time, the load was disconnected around 3:45p.m. As the output from the

PV declined considerably to a minimum value, the external load was disconnected when the SOC of the battery touched close to 60%. Gradually, due to the presence of internal load, the battery SOC declined below 60%, the current from the grid surged in to charge the battery. At 3:45p.m, after the load was disconnected, PV and battery met the load of 12kWh, this is evident from the Quick View data shown in Figure 8-.17. This experiment showcases the micro-grid reliability even on the winter days like 19.6.18 when the sunlight is good enough to produce power to charge the batteries or meet the load. The external grid was always available to charge the battery and maintain the SOC of the battery to an optimum value. This shows the flexibility of the individual energy sources available at any instant to meet the load. This also helps in planning the energy consumption according to the energy availability

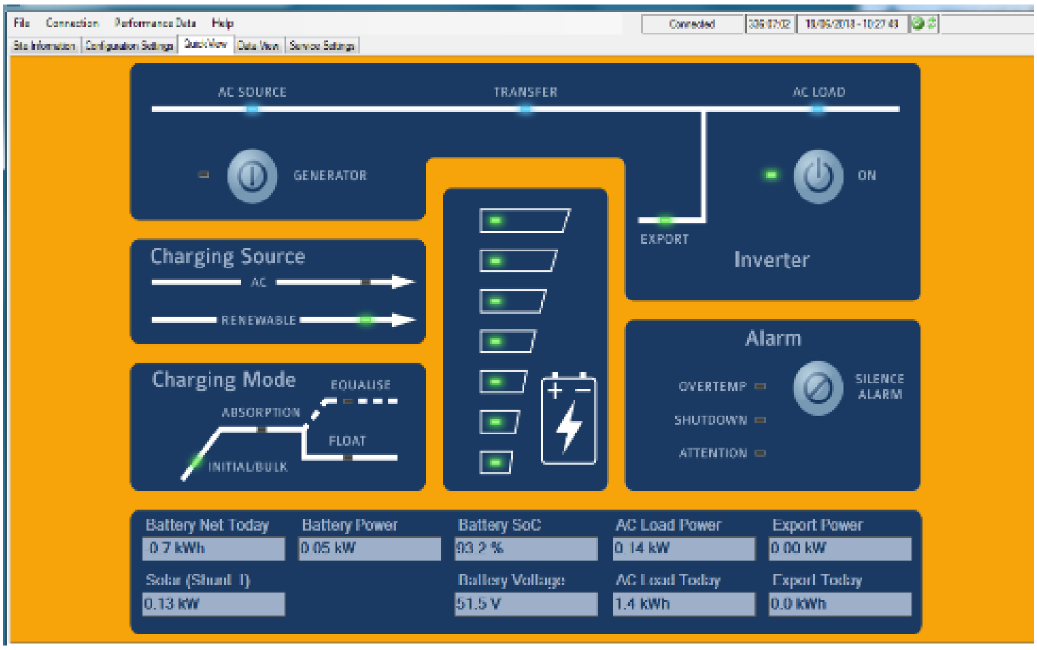


Figure 8.16 Quick View screen of SP Link software just before the load connection on 19.6.2018

On the day the experiment was performed the maximum output from PV was 1.31kW by 12:00p.m and the PV output gradually reduced after 4:00p.m. A constant 2kW load was connected to the system at 10:30a.m. At any instant of time, the A.C. load was met by the battery and PV output. This was until the SOC of the battery was approximately 60%, when the SOC of the battery reduced to 60%, the A.C. grid charged the battery and until the battery SOC reached 70%. With the available PV output and the battery power, the external 2kW A.C. load was met until about 3:45pm. The battery voltage reached a maximum value of 51.34V before the external load was connected at 10:30a.m while the current reached a maximum of 0.53A. Due to the presence external load, there was approximately13.45kWh is the total A.C. load on that. 3.84kWh is the total PV output and 8.86kWh is the accumulated battery by the end of the day. Since the PV output was considerably moderate during the day, this experiment was considered as the best case scenario to understand the working of HRES at VU micro-grid.

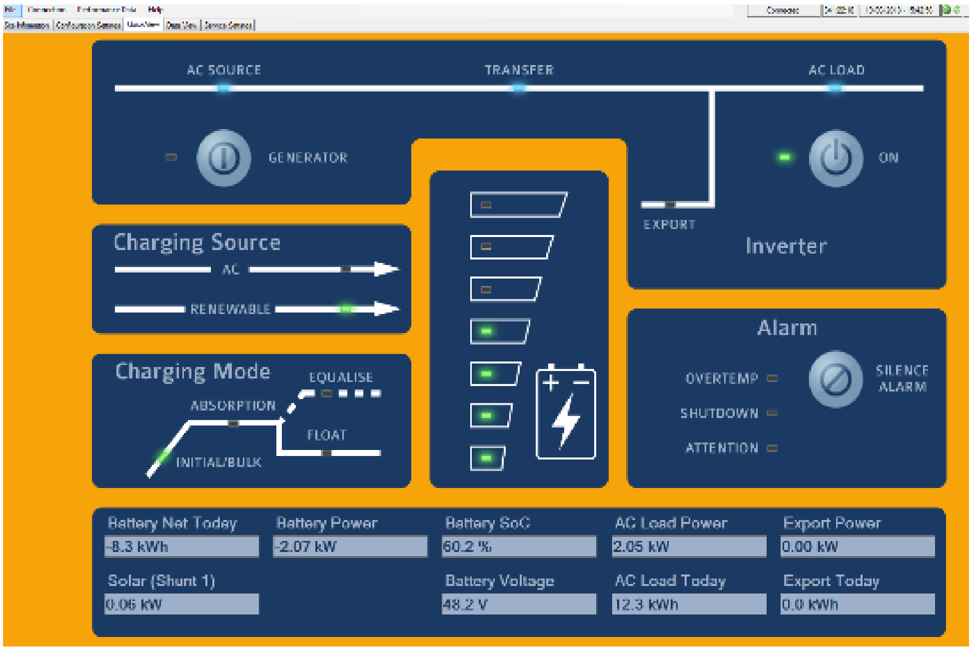


Figure 8.17 Quick View screen of SP Link software just after the load connection

This experiment explicates to the availability of high value of SOC from the batteries would be a supportive approach to meet the load at any instant due to the stochastic behaviour of RE. However, in this experiment, the load met by the end of the day is much higher than the average house load, the A.C. grid reliance is witnessed when the house load soars while the RE and battery power is not available. The stochastic behaviour of RE, the availability of the battery to supply the power as a main priority to meet the load in the absence of PV power and grid reliance when PV and battery power is insufficient to meet the load is scrutinised in this study. At any instant of time, the VU micro-grid is able to supply power to the load by RE, battery and grid (priority wise) is comprehended from this stud

Table 8.3 Daily event description for the experiment conducted with the value of external load 2kW for Phase 2 experiment (Best case scenario)

Date	Experimental Description	Event Schedule	Daily Event description and HRES performance interpretations from the Performance graphs
19.6.2018	Experiment to understand the HRES performance in the presence of an external load.	An external load with the value of 2kW was connected to the HRES at 10:30a.m.The external load was disconnected around 3:45p.m. (PV output was considerably moderate, hence this experiment has been considered as experiment conducted for the best case scenario. Battery discharged some power (until SOC reaches 60%) at every instant of time to meet the 2kW load along with the PV)	a. *PV output power:* From Figure 8.18, • PV convers incident solar energy into useful energy from 8:00a.m until 10:30a.m (until load is connected). This is shown as battery charge power plot shown in the Performance data plot. • PV output power at : 8:00a.m : 0.01kW 12:00pm: 1.31kW 2:00p.m:0.72kW 4:30p.m: 0.01kW b. *A.C. Load Power:* • 2.0kW of the load that was set, at 10:30a.m, was met by PV and the battery. As the battery SOC reduced to 60%, the grid supplied power to charge the battery and also meet the load. This is observed in Average A.C. load curve from Figure 8.18. c. *Battery Voltage, Battery current and Battery SOC:* From Figures 8.19, • Battery voltage at: Start of the day:51.09V, 10:30a.m: maximum value of 51.34V , 3:45p.m: Minimum of 48.35V (Grid exported power to charge the battery when the SOC reduced to 60%), End of the day: 50.05V • Battery current at: Start of the day:-1.58A, 10:15 am:0.53A, 3:30:p.m:-42.07

			End of the day:-1.58A From Figure 8.20, • SOC of the battery at: Start of the day: 95.8% 10:30a.m: 93.2% 3:45p.m: 60% End of the day:67.7% *d. Accumulated energy of the battery output, solar output:* From Figure 8.21, • 13.45kWh is the total A.C. load on that day, • 3.84kWh is the total PV output and • 8.86kWh is the accumulated battery by the end of the day. This implies, with PV, battery and A.C. grid, the micro-grid has the capacity to meet a load of approximately 13.5kWh. *e. Temperatures of batteries, transformer and heatsink:* From Figure 8.22, • The maximum temperature reached by: Transformers: 67^0C, Heatsink: 52^0C, Batteries: 25^0C

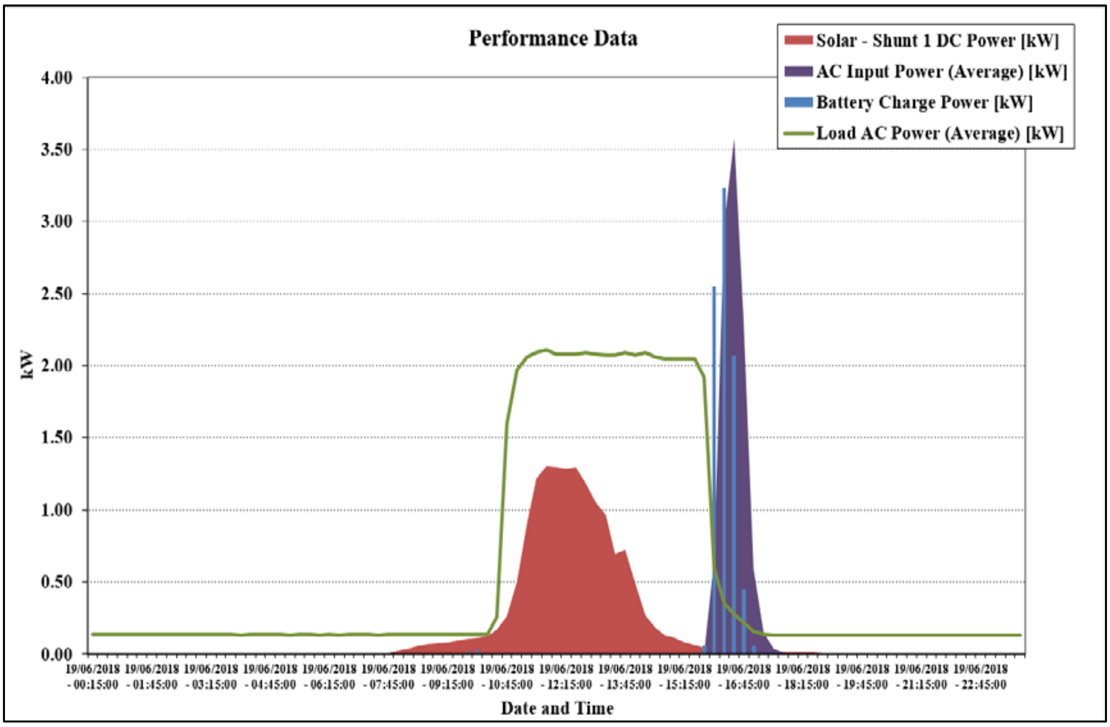


Figure 8.18 Performance Data highlighting the Performance of PV, Battery and Load on 19.6.2018

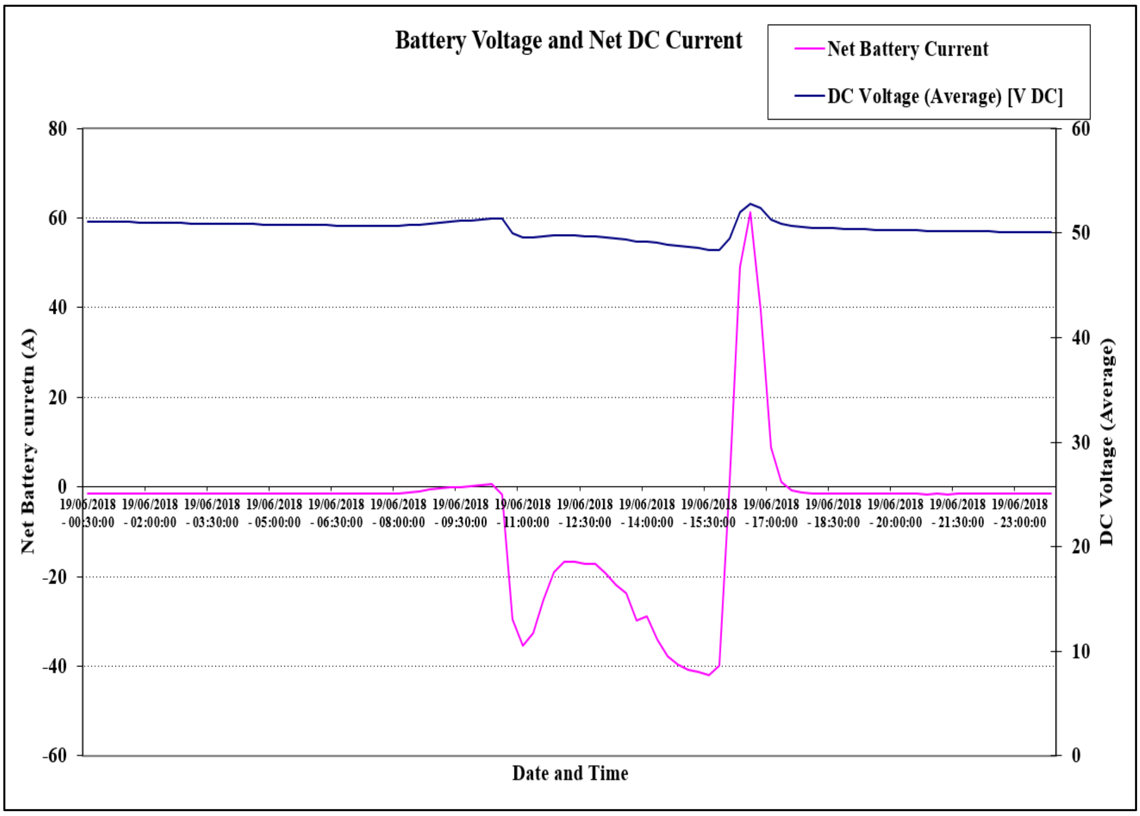


Figure 8.19 Battery Voltage and Net Battery Current of the system

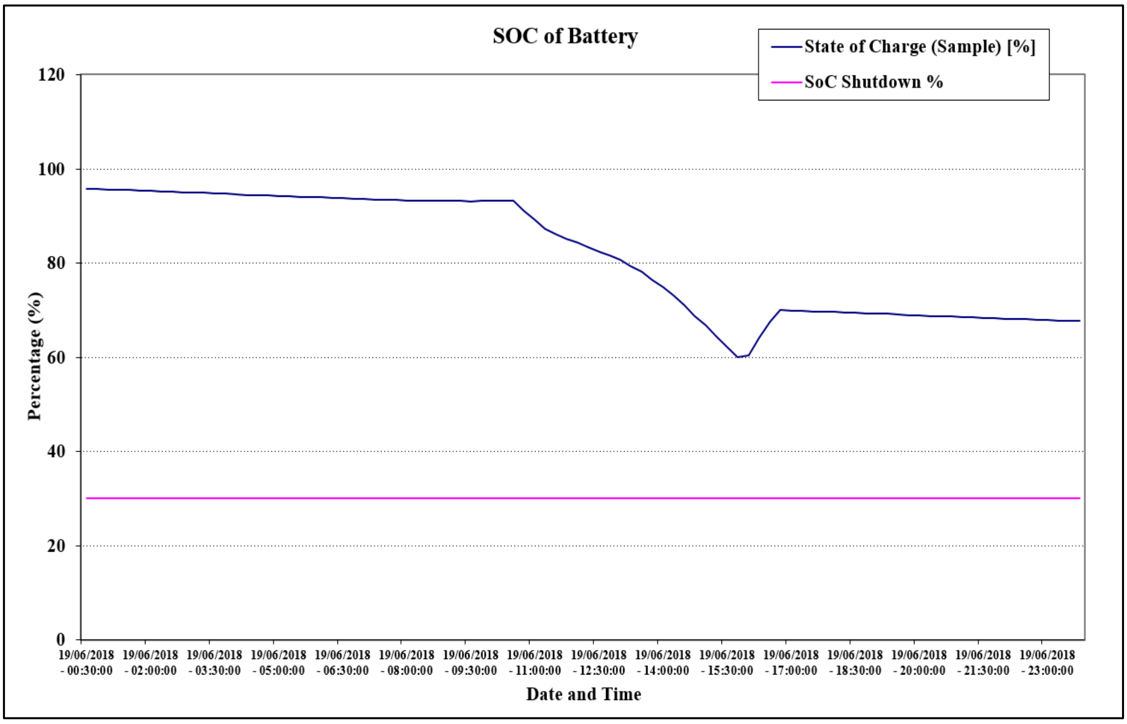


Figure 8.20 SOC of the Battery

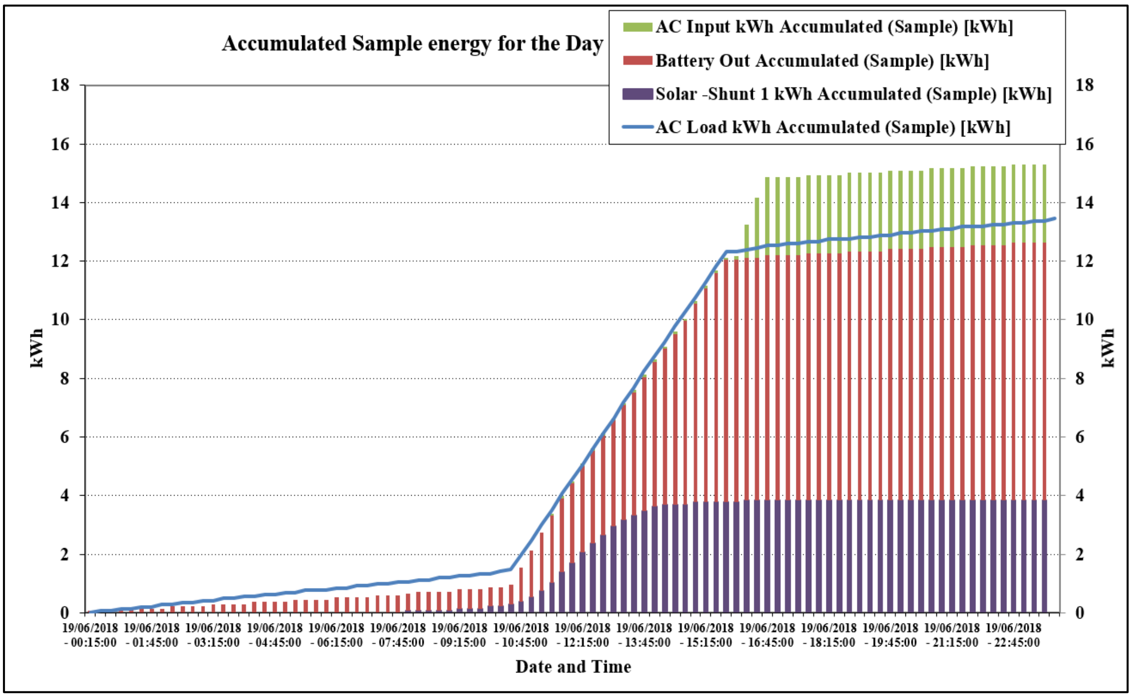


Figure 8.21 Accumulated energy of Battery, PV (Solar shunt) and A.C. Load for the day (on 19.6.2018)

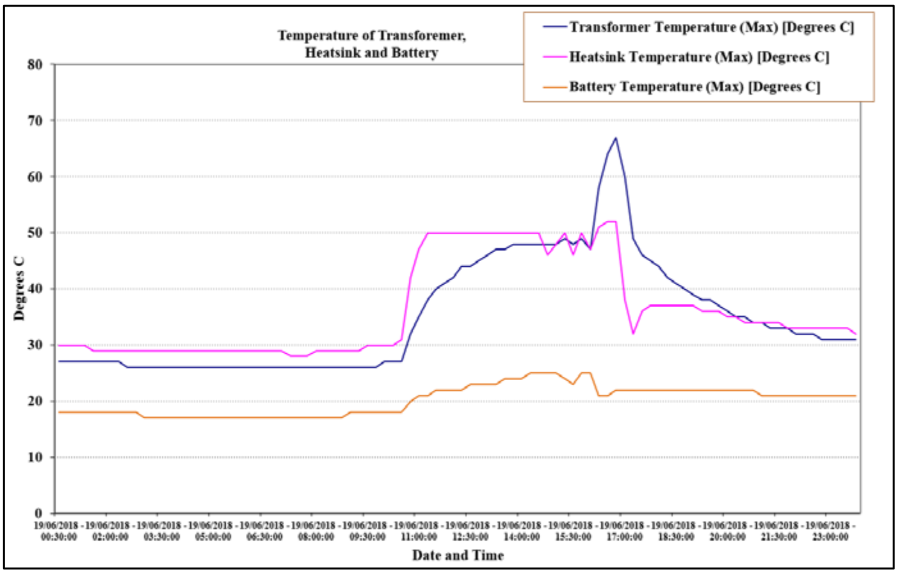


Figure 8.22 Temperatures of Transformer, Heatsink and Battery

8.2.1.3 For a Constant load of approx. 2kW in Spring Season

This experiment was performed to understand the PV availability in Victoria University (in Footscray) during the spring season and analyse the performance of the HRES. The experiments discussed in the Sections 8.2.1.1 and 8.2.1.2 were performed in autumn and winter seasons, hence the PV output were considerably minimal during these seasons. This experiment which is being discussed is performed on one of the days in spring season (26.9.2018). The PV output was comparatively greater as compared to the previous scenario considered in Section 8.2.1.2.2. The battery was charged to 97% before the load was connected. Figure 8.23 is the screen shot of Quick View screen of the software when the 2kW load was connected at 10.30a.m. This helps in understanding the PV, battery and load for that day. The description of the performance of the HRES when the experiment is conducted is explained in Table 8.4.

On the day the experiment was performed the maximum output from PV was by 11:45a.m of 1.61kW and the PV output gradually reduced after 4:00p.m. A constant 2kW load was connected to the system. At any instant of time, the A.C. load was met by the battery and PV output. With the available PV output and the battery power, the external 2kW A.C. load was met until about 5:15pm. As the PV output reduced to a minimum value, the external load was disconnected at 5:15p.m. The battery voltage maximum value of 55.88V and maximum current of 8.81A at 8:00a.m respectively. Due to the presence external load, there was approximately15.35kWh is the total A.C. load on that day.

7.39kWh is the total PV output and 7.39Wh is the accumulated battery output by the end of the day. Since the PV output was considerably relatively moderate during the day, this experiment was considered as the worst case scenario to understand the working of HRES at VU micro-grid. Hence this experiment has been considered as experiment conducted to understand the HRES performance in spring season. It has to be noted that the external grid was always available in case, to charge the battery and maintain the SOC of the battery to an optimum value. However, there was no role of external grid supply to meet the load or charge the battery for this experiment. This clearly highlights that weather plays a crucial role in the micro-grid performance when HRES is integrated into it. This shows the flexibility of the individual energy sources available at any instant to meet the load. This also helps in planning the energy consumption according to the energy availability

Figure 8.23 Quick View screen of SP Link software just before the load connection on 26.9.2018

Table 8.4 Daily event description for the experiment conducted with the value of external load 2kW for Spring season

Date	Experimental Description	Event Schedule	Daily Event description and HRES performance interpretations from the Performance graphs
26.9.2018	Experiment to understand the HRES performance in the presence of an external load.	An external load with the value of 2kW was connected to the HRES at 10:30a.m.The external load was disconnected around 5:15p.m. (PV output was considerably high due to Spring, hence this experiment has been considered as experiment conducted to understand the HRES performance in Spring season. Battery discharged some power at every instant of time to meet the 2kW load along with the PV throughput the day without the reliance on the external grid).	➢ *PV output power:* From Figure 8.24, • PV convers incident solar energy into useful energy from 8:00a.m until 10:30a.m (until load is connected). This is shown as battery charge power plot shown in the Performance data plot. • PV output power at : 6:30a.m : 0.01kW 8:00a.m: 0.58kW 10:15a.m: 0.23kW 11:45a.m: 1.61kW 4:30p.m: 0.05kW ➢ *A.C. Load Power:* • 2.0kW of the load that was set, at 10:30a.m, was met by PV and the battery until 5.15p.m. This is observed in Average A.C. load curve from Figure 8-24. ➢ *Battery Voltage, Battery current and Battery SOC:* From Figures 8.25, • Battery voltage at: Start of the day:51.72V, 8:00a.m: maximum value of 55.88V, 10:30a.m:55.3V, 3:45p.m: 50.5V, End of the day: 50.4V • Battery current at: Start of the day:-1.45A, 8.00a.m:8.81A 10:30a.m:1.78A, 3:45p.m:-2.34

			End of the day:-1.52A From Figure 8.26, • SOC of the battery at: Start of the day: 96.8% 8.00a.m:96% 10:30a.m: 97.7% 3:45p.m: 81.4% End of the day:68.6% ➢ *Accumulated energy of the battery output, solar output:* From Figure 8.27, • 15.35kWh is the total A.C. load on that day, • 7.39kWh is the total PV output and • 7.39Wh is the accumulated battery by the end of the day. This implies, with PV, battery and A.C. grid, the micro-grid has the capacity to meet a load of approximately 15.35kWh. ➢ *Temperatures of batteries, transformer and heatsink:* From Figure 8.28, • The maximum temperature reached by: Transformers: 34^0C, Heatsink: 36^0C, Batteries: 24^0C

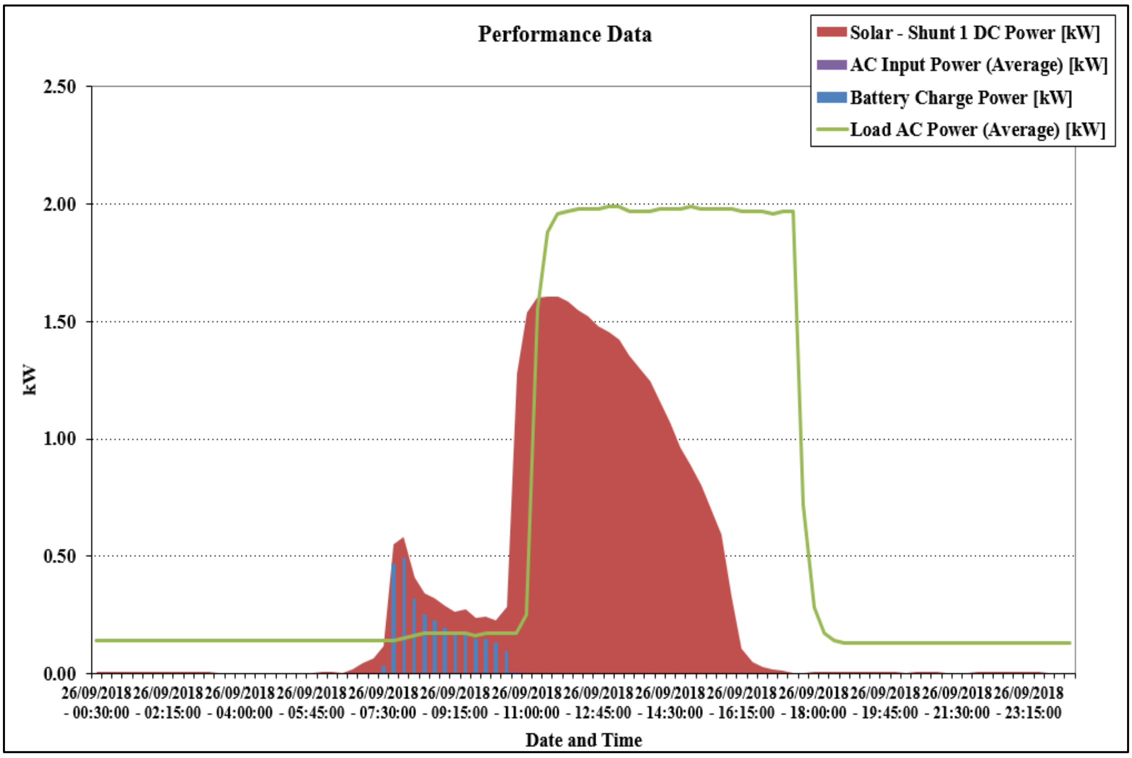


Figure 8.24 Performance Data highlighting the Performance of PV, Battery and Load on 19.6.2018

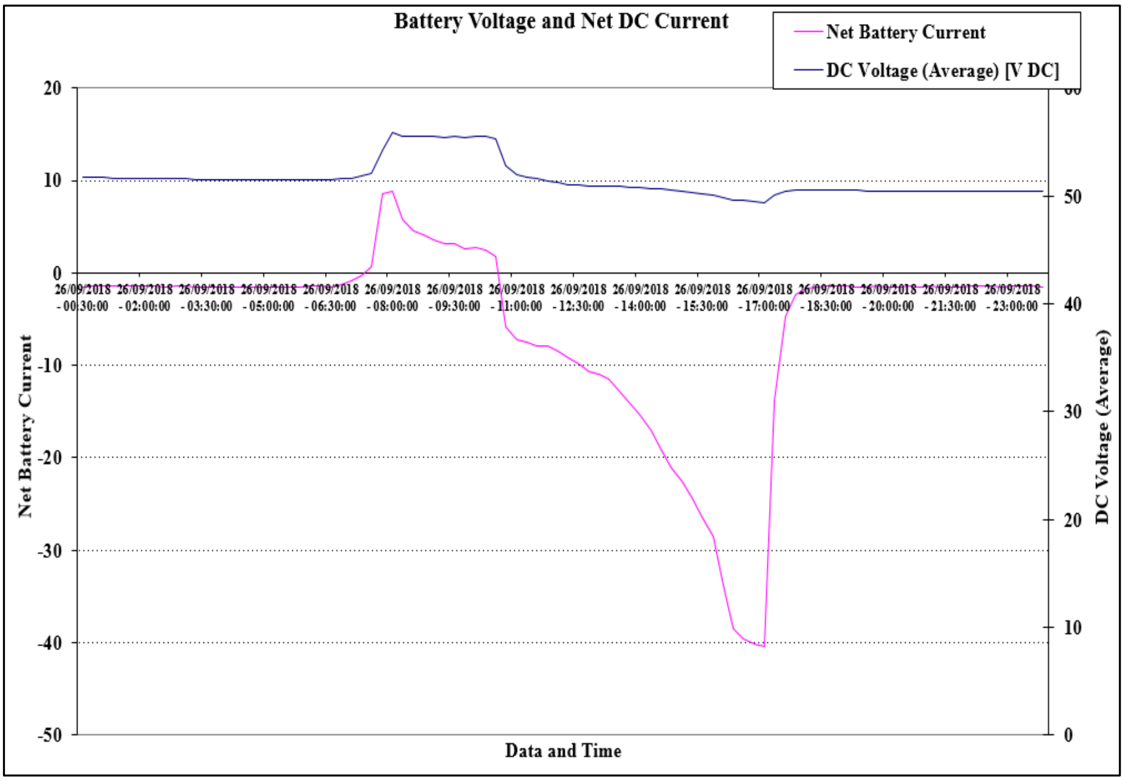


Figure 8.25 Battery Voltage and Net Battery Current of the system

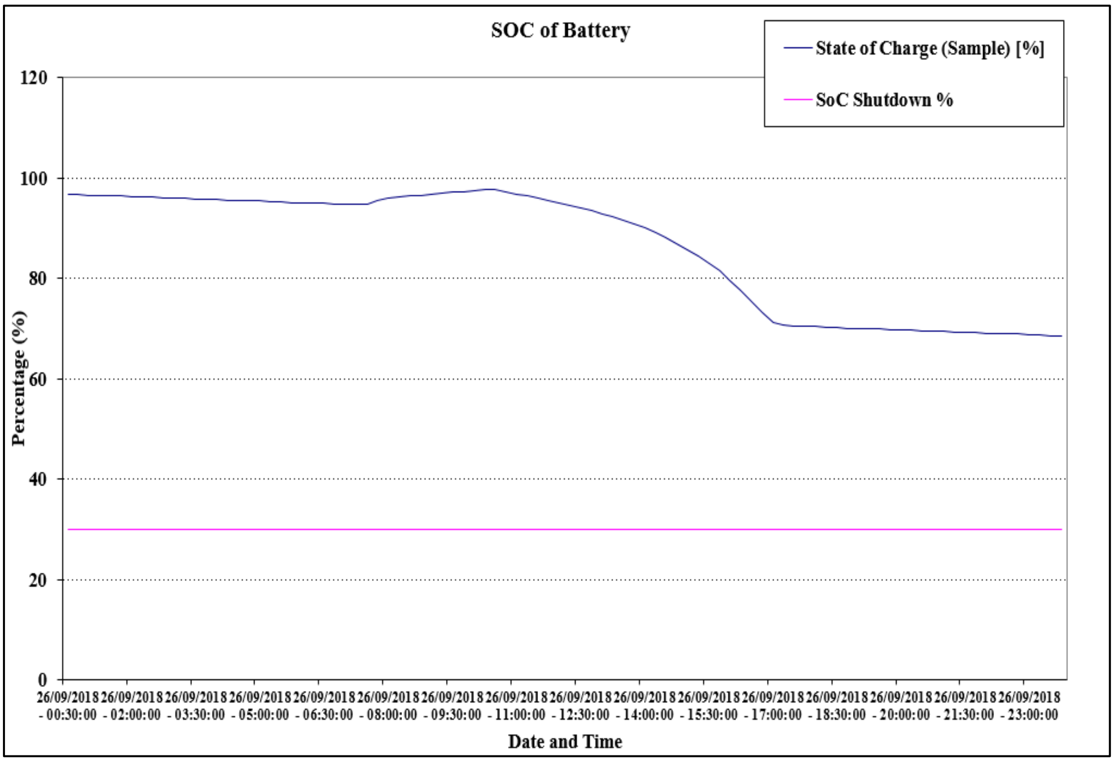


Figure 8.26 SOC of the Battery

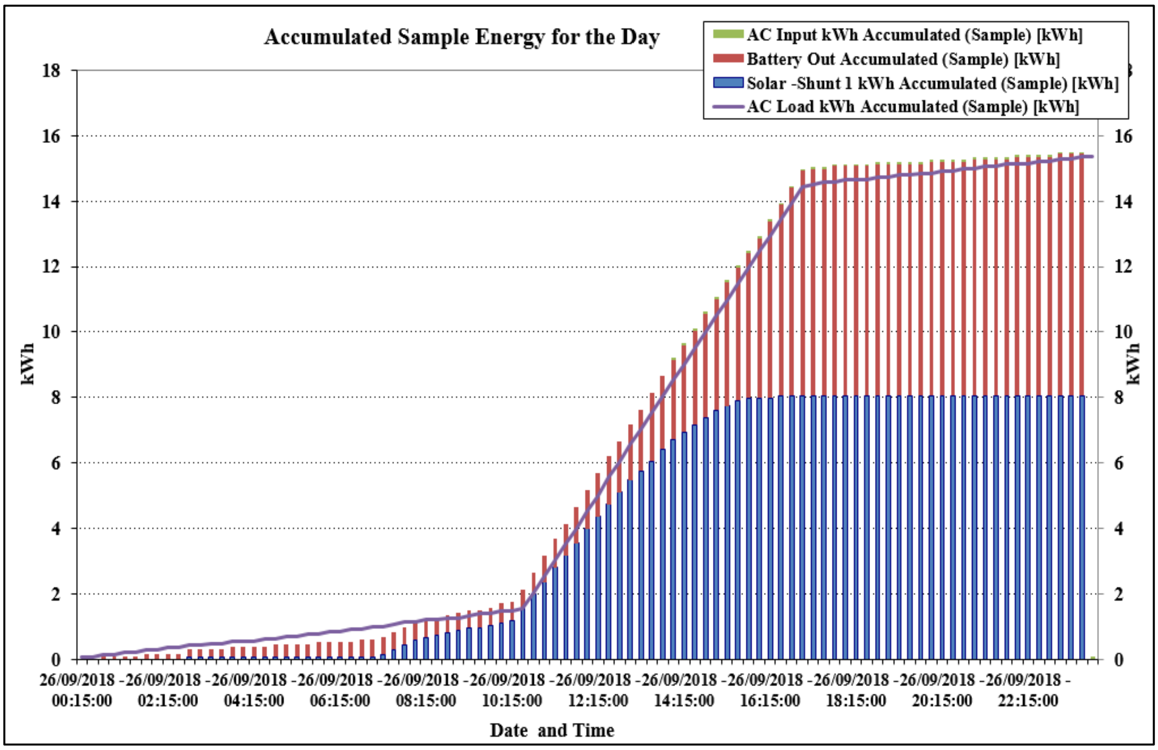


Figure 8.27 Accumulated energy of Battery, PV (Solar shunt) and A.C. Load for the day (on 26.9.2018)

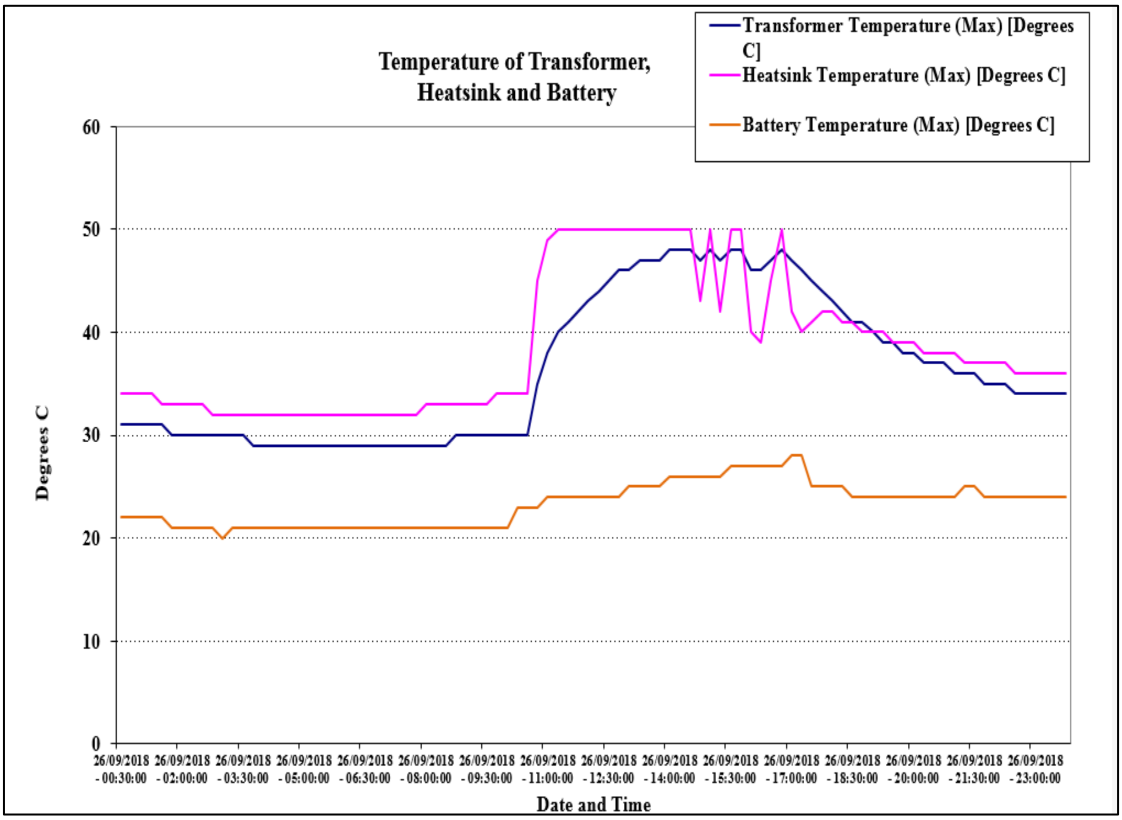


Figure 8.28 Temperatures of Transformer, Heatsink and Battery

This experiment explicates to the availability of high value of SOC from the batteries would be a supportive approach to meet the load at any instant due to the stochastic behaviour of RE. However, in this experiment, the load met by the end of the day is much higher than the average house load, the A.C. grid reliance is witnessed when the house load soars while the RE and battery power is not available. The stochastic behaviour of RE, the availability of the battery to supply the power as a main priority to meet the load in the absence of PV power and grid reliance when PV and battery power is insufficient to meet the load is scrutinised in this study. At any instant of time, the VU micro-grid is able to supply power to the load by RE, battery and grid (priority wise) is comprehended from this study. This experiment was studied to understand the PV larger PV power availability during spring season as compared to winter is highlighted. This has resulted in meeting large accumulated load and maintaining the SOC of the battery without the assistance of external A.C. load is understood.

8.2.2 Experiment with Variable Load

This experiment was performed to understand the behaviour VU micro-grid and its reliability when the external load is varied (unlike a constant load set to 2kW in Sections

7.6.1.2. and 7.6.2.2). It is very common to observe that the consumption load for a house or office building vary over time. This experiment highlights the compliance of VU micro-grid to meet such variable load power at any instant of time.

Figure 8.29 and Figure 8-.30 shows the Quick View screen of SP link software before the external load was connected and just after the external load being disconnected respectively. Prior to the external load connection at 10:30a.m, the PV output was approximately 0.2kW, an internal load of 0.15kW. Until then, PV and battery was available to support the internal load. This is represented as “Battery Net Today” value to be -0.6kWh in Figure 8.29. The SOC of the battery and battery voltage were 75.1% and 52.1V respectively before the load was connected at around 10:00a.m. It is evident that PV was charging the battery and battery was in absorption mode during this instant. From Figure 8.30 it is observed that, the PV output was not high (during 4:00p.m) and the SOC of the battery just reached 60%. The external load was switched off as the external grid was about to surge in power to charge the batteries. Until 4p.m, the battery discharged about 4.1kWh and A.C. load was 8.7kWh and the battery voltage declined to 49.4V. Table 8.5 comprehends the performance of HRES when the experiment was performed.

On the day the experiment was performed, certain value of load was fixed for certain time and was varied in different time steps, i.e., between 10.30a.m to 11.20a.m load of 1kW was set, 11.20a.m to 1:00p.m, 1.5kW of load was set and from 1p.m to 3:00p.m, 2kW of load was set. The maximum output from PV was by 12:30p.m of 1.36kW and the PV output gradually reduced after 4:00p.m. A constant 2kW load was connected to the system. At any instant of time, the A.C. load was met by the battery and PV output. This was until the external load was disconnected at 3:00p.m. However, it must be noted that at 3:45p.m the SOC of the battery was approximately 60%, when the SOC of the battery reduced to 60%, the A.C. grid charged the battery and until the battery SOC reached 70%. The battery voltage and current was of 54.65V and 61.31A respectively at 3:45p.m. Due to the presence external load, there was approximately 10.07kWh of total A.C. load on that day. 2.75kWh was the total PV output and 4.8kWh was the accumulated battery output by the end of the day. This experiment was performed to understand the compliance of VU micro-grid to meet such variable load power at any instant of time as battery discharged some power at every instant of time to meet the variable load along with the PV until the external load was disconnected.

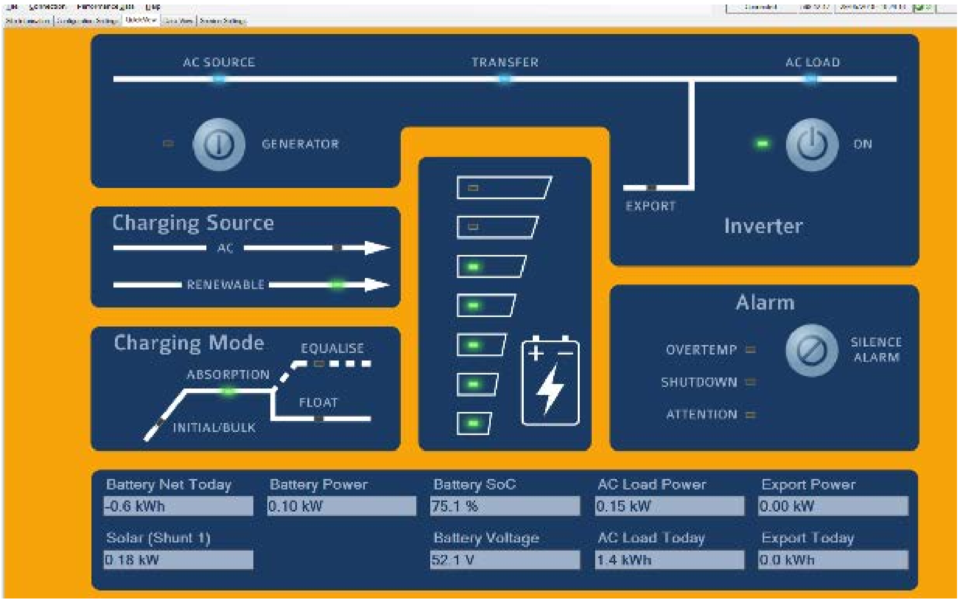


Figure 8.29 Quick View screen of SP Link software just before the load connection on 29.5.2018

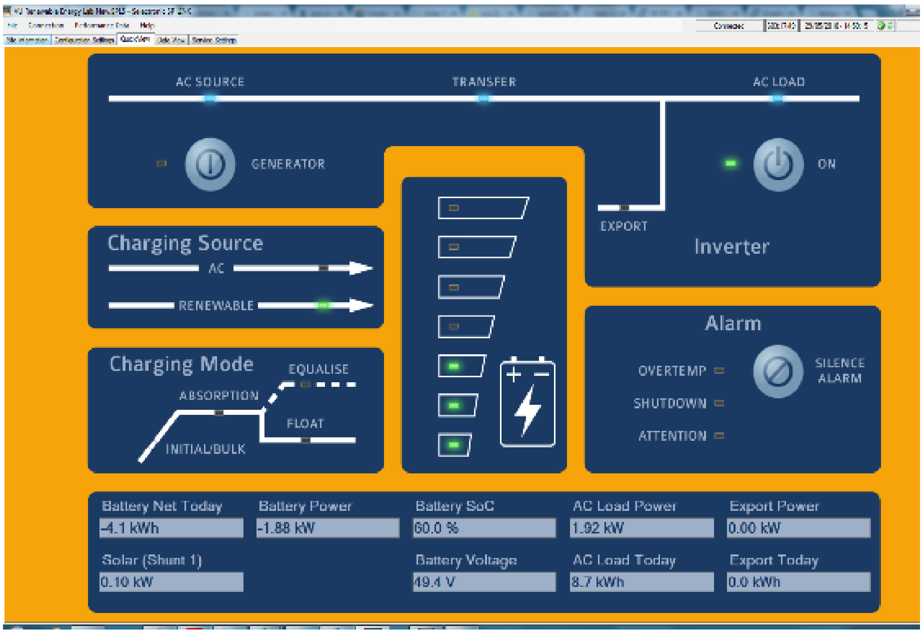


Figure 8.30 Quick View screen of SP Link software just after the load connection

This study was conducted to understand the performance of the VU micro-grid whne different vlaues of external load are set. The study implies that initial value of SOC plays a vital role in meeting the external load. However, it should be noted that the experiment was conducted during the weather transition from Autumn to Winter. This means, the PV availability is considerably less compared to the summer season. However, there are many performance aspects noted when these experiments were performed. These aspects have already been discussed in the Section 8.2 of this chapter.

Table 8.5 Daily event description for the experiment conducted with the variable external load value

Date	Experimental Description	Event Schedule	Daily Event description and HRES performance interpretations from the Performance graphs
29.5.2018	Experiment to understand the HRES performance in the presence of an external load.	An external load with different values was set at 10:30a.m.The external load was disconnected around 3:00p.m Variable load values set were: • 10:30a.m to 11:20a.m: 1kW • 11:20a.m to 1:00p.m: 1.5kW • 1:00p.m to 3:00p.m: 2kW (This experiment was performed to understand the compliance of VU micro-grid to meet such variable load power at any instant of time) Battery discharged some power at every instant of time to meet the variable load along with the PV throughput the day. Around 3.45p.m when the SOC of the battery reduced to 60%, the grid charged the battery while the external load was disconnected).	*a. PV output power:* From Figure 8.31, • PV convers incident solar energy into useful energy from 8:00a.m until 10:30a.m (until load is connected). This is shown as battery charge power plot shown in the Performance data plot. • PV output power at : 8:00a.m : 0.01kW 11:15a.m: 0.91kW 11:45a.m: 0.44kW 12:30p.m:1.36kW 4:30p.m: 0.01kW *b. A.C. Load Power:* • Variable load at 10:30a.m, at every instant of time until 3:00p.m was met by PV and the battery. At round 3.45p.m when the SOC of battery reduced to 60%, grid supplies power to charge the battery. This is observed in Average A.C. load curve from Figure 8.31. *c. Battery Voltage, Battery current and Battery SOC:* From Figures 8.32, • Battery voltage at: Start of the day:51.25V, 10:15a.m:51.93V, 3:45p.m: 54.65V, End of the day:51.28V • Battery current at: Start of the day:-1.5A,

			10:15a.m:1.06A, 3:45p.m:61.3A End of the day:-1.48A From Figure 8.33, • SOC of the battery at: Start of the day:77.5% 10.15a.m:75.1% 3:00p.m: 60% 4:00p.m:70% End of the day:67.5% *d. Accumulated energy of the battery output, solar output:* From Figure 8.34, • 10.07kWh is the total A.C. load on that day, • 2.75kWh is the total PV output and • 4.8kWh is the accumulated battery by the end of the day. This implies, with PV, battery and A.C. grid, the micro-grid has the capacity to meet a load of approximately 10kWh. *e. Temperatures of batteries, transformer and heatsink:* From Figure 8.35, • The maximum temperature reached by: Transformers: 62^0C, Heatsink: 51^0C, Batteries: 23^0C

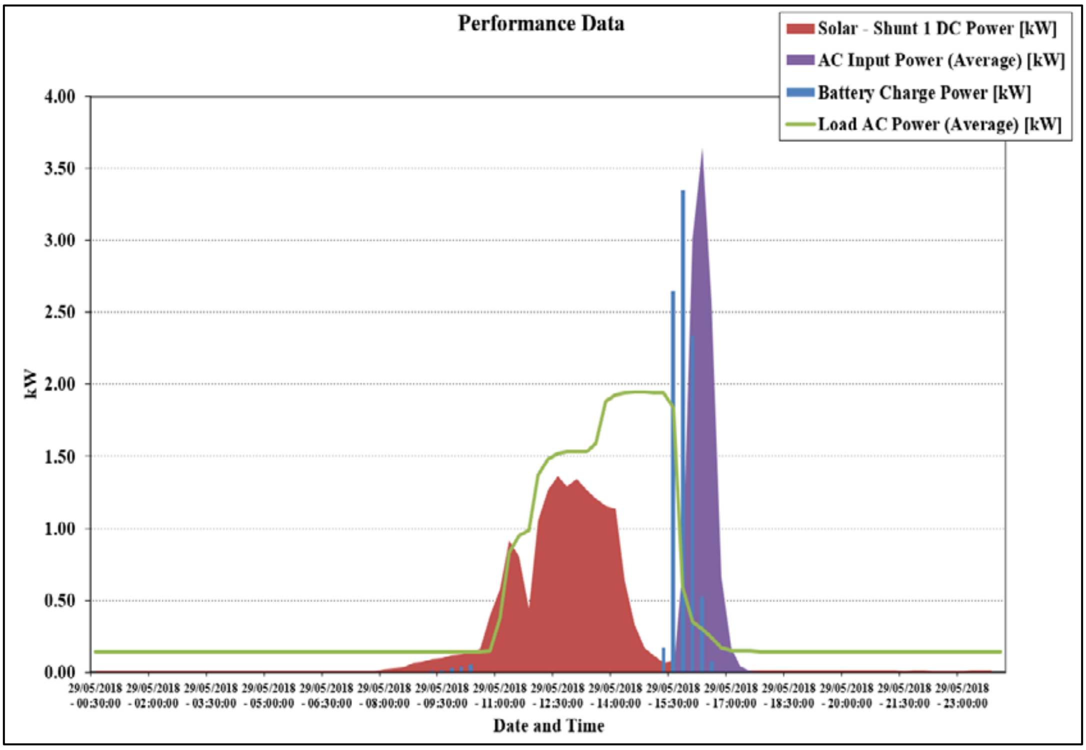


Figure 8.31 Performance Data highlighting the Performance of PV, Battery and Load on 29.5.2018

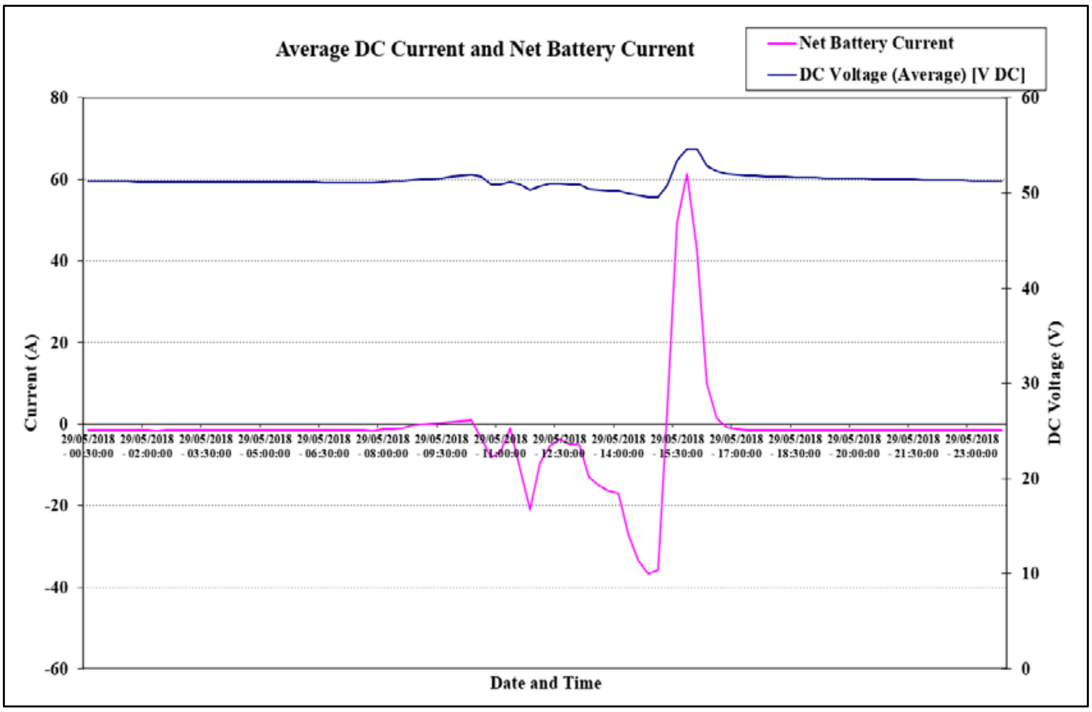


Figure 8.32 Battery Voltage and Net Battery Current of the system

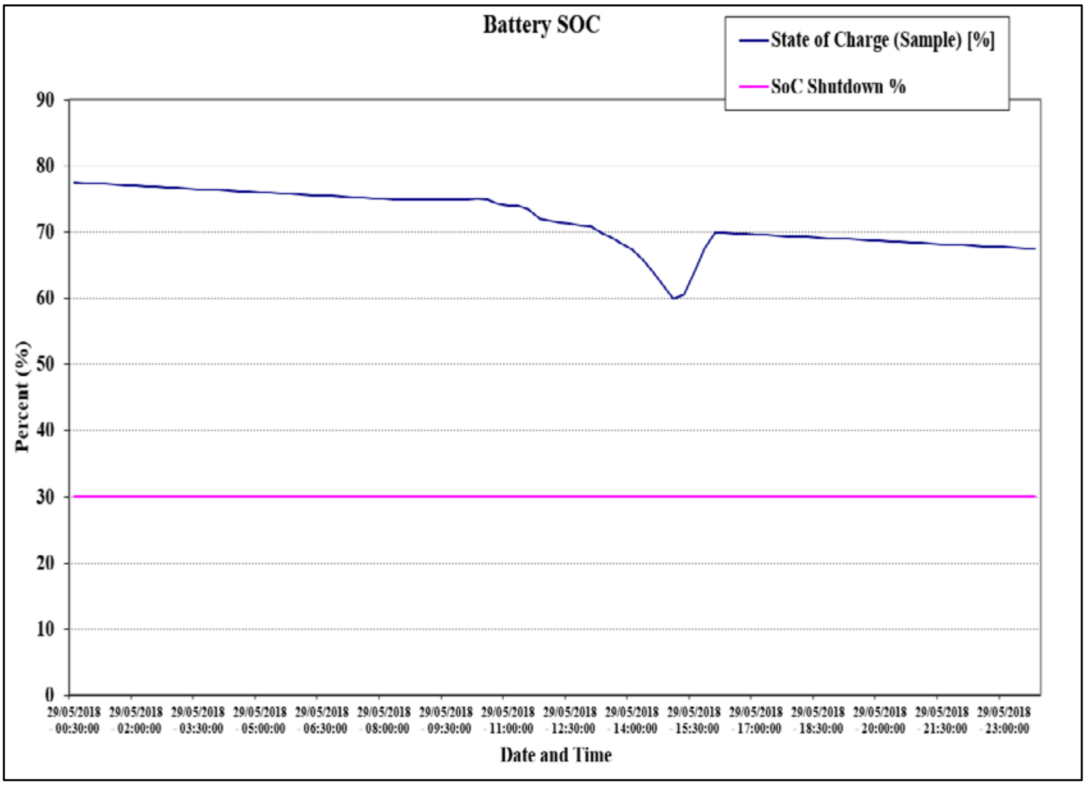


Figure 8.33 SOC of the Battery

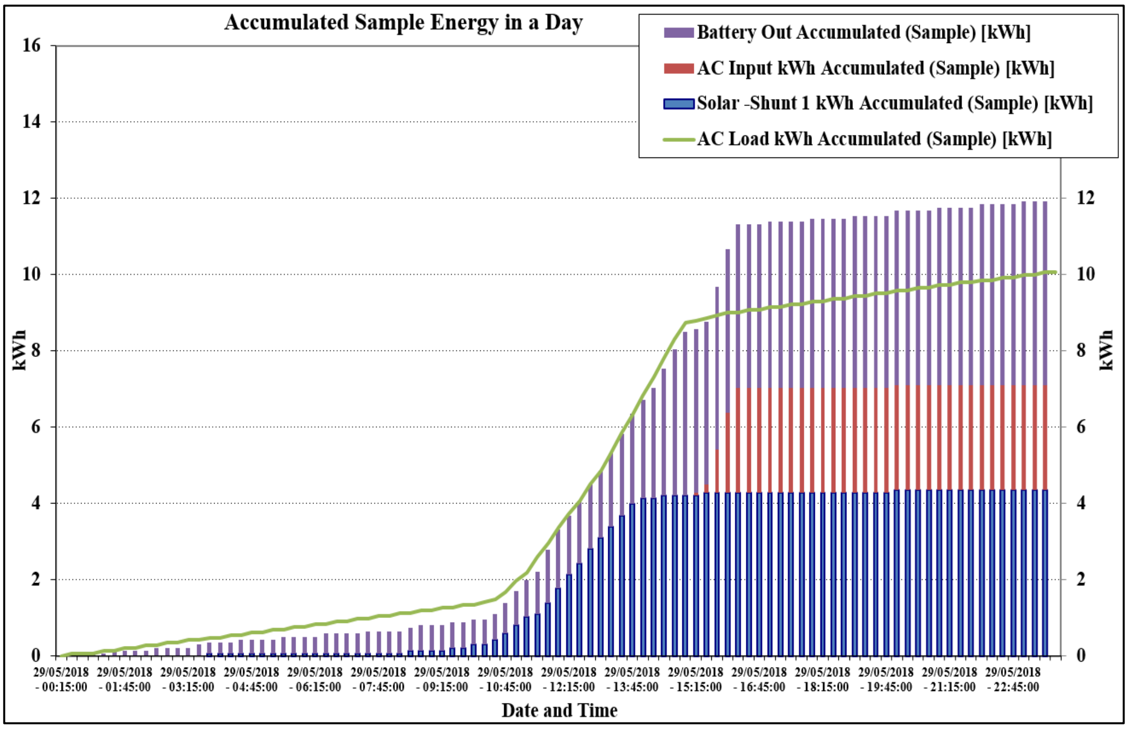


Figure 8.34 Accumulated energy of Battery, PV (Solar shunt) and A.C. Load for the day (on 29.5.2018)

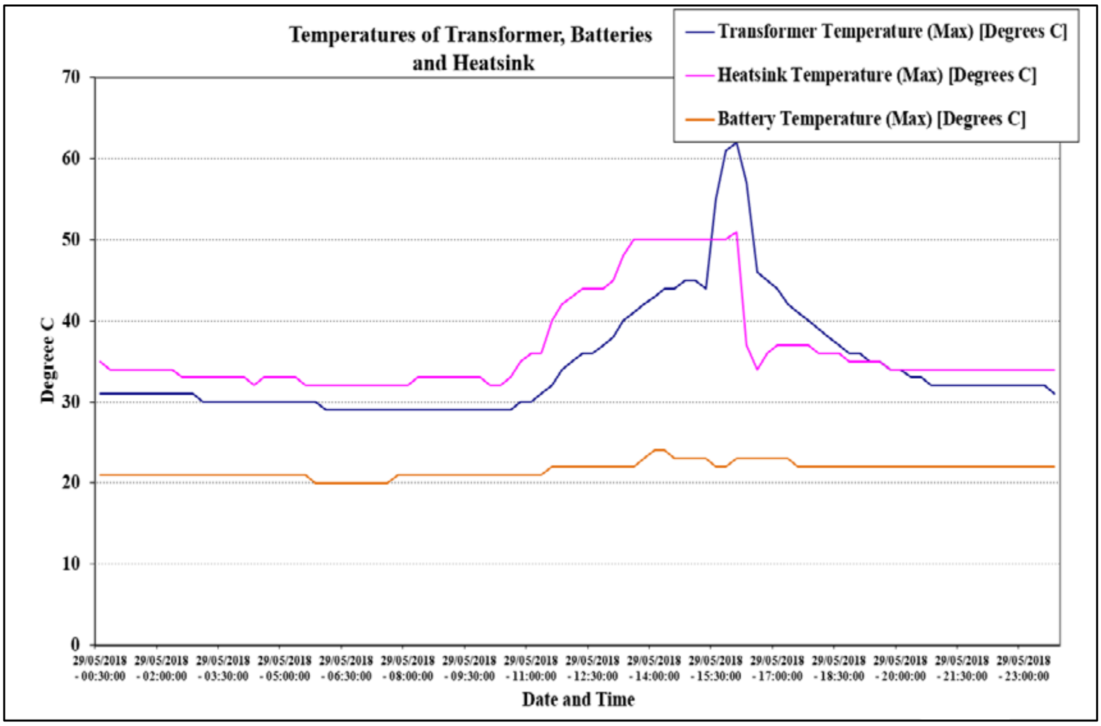


Figure 8.35 Temperatures of Transformer, Heatsink and Battery

8.3 Overall Performance of HRES at VU

This section summarised the performance of the VU micro-grid setup in the VU Renewable Energy lab. This section considers summarising the performance for one month and total performance until 6.8.2018. Selectronic inverter has the memory restriction and also the performance data gets erased if it is switched off. The micro grid was switched off due to the failure in the fuse in April 2018. However the experiments performed prior to this was manually saved (hence the overall Performance data is restricted to the months from June and not any date earlier). However as the performance data for May was manually downloaded, the micro-grid performance for the month of May has been discussed in Section 8.3.1. In Section 8.3.2, the VU micro-grid performance from 2.6.2018 to 2.8.2018 is discussed.

8.3.1 Micro-grid performance for a month

This Section investigates the performance data for the month of May. As the system was switched off when the battery was upgraded, the data for the monthly performance by the Selectronic inverter was available from 9.5.2018 to 31.5.2018. This autumn month in Melbourne helps in perceiving the RE availability and overall system performance and system reliability in case of extreme weather conditions which is observed in Melbourne.

Figure 8.36 illustrates the Performance Data of the PV, battery, A.C. load and A.C. grid. It is observed that, the days when some of the experiments were performed with the external load of 2kW maintained for a constant value, the A.C. grid power surged in, to maintain the battery SOC. This is noticed as peaks in A.C. input Power, however there exists internal load (of approximately 0.13kW) from the system in the absence of external load. PV output power (represented as Solar Shunt 1 D.C. Power in Figure 8.36) and battery charge power were adequate to meet the external load on the other days. From the PV output power in the month of May, it can be noticed that the maximum PV output was 1.4kW and minimum of 0.13kW. This showcases the stochastic behaviour of RE availability in the location Footscray, Australia.

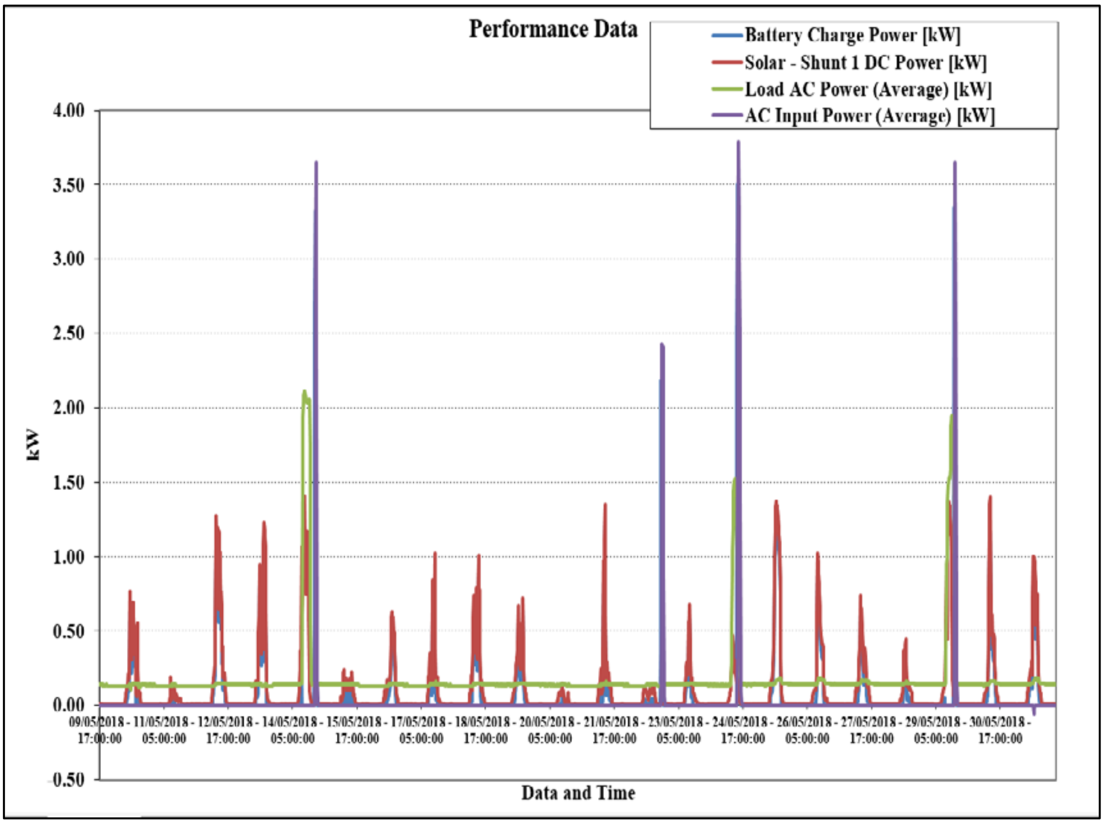


Figure 8.36 Performance Data highlighting the Performance of PV, Battery and Load from 9.5.2018 to 31.5.2018

Figure 8.37 and Figure 8.38 illustrates the Average voltage of the battery and the Net current, and SOC of the battery respectively. The battery voltage during the month of May has been maintained between 49V to 57V. The battery voltage depends on the RE availability and load presence. In the presence of external load of 2kW, the battery voltages reduces to 49V, at the sametime, the A.C. grid supplied power to charge the batteries. Concurrently, the Net current of the battery soared to a maximum of 64.22A during this time.

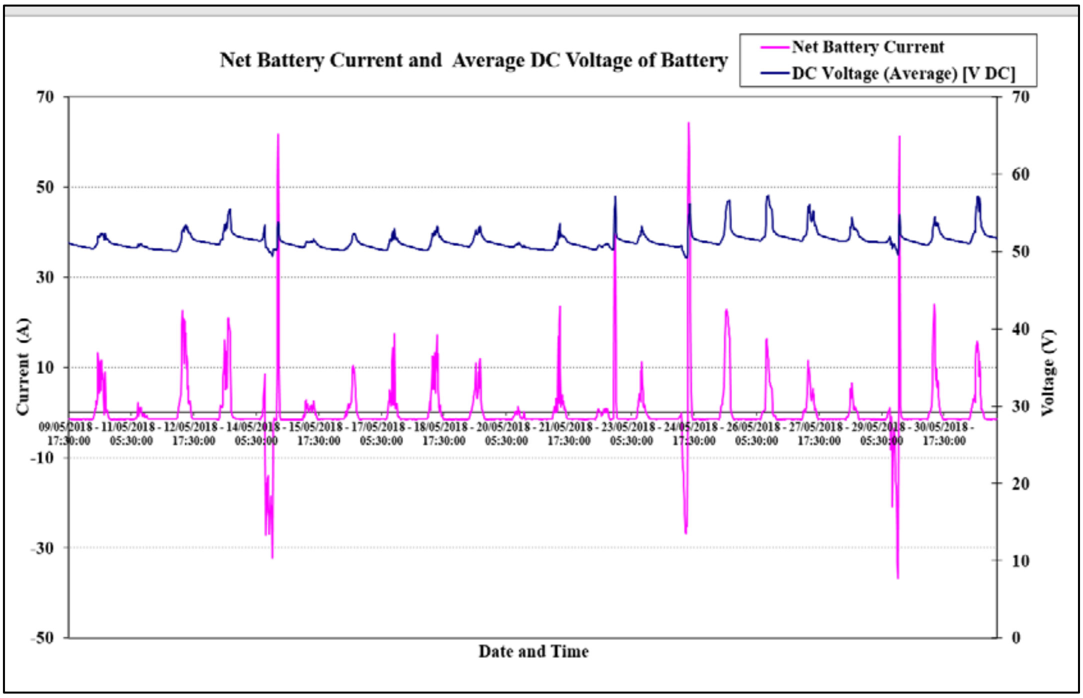


Figure 8.37 Battery Voltage and Net Battery Current of the system in May (above)

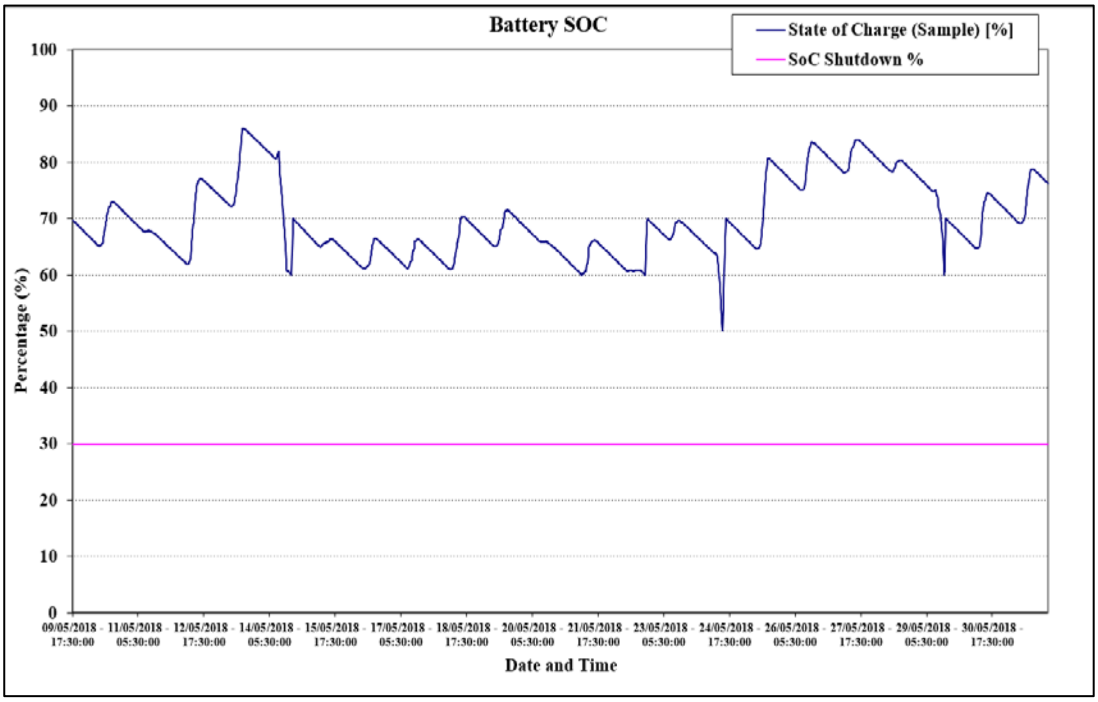


Figure 8.38 SOC of the Battery (below)

The days when the external load was smaller than 2kW, the battery voltage was maintained between 50V to 57V. The net battery current was in the range of 10A to 20A. Figure 8.38 shows the variation in the SOC in the month of May. There is strong variation in the SOC observed, mainly when the external load of approximately 2kW was set to perform the experiment. However, the SOC of the battery was maintained to be greater than 60% (except on a day when the SOC of the battery was reduced to 50% to perform an experiment, after which the minimum value of SOC was set to 60%). In May, due to the stochastic behaviour of RE, the battery SOC of the batteries fluctuated.

Figure 8.39 shows the accumulated PV (Shunt 1) ouput, battery output, A.C. input and A.C. load for the month. As the micro-gird involved the presence of PV, battery, external load and A.C. grid presence, this plot addresses the individual output by the end of the month. This study helps in understanding the reliance of indiviual system units and the whole micro-grid in general for further studies. It also helps in analysing the battery and PV performance to efficiently to meet a particular load size in a month.As the PV output power varied due to the availability of solar energy was considerably low. The maximum PV accumulated energy was 5.1kWh on 14.5.2016 and minimum accumulated energy is about 0.5kW on 1.5.2018 and 20.5.2018. However it can be observed that PV supplied enough power to charge the battery and to meet the load on most of the days in the month of May. However, it can be noted on days when the load was larger than 6.4kWh, the grid power was required to meet the load. This is due to the less availability of PV in the presence of high value of external load. However, if the load is below 6kWh, the battery and PV had enough energy to meet the load at any instant of time (this also includes the load presence in the night, as the battery power is available to meet the load while the PV charges the battery during the day).

Figure 8.40 shows the temperatures of the battery, transformer and heatsink. It is observed that the temperature of battery, transformer and heatsink increased with the connection of external load. Temperature reduces as the external load is switched off and grid disconnects producing power to support to charge the battery. At this interval, the maximum temperature reached by transformer is maximum of 63^0C on 14.5.2018 and 24.5.2018, while the maximum temperatures reached by the heatsink and batteries were 51^0C and 24^0C respectively. However it must be noted that, the temperatures of the system (battery for example) is maintained at a steady temperature.

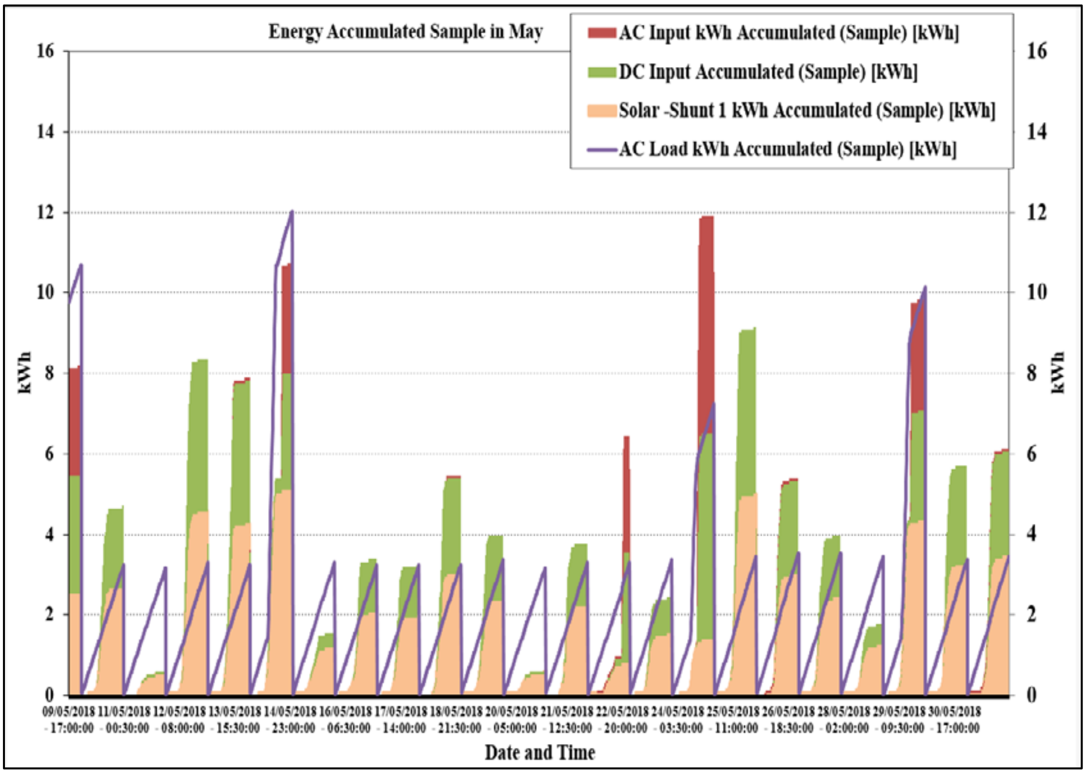


Figure 8.39 Accumulated energy of Battery, PV (Solar shunt) and A.C. Load for the month (above)

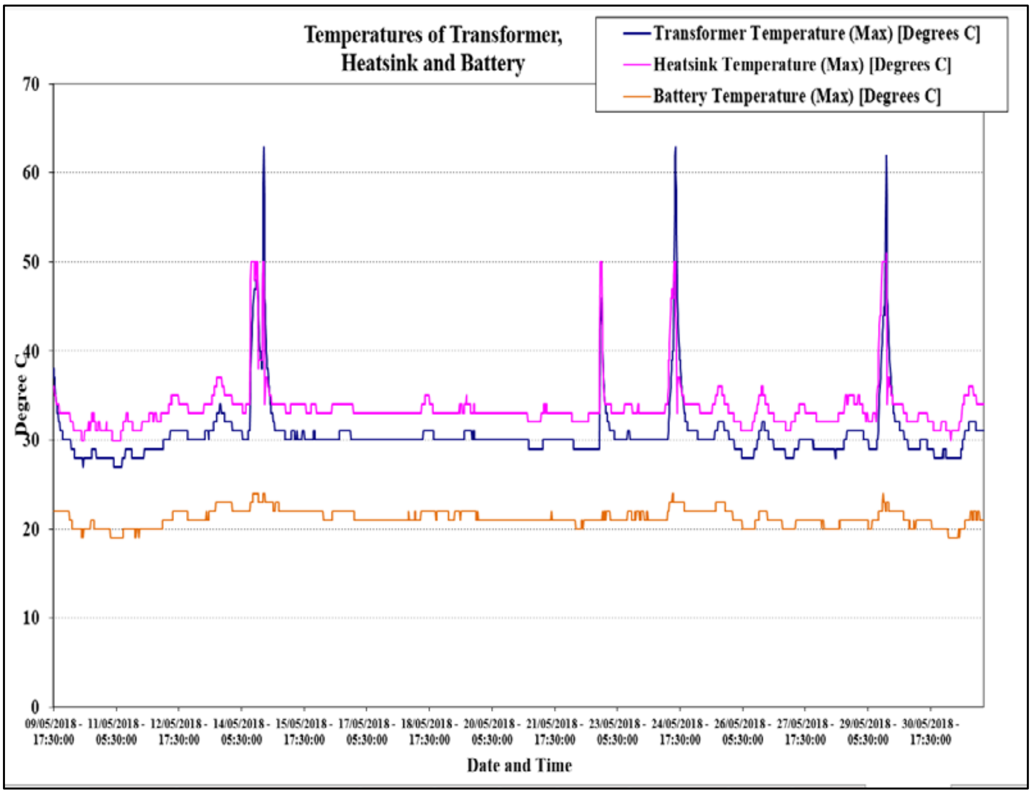


Figure 8.40 Temperatures of Transformer, Heatsink and Battery

8.3.2 Overall Performance of the micro-grid

This Section provides the summary of the total performance of the system until 6.8.2018 and the average output of individual components in the micro-grid. Figure 8.41 illustrates the Performance Data from 5.6.2018 to 6.8.2018. From the Performance data plot of Solar (shunt) Power, the maximum output of PV was 1.4kW and peak output of approximately 1.4kW was observed only on few days in this duration. This is because the data collected is during autumn and winter seasons in Victoria, Australia. However, the available power from the PV was able to charge the batteries and also met the internal load (minimum load present in the system) appropriately. This is at least 50% of the average household load in Footscray.

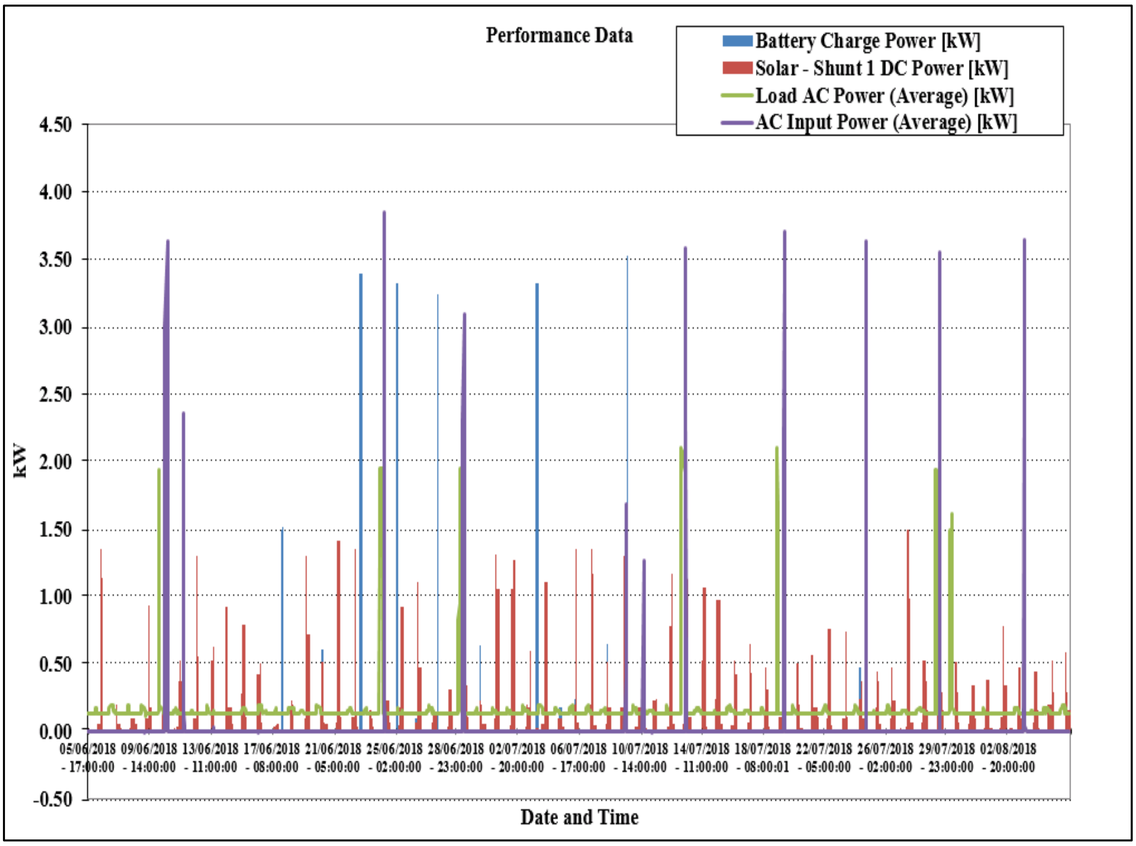


Figure 8.41 Performance Data highlighting the Performance of PV, Battery and Load from .6.2018 to 6.8.2018

Figure 8.42 and Figure 8.43 illustrates the Average voltage of the battery and the Net current and SOC of the battery respectively. The battery voltage during the month of June, July and early August have been maintained between 48V to 57V. The battery voltage depends on the RE availability and load presence. In the presence of external load of 2kW, the battery voltages varied and had touched to a minimum value of 48V, in the sametime the A.C. grid supplied power to charge the batteries. Concurrently, the Net current of the battery soared to a maximum of 64.8A during this time. The days when the external load were smaller than 2kW, the battery voltage was between 50V to 58V. The Net battery current was in the range of -44.6A to 63A. The minimum value of current was due to the PV availability to be marginal to charge the batteries, and the maximum current is when the A.C grid surged in current to charge the batteries when the minimum set SOC was reached. However, the negative current implies the current dicharges from the batteries to meet the load. The maximum discharge current by the batteries in this duration was -42A.

Figure 8.43 shows the variation in the SOC in these months. There were strong deviations in the SOC observed, mainly when the external load of 2kW was set to perform the experiment. However, the SOC of the battery was maintained to be greater than 60% (except on a day when the SOC of the battery was reduced to 50% to perform an experiment, after which the minimum value of SOC was set to 60%). However, the fluctuations in the SOC of the batteries implicates the randomness in the solar energy during this period.

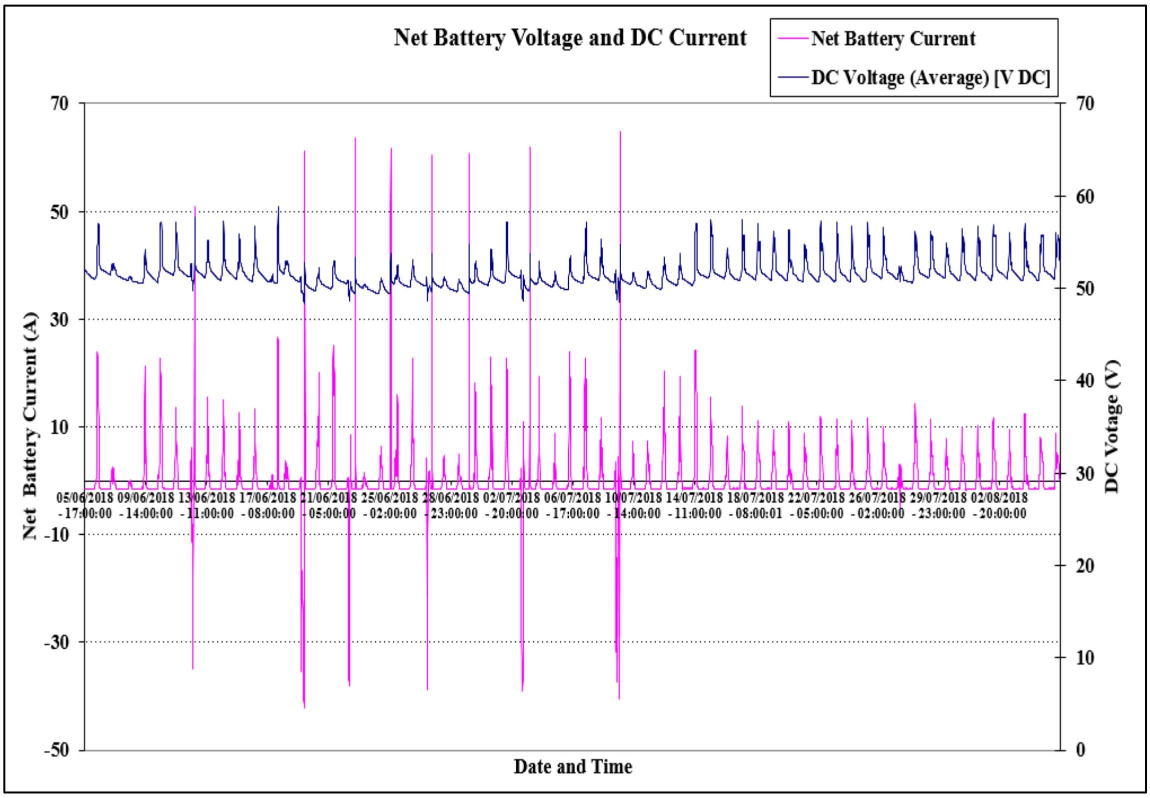


Figure 8.42 Battery Voltage and Net Battery Current of the system

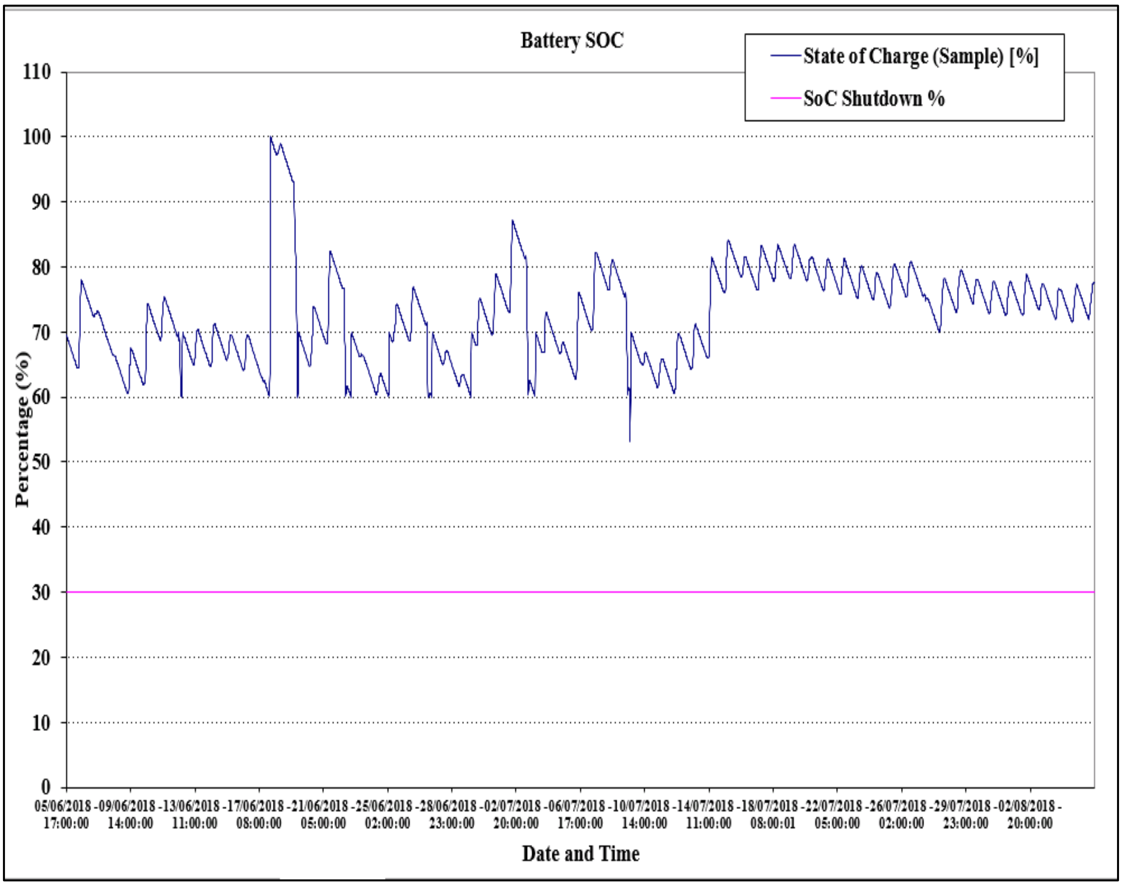


Figure 8.43 SOC of the Battery in this duration

Figure 8.44 shows the accumulated PV (Shunt 1) ouput, battery output, A.C input and A.C load for the considered duration. As the micro-gird involved the presence of PV, battery , external load and A.C grid presence, this plot addresses the individual output by the end of the day in the considered time duration. The maximum PV accumulated energy was 4.3kWh on 14.5.2016 and minimum accumulated energy was about 0.1kWh on 6.6.2018 and 4.7.2018. However it can be observed that, PV supplied enough power to charge battery and to meet the load for most of the days in this duration. However, it can be noticed that on days when the load was higher than 6.4kWh, the grid power was required to meet the load. This is due to the less availability of PV during the presence of high value of external load. However, when the load is below 6kWh, battery and PV have enough energy to meet the load at any instant of time (this also includes the load presence in the night, as the battery power is available to meet the load while the PV charges the battery during the day).

Figure 8.45 shows the temperatures of the battery, transformer and heatsink. It is observed that the temperature of battery, transformer and heatsink increases with the connection of external load. Temperature reduces as the external load is switched off and grid supplies power to support to charging the battery. At this interval, the maximum temperature reached by transformer is maximum of 69^{0}C on 9.7.2018, while the maximum temperatures reached by the heatsink and batteries are 52^{0}C and 24^{0}C respectively on 19.6.2018. However it must be noted that the temperature of the battery was maintained at a steady temperature.

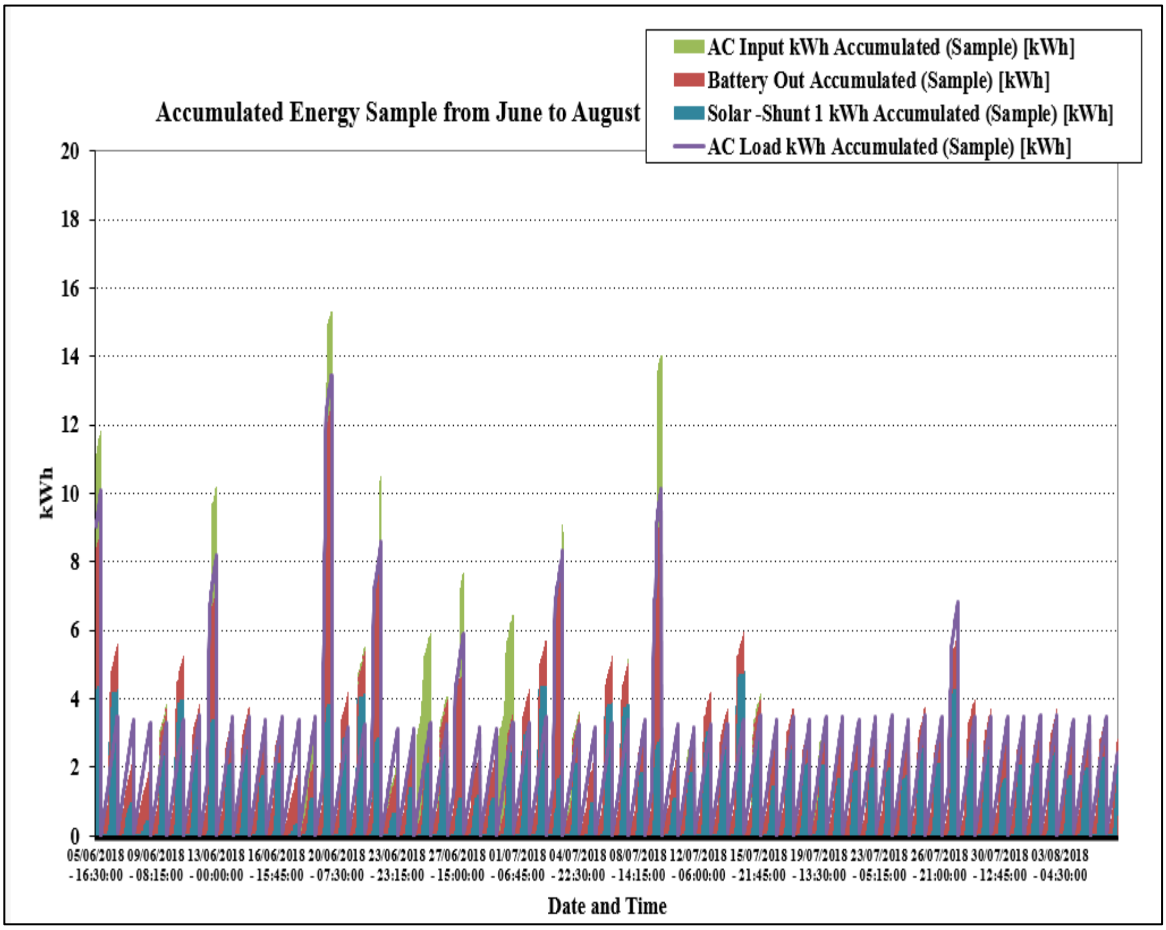


Figure 8.44 Accumulated energy of Battery, PV (Solar shunt) and A.C Load from 5.6.2018 to 6.8.2018

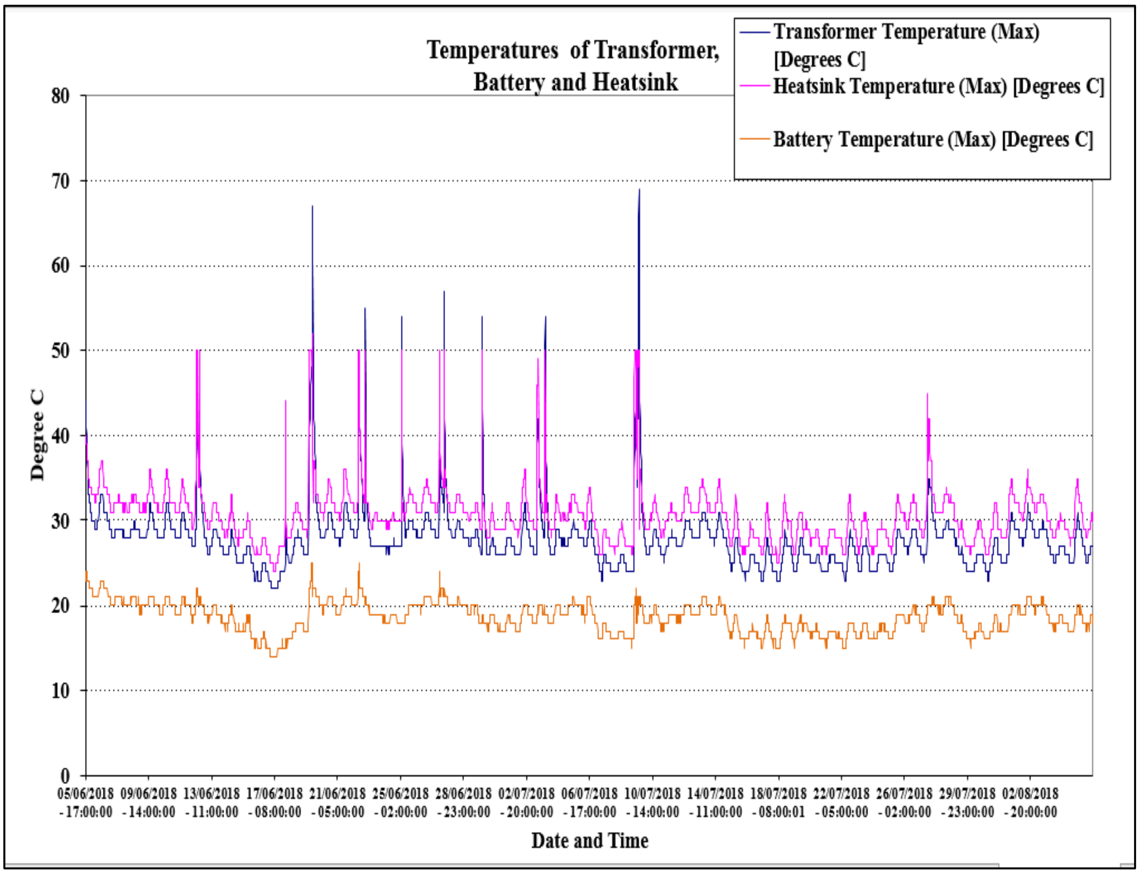


Figure 8.45 Temperatures of Transformer, Heatsink and Battery

The Figures 8.46 and 8.47 shows the D.C. history and A.C. history of the system until 6.8.2018. It can be noted that, though the upgraded system is less than a year old, the 365 total consolidated value in the D.C. history and A.C history is the future prediction according to the present micro-grid functioning. The history summarised below also includes the energy of the previous day, a week, a month and 365 days and daily average values. From the D.C. history it can be realised that, the battery output energy and battery input energy for 365 days total would be 254kWh. Solar shunt energy is 401kWh while the inverter energy is 540kWh for 365 days total. When the A.C history is considered, the A.C load energy is 719kWh, A.C input energy and export energy is 38kWh. APPENDIX D-1 highlights the detailed summary of D.C. and A.C history of the system. APPENDIX D-2 summarises the daily energy data summary since the installation.

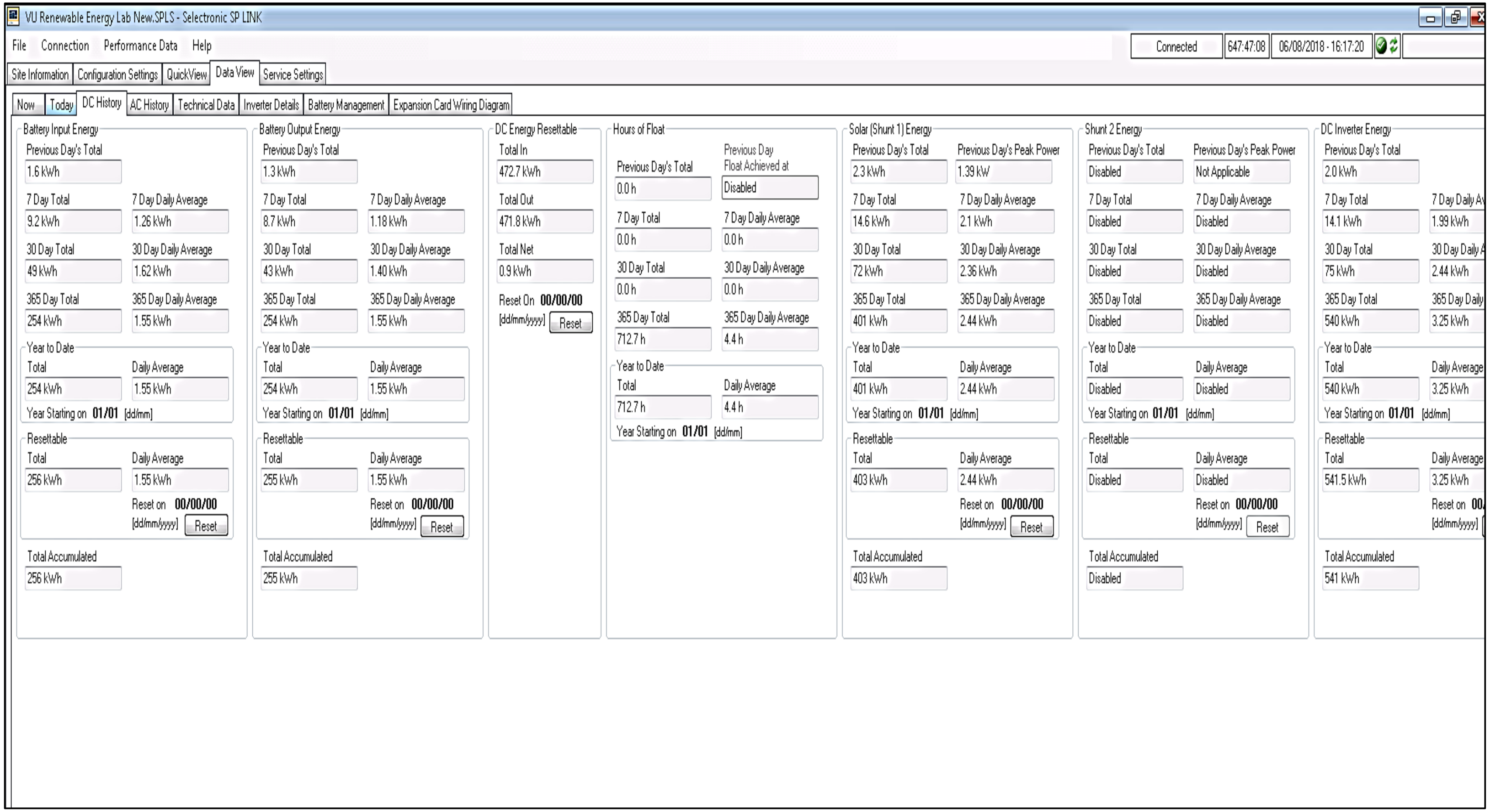


Figure 8.46 D.C. history of the micro-grid

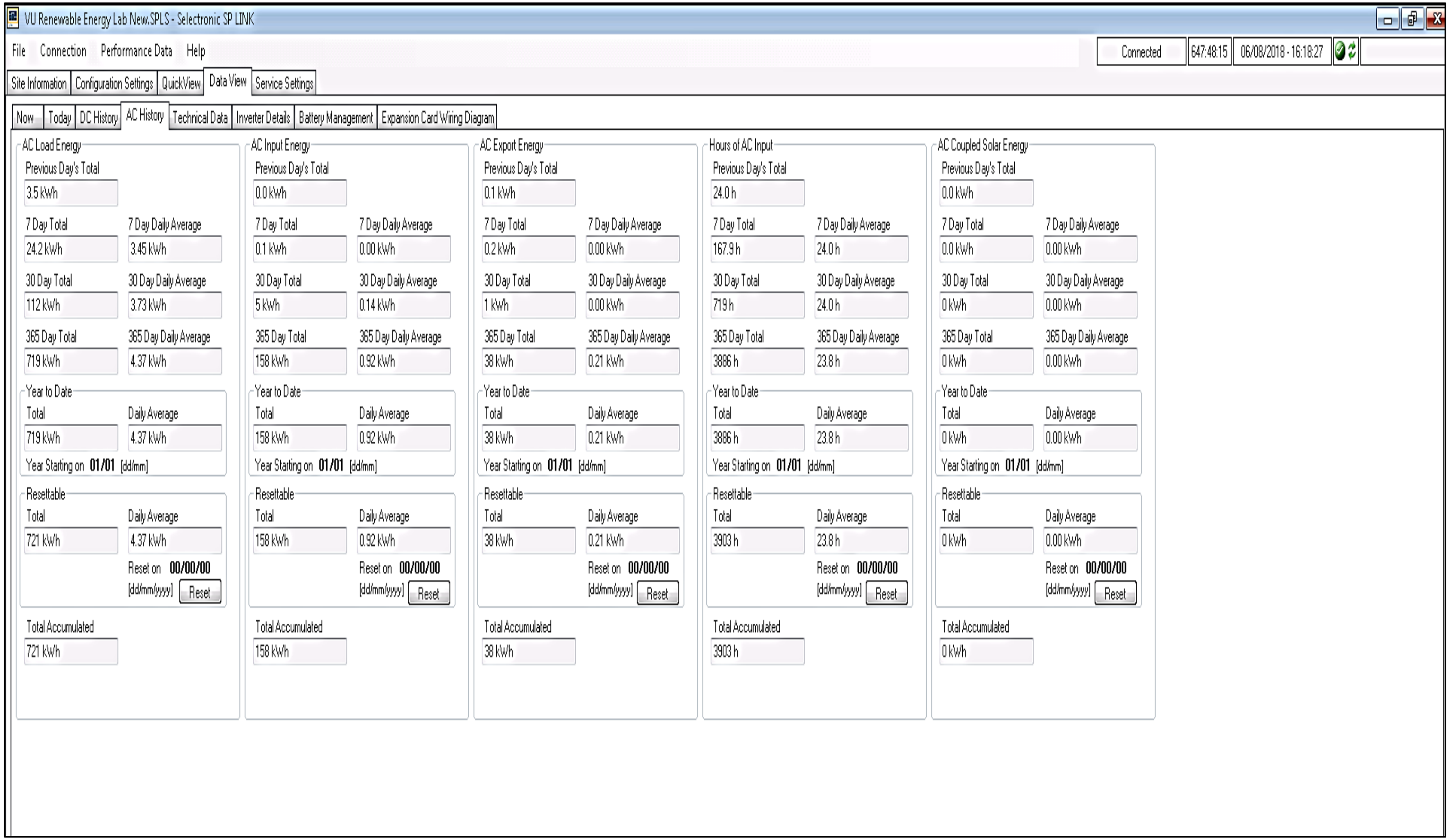


Figure 8.47 A.C. history of the micro-grid

8.4 Conclusion

Integration of RE like PV has been studied for a micro-grid at the VU RE lab. Different experiments have been performed and discussed based on the available resources at VU. The experiments includes the different load values, availability of RE and battery capacities. It can be noted that, the PV performance depends on the availability of sunlight and efficiently convert into useful energy. If the micro-grid consists of RE like PV connected to the grid (otherwise called as grid connected micro-grid), due to the stochastic behaviour of RE, the dependency of grid to meet the load will be high. In developing countries like India, the grid availability is not consistent. If the micro-grid is a stand-alone model, there would be a possibility of over sizing the RE system or the storage unit. To avoid such problems, the micro-grid connected to battery storage system has been discussed in this chapter. The experiments discussed in this chapter have been performed in Autumn and Winter months in Melbourne, when the Solar Energy availability is minimum. Hence it can be noted that the discussed results are the worst case scenario. However, the weather warms up in September to November during the Spring season, whilst the top temperatures are usually in January and February. Hence this implicates, the solar output can be maximised during Spring and Summer seasons. And thus when the experiments were performed, the battery power and power from PV were able to meet any load under 4kWh and the presence of grid assisted system to meet total additional load of nearly 2kW. However, it should be noted that, due to the internal constraints, the distributed load for the day was not able to be recreated and thus a constant load of 2kW was considered. The total load by the end of the day was equivalent to the average load of a household in Footscray. Considering this fact, there are possible improvements that can be considered for the future development of VU RE lab.

- PV: The Solar panels have been located on the 2nd floor of the rear entrance of Building C. Due to the PV being installed in the lower level of the building and the presence of trees around the building shown in Figure 8-48, there is shading effect from the adjacent building and the trees around. When the experiment was performed, it was noted that by 3.30pm, the PV output reached minimum value even though the sunlight was available (at least for an hour). This problem would be more pronounced in the summer season as the sun availability is abundant in Southern hemisphere regions (like

Melbourne). Relocation of PV panels can be considered for better PV performance and thus resulting in significantly higher energy availability from PV.


Installed Solar Panels

Figure 8.48 Panoramic view of the Solar Panels installed location

- WT: As discussed earlier in this chapter, the unavailability of technical data like power curve data of VU's WT, it is difficult to understand its characteristic and performance. Due to its improper installation, it has been found difficult to repair and maintain the system. Supplementing to this, the location of WT shall be looked at for the future applications. However, the WT replacement or maintenance of WT makes the whole process an expensive option.
- Batteries: The current battery storage system consists of AGM batteries for which the SOC is maintained above 60% (as instructed by the battery supplier). Hence to improve the efficiency of the battery and increase the Depth of Discharge (DOD), example: Li-ion batteries can be considered.
- Load: The load bank that has been used is a resistive load bank which is very old. It has to be monitored by a person all the time when in use, it cannot be remotely monitored nor can it be monitored using any software (digitally). The other drawback of this load bank is: it gets hot, when it is used for a long duration (even when the internal fan is kept ON). Hence during the performance of the experiment, the temperature of the load bank and the lab

was maintained by switching the ceiling fan of the room. It would be a better option to upgrade the load bank that can be programmed according to the experiment's requirements. E.g. Chroma Electronic Load [139].

- It shall be noted that, the inverter stores the data at every 15 minutes interval, this results in the available memory of the inverter being small. Hence, the user may be required to download the data manually to avoid the loss of the required data. This is more prominent when the overall performance data of the system over an extended amount of time has to be studied.

Chapter 9

Conclusion and Future Work

- Brief of the research study and meeting the aims.
- Emphasis on the optimum sizing of HRES in both case studies and exploring the benefits of their possible adoption.
- Focus on the improvement at VU micro-grid for future studies.
- Importance and possible hurdles to meet RE adoption globally, in Australia and India specifically.
- Scope for future work

9.1 Conclusion

A nation's development is dependent on its citizen's lifestyle/welfare. Energy has played a vital role in moulding a country's profile through human development and the lifestyle of its people. Any form of power shortfall or energy deficit creates a vast social and economic impact on a country. A huge impact has been observed at many locations due to the energy supply deficit leading to blackout in locations like California, Canada, Brazil and many other places. Such incidents are more prevalent in the developing countries like India. However, Australia is not immune to such incidents. In 2015, Darwin, Australia exprerienced such an event and the very recent incident in South Australia was catastrophical, leading to a substantial economical loss and impacting the social lives of many. Similarly, a major catastrophic event shook India on the 30th and 31st July 2012, shedding 32GW of generating capacity of power due to grid failure. Two grave blackouts affected northern and eastern part of India, affecting nearly 230 million population and 620 million population respectively on those days. This affected about 9% of the world's population. That incident created a significant impact on the life of the citizens causing loss of millions of rupees. This problem highlights the challenges that are faced due to poor transmission and distribution grids. As the energy mix evolves, these underlying problems will only be magnified and significant investement will be needed to improve these.

In order to improve and increase the electricity supply, India is endeavouring to increase its RE share through its RE policies and NSM. Australia has also been urged to improve its energy sector by increasing the share of RE in the energy mix. This research is focussed on integrating the RE into a micro-grid for a university building in Australia and for a small community in India. The two locations have different RE availabilty, energy consumption trend and energy policies, these factors are primarily explored for the real-world scenario. The importance of this research and its aims and contributions are synopsised in Chapter 1. Chapter 2 discussed the global energy scenario and importance of RE in electricity production. The RE availability in Australia and India has been discussed. Understanding the methodology to meet the RE at these locations in Australia and India have been explored in Chapters 2. However, Chapter 3 dicussed the detailed procedure of modelling RES using HOMER and iHOGA packages, while it also focused on the different case studies conducted using these two software packages. The essential factor for RE adoption at any location is exploring the RE availability and means to reach them. This was done by studying the RE policies putforth by Australia and India along with many other developed countries, this topic was reviewed in Chapter 4. The existing energy policies driving the energy sector of both the coutries were examined and a case study on the FiTs for an Australian scenairio was discussed. The dearth in the actions or initiatives engaged by both Australia and India on comparison with the developed countries was highlighted.

In this aspect, optimium sizing of HRES was studied to introduce RE at chosen locations (Warrnambool and Aralvaimozhi). The real market prices of these RES was procured and the sizing of RES has been studied using two software packages, HOMER and iHOGA. The results were compared and analysed in Chapter 5. Although, there are many methodologies in the literature to optimally size RES for a desired location, HOMER and iHOGA have been chosen due to their detailed approach to model RES compared to any other methodologies. These software packages have many advantages. The two chosen software packages include mostly all the essential features of RES considered for a location. The other advantages of choosing software for optimum simulation are: the simulation time used by the software (HOMER in particular) is small, the ease of use, modelling RES considering all the salient features etc. The results from both the software packages highlighted a small discrepancy due to difference in the methodology used by them for simulation. Since the optimum sizing of HRES were conducted for the existing market prices, there is always a probability of change in the variables studied, e.g. price of HRES, electrical load of the chosen location etc. These probable variables were considered and the optimum sizing of HRES was studied using iHOGA software. Simultaneousy, a set of variables that govern the sizing of HRES for a given location, e.g. inflation rate, wind speed, solar radiation etc were alos considered. The optimum sizing and analysis was conducted using the iHOGA software by varying these probability variables. For any practical application of a project, it is crucial to examine its advantages and disadvantages. This was done by TBL analysis and the results were discussed in detail in Chapter 6.

A prototype model of HRES system including the battery was conncted to the Victoria University main grid. The model was further updated with a battery storage system. The real time data was taken, analysed and discussed in Chapters 7 and 8. Different load cases were considered for different days and this helped in analysing the probable scenario that could occur if a similar HRES is considered (of similar size or capacity). Further, the improvements necessary for the existing VU microgrid system in RE lab have been discussed. Thus, the summarised aims and objectives described in the earlier part of the thesis has been found to be met in the aforementioned chapters.

The consistent focus on improving the present grid has been observed world-wide. With the concern over rising global GHG emissions and volatile energy market, the technological improvements have made RE an alternate option to conventional energy sources. India and Australia have set respective RETs to achieve within a stipulated time frame. Although Australia is on its way to achieve its target, there are hurdles that have to be surpassed by both the countries to achieve this target. To assist the country's RET there have been RE policy assisted schemes. However, there is inconsistency in the set policies and the objectives met by them in exploring the RE technology. Focusing on the social acceptance of RE technology, there is considerably more to be achieved by Australia and India, when compared to the social participation and acceptance of RE by developed countries. Nonetheless, the privatisation of Australia's energy sector, competition over the electricity prices offered by the suppliers within; a massive initiative by the energy suppliers in reaching the RE to the customers are some of the vital step in this aspect. Thus, in Australia, the customer awareness in RE adoption is underway. Inspite of the knowledge about RE slowly creeping in and reaching the general public in Australia, the action taken by these consumers in adopting the RE is however considerbly low. There is still a convenient mindset of the household electricity consumers to retain their reliance on the coal based source for electricity grids, this is one of the significant hurdle noticed in Australia. Considering the fact that the Australian government is offering rebates on RE (which are scrutinised in Chapter 4), there is a wide gap in terms of RE affordability. It must be noted thar , some of the respective state governments are introducing newer schemes.

In terms of India's RE scenario, there has been inconsistency in the Indian economy due to demonetisation, the effect of demonitisation has been apparently visible in India's changing inflation rates. The effect of inflation rate on the economics of HRES has been dealt with in Chapter 6. The "Make in India" campaign inaugurated by the Prime Minister of India, has been successful as an intitiative to bring several technologies to India. RE has taken a regress through this campaign from the customers' perspective. The recent introduction of GST in India is causing various concerns to be raised regarding the costs involved in setting up of the solar power plants. This is because, there has not been an agreement on how much GST needs to be levied on the various parts of the project. This is resulting in a potential higher price per unit of energy generated. This uncertainity can deter establishment of new solar projects and thus hindering PV adoption [140].

Nonetheless, India has claimed to have achieved 100% electrification in present political tenure. The anomaly in the policies laid by the state government compared to the central government, and not keeping up the pace with the central government laid regulations are clearly observed in Chapter 4. There is non existence of data (data being not updated) by several state governments in achieveing its respective targets. This slack in the state government initiatives have also contributed to India's retarding development and overall progress in RE. When the social participation is considered, not many citizens are aware of NSM. The lack of awareness in the majority of the public is a most significant hurdle for a country like India to achieve its target, as population is its biggest asset. A small initiative by every individual in RE adoption could make India achieve larger goal in RE. Although, India as a developing country, is striving to achieve its targets with several glitches including corruption, poverty etc., the focus on RE has taken a step behind. Nonetheless, one of the crucial means for India to curb the GHG emissions and thus adopting to alternate energy source would solve majority of the problems India is facing.

In a global scenario, the importance of RE have been discussed earlier, it is imperative to scrutinise the social awareness and techno-economic ease to achieve RE adoption. This is because, any new technology to have its presence felt, should surpass the technological ease to adopt (this includes the affordability of the technology). These two are the significant hurdles seen for RE adoption. There are already speculations about the RES like PV prices reducing. If the government entices its citizens to adopt RE by providing attractive rebates and prices, it is definitely possible for every country in the world to exploit its RES and achive its respective targets.

This research broadly covers the RE adoption, it is a peliminary intitation for RE adoption, this work is an examplar for India and Australia to achieve many similar projects and thus improving its energy sector and meeting its respective energy targets by reviewing the exisitng energy policies. This could lead to the initiation of future work on this.

9.2 Scope for future work

RE integration into the micro-grids thrust area of research especially focusing on developing countries. It provides ample opportunities to the researcher to explore many potential challenges in this area. The following are some of the opportunities that have been planned to investigate in our future research are as follows:

- As an introduction to future work with the available VU micro-grid facility, EV charging methodology was proposed and its economical benefit is discussed for a household as a casestudy. The advantages that EV offers to a household by strategically using it along with the available micro-grid has been presented in [141]. Vehicle to House (V2H) and Grid to Vehicle (G2V) operating mode is considered, the electricity cost for the household in a month reduces by A$19.8, this exhibits approximately 11.6% of drop in the monthly electricity price paid by the EV owner. Thus, including EV in Home Energy Management Systems (HEMS) results in a considerable economic benefit if EV charging and discharging is efficiently planned.

  The existing micro-grid controller system lacks the control of inputs like the energy pricing etc., nonetheless, this experiment was performed as a preliminary work to the future research. Integrating RE along with the coordinated control of EV, considering other (better) storage systems in HEMS, and economic benefit of their operation and control will get further attention in future work.
- Like Aralvaimozhi and Warrnambool, there are many other locations in India and Australia respectively where RE is abundant. Exploring these locations for their RE suitability would be a good future work option.
- India and Australia lack public involvement in RE adoption. If the respective governments initiate campaigns to showcase the awareness and improve the knowledge of RE, it could further help drive RE adoption.
- There has been technological advancement in RE from the increase in efficiency of PV to the technological advancement in Perovskite type of PV.

Apart from PV, exploring other RE sources like biomass can improve the micro-grid reliance, especially for developing countries like India.

- Storage systems have been growing tremendously. As an example, Tesla batteries are revolutionising the battery storage facilities, Other than Tesla batteries, commercially available HFC (like Bloom Energy) would help in improving the reliance and efficiency of the micro-grid.
- Like the Australian state of Victoria which provides 50% rebate on the installation household solar panels to increase RE adoption, other Australians states and India could also initiate such schemes to help in further accelerating in RE adoption.
- Understanding the energy-as-a-service model can be studied as a future work for a micro-grid. Energy-as-a-service model works similar to power purchase agreement. Periodic or short-term payments can be made by the energy consumers to the owners for a specific tenure (as specified in the agreement) to acquire the electrical services. This will reduce the expenditure on the capital costs of RES.
- The emerging technologies like Block chain could help in sharing excessive energy produced by micro-grid within a community, thus enabling better sharing of excess energy produced.

Appendices

- **APPENDIX A**
  1. Literatures on the Case studies conducted using HOMER software
  2. Literatures on the Case studies conducted using iHOGA software
- **APPENDIX B**
  1. Regulatory Policies of Denmark
  2. Renewable Energy Policy Framework of Germany
  3. Renewable Energy Policy framework in the USA
- **APPENDIX C**
  1. Electricity Consumption Data of 70 houses in Aralvaimozhi, India
  2. Energy consumption of the university in Warrnambool, Australia
  3. Technical details of the HRES considered for Aralvaimozhi, India
  4. Power curve Unitron 1500 (U1500)
  5. Technical details of the HRES considered for Warrnambool, Australia
  6. Power curve of AWS 5.1kW Wind Turbine
- **APPENDIX D**
  1. Summary of D.C. and history of the micro-grid
  2. Summary of Overall Performance of the micro-grid (Daily Performance)

APPENDIX A

1. Literatures on the Case studies conducted using HOMER software in Australia and rest of the countries

CASE STUDIES FROM AUSTRALIA				
Sl No	Year	***Energy system studied***	***Location***	***Comments***
1	2011 [142]	Wind-diesel-battery system	French Island in Victoria, Australia (Remote community)	The wind energy system was found to be economically viable option with least value of NPC and COE and Wind energy is considered the better option to substitute the diesel energy system.
2	2009 [47]	Wind turbine, Battery, PV, Grid	Hotel in Gold Coast, Australia	Grid Connected wind Turbine has proved to be the feasible model compared to Grid only or hybrid renewable energy system considering the energy consumption price of 2004. The NPC and RE fraction have been studies as the deciding factors for the feasibility study. This system has a payback time of 14years and less emission and Vestas Wind turbine are considered to be more efficient compared AOC wind turbine for the considered location.
3	2008 [143]	PV-Wind-Diesel generator-Battery	Large Hotel, Queensland	HYBRID and HOMER software has been used to analyse the economic feasibility for integrating HES to a large hotel in Queensland, Australia. A generic flat plate PV, lead-acid batteries and AOC and Vesta types of WTs have been analyzsd for its performance by considering the NPC and RF as the deciding factors. Vesta WT was found to be more economically viable option compared to AOS and PV was found to be not a great option for economic viability. On comparing the NPC of the optimized systems like RES only, diesel generator only and hybrid diesel with RES systems, the WECS only; hybrid-diesel energy system resulted in the lowest NPC

				using HOMER software. When the results of HOMER was compared with HYBRID software results, the results were similar.
4	2011[144]	PV-wind-biomass-battery	Residential area in Australia	For different locations in Australia, the adoptability of HRES was studied. It was found that a PV-WT, biomass, battery and converter system was the economically feasible option. The analysis included the rise in biomass price. The NPC, COE of the HRES system was found to have smaller emissions and economically more feasible option when compared to the diesel based system.

CASE STUDIES FROM REST OF THE WORLD				
Sl No	Year	***Energy system studied***	***Location***	***Comments***
1	2011 [145]	Stand-alone and grid connected modes with PV, Eco-wind turbines, Zebra batteries	Greek island	In the study, emission cost and the revenue from transporting excess of energy from the grid is calculated whilst for the project's lifetime the annual replacement costs are separately calculated. Grid connection has been considered as the energy backup solution and for trading the excess energy produced from RES. Integrating PV and wind energy systems have been considered the economically viable option
2	2014 [146]	Standalone (PV, WT ,battery energy storage)	Remote Island	Sizing of PV panels, wind turbine, and battery bank capacity was conducted and the system reliability and economic performance were studied. Due to the timing mismatch between the energy production and consumption along with a negotiation involving the unmet load is considered the economics of the RES would be considerably lowered. Off-grid energy system is a promising option when there is a development in the battery storage system and RE industry. This would highlight on the reduction in the cost of the system, thus engaging the off-grid system in remote places could be more promising.
3	2004 [147]	Jacobs 23-10 10kW WT, grid-tied inverter, Battery bank (for emergency need) Grid	St John's, Newfoundland d	R-2000 complaint a single-family home in Newfoundland represents zero energy home using wind turbines are considered the feasible option.

4	2015 [148]	Solar-wind-battery-diesel off-grid energy system	Dhahran, Saudi Arabia	A mathematical model was using the HRES was solved using MATLAB to solve and their performance analysis for the optimally sized system was studied and compared with HOMER. Increasing the size of WT and PV to compensate for the size of the expensive batteries have been studied. The LCE of the system significantly reduces on increasing the size of the energy sources. However, in such case, the LPSP increases
5	2010 [149]	Grid connected PV system	Amman/Jordan	Application of Homer is used to understand the energy pricing scheme of Jordan by energy sale to the grid for definite hours using specific features of PV system is studied
6	2013 [150]	Stand-alone: PV-fuel cell-battery	Tocantins, Brazil	An economic analysis conducted using HOMER software resulted in an increase in NPC and total system cost due to the presence of fuel-cell, though this system involves less maintenance with least interruptions. However, the PV-battery system would minimise the economics (COE) of the system was understood.
7	2009 [151]	Wind–PV-battery	Community in Sitakunda, Bangladesh	Considering the fact of the national electricity grid which does not meet the community load demand has suggested Hybrid wind -PV-battery system as an economically viable option with least value of COE
8	2015 [152]	Wind-PV-diesel-Battery	Tourist Village, Egypt	Considering the factors like : NPC, COE of the systems and the influence of ambient temperature and GHG emission penalties, four Egyptian cities namely: Luxor, Giza, Alexandria, Qena and Aswan were studied. The study aimed at making these cities environmentally friendly by adopting different energy sources.
9	2010 [153]	PV-GE 1.5sl WT-Hoppecke 20 OPzS 2500 battery-Grid and Diesel back up	Gokceada island, Turkey	HOMER has been used to study the optimal adoptability of hybrid or non-hybrid system for Gokceada island. It was understood from HOMER analysis that the. Wind energy adoption has been found suitable when connected to the grid, as it provides an additional revenue through grid sale.
10	2014 [154]	PV-Wind-Battery	Remote areas of southern Ghana	LCOE and NPC were been considered the factors for the feasibility of energy system used. The chosen location in Ghana had a mean wind speed of 5.11 m/s whilst the annual daily average incident global solar radiation is 5.4 kW h/m^2/day. Though the annual mean wind speed is

				comparatively low, with an optimum size of PV-WT and battery system can meet the load demand with $0.281/day as COE.
11	2015 [155]	Off -Grid system consisting:119 kW hydro turbines, 24 kW owind power capacity, 54 kW ofPV capacity and 160 kW of diesel generator capacity (as a back-up)	Isle of Eigg (Scotland)	Adopting an off-grid energy system for Isle of Eigg was considered. On careful examination of the accessible resources and demand, it was understood that the chosen location proved to be an example for the developing countries. The off-grid system designed for the Isle of Eigg has broken the stereotype of off-grid energy adoption to be superior and permanent solution by having 90% of energy access through RES and backup option with a active user participation has provided the best example in the real-time scenario.
12	2012 [135]	Grid connected PV	Uganda	Adopting RE instead commonly used diesel source for fuel has been discussed. The fluctuating diesel price and emissions involved in the adoption of diesel energy source is the motive behind RE option for Uganda. Considering the scheduled rates of electric prices and feed-in tariffs. A PV connected to the grid and storage system with grid connection were considered as the feasible options to a replaced diesel energy system with least value of COE and NPC.
13	2014 [156]	PV-Generator-Battery	The northern part of Nigeria	Systems considering: generator only system, generator-battery system, PV-Generator system and PV/Generator/Battery systems were analyzed for the economic viability. Considering the interest rate for the location the HOMER simulation was conducted. However, it was noticed that the energy consumption data was analyzed from the available literature for African countries and the actual energy consumption bills are not used in the analysis.
14	2012 [157]	PV-wind-diesel	4 storeys building in Universiti Technologi Malaysia, Malaysia	HRES like: Stand-alone diesel system, PV-diesel system connected to battery and without battery storage, a wind-diesel system with battery storage and without battery storage, PV-wind-diesel system with battery storage and without battery storage were studied for variable capacities of PV, WT, and battery. The load following strategy was considered for HOMER simulation to minimise the NPC of the system. PV, wind, diesel, battery has found to be economically viable option with smaller value of COE and relatively lower CO_2 emission for the desired location.
15	2009 [158]	Genset-PV-Wind Turbine-Battery	Three Tourist Accommodations	Considering carbon tax and increasing diesel price resulted in larger value NPC in the analysis. However, the NPC and Renewable energy fraction (RF) was found to be inversely related to the HES considered.

				The integration of energy system seems to be more economically viable for smaller tourist accommodation compared to the bigger accommodations.
16	2016 [159]	Solar-Hydro-Diesel Generator-Battery	Rural electrification in southern India	Considering the seasonal availability of hydro power and wind energy for a small community with the calculated load PV, WT, Hydro, battery and PV, WT, battery systems were simulated for the least NPC and COE. Solar/Wind/Hydro/ Battery system provides a better reliability for the load as well as an economically feasible option compared to Solar/Wind/Battery systems or Grid along with grid extensions facilities was understood.
17	2013 [160]	PV connected to Grid	Greece	To mitigate the GHG emissions and reduce the dependency on a conventional source of energy, the PV connected to the grid was studied for 46 locations. Based on the economics of the system simulated from Homer and also the diminishing PV prices in the future would result in the easy adoption of PV system especially in Tymbakion compared to the economic merits for PV integration in Ioannina.
18	2014 [161]	Biomass-PV-Battery connected to the grid.	Remote area, Bangladesh	A novel model using biomass and PV as the source along with the battery has been analyzed for remote areas in Bangladesh. The proposed model would cater to the primary loads and deferrable loads for 22.8kW for the community where the power supply from national grid is difficult.
19	2014 [162]	PV-wind -battery -diesel generator charging station for electric vehicles.	Rural areas of the Democratic Republic of Congo	Two scenarios have been discussed to charge tuk-tuk using the PV-Wind-battery system. The scenarios include, one Tuk-tuk to be charged per day and the other includes several Tuk-tuks to be charged during a day. The sizing of the energy system is done by including most unfavorable month. The RE is sized according to the least value of NPC and this model could be an example for other charging power stations.
20	2012 [163]	PV-wind-turbine-diesel generator-battery	Ethiopian Remote Area	Due to the shortage or absence of electricity supply in a rural area in Ethiopia, a hybrid stand-alone system is modeled for the least value of NPC and COE. It is observed that the COE and NPC are higher when 100% RE is considered, whilst COE and NPC are lower from smaller renewable energy factors. The above system was studied considering LF as a control strategy.

21	2013 [164]	PV-battery	A fish pond with aeration system in Sleman Regency, Yogyakarta	PV-Battery system was optimally sized considering the load required for solar powered aeration system at Yogyakarta. Considering 1 kW PV connected to 8 battery of nominal capacity 200 Ah through an inverter of 0.2 kW is required to meet the load demand of the desired location. It is estimated that for the HRES chosen the COE is 0.769 $/kWh.
22	2017 [165]	PV-battery-Diesel generator	Water pumping system for Sohar city, Oman	A comparison between PV pumping system and diesel generator pumping system is done. To access the systems of study, yield factor and capacity factor were considered as the technical factors whilst payback period and COE was used as economic factors. The study resulted in COE with diesel generator was comparatively high of 0.7$/kWh than PV system sized by HOMER which is 0.309USD/kWh. This concludes that the PV water pumping system is economical, technically and environmentally viable option for rural areas in Oman
23	2012 [166]	PV-hydrogen power generation (Fuel Cell) connected to the grid	Kirklareli university, Kavakli campus, Turkey	Comparative study of the economics of PV-grid connected system and the PV-Fuel cell grid connected system has been analyzed to meet the university load demand. It is observed that the COE and NPC. After analyzing the load of the place, the system configuration was set up and HOMER provided optimized results. The grid-connected PV system had NPC of $82,000 with COE 0.256 $/kWh whilst the grid-connected PV-FC system had COE of 0.294$/kWh. This hybrid PV fuel cell is not only economical but also has high RE penetration and lesser gas emissions when compared to the grid-connected PV system.
24	2011 [167]	Wind-Diesel	Lesvos island, Greece	Increasing the RE penetration by integrating two types of WT for wind farms and diesel generator farms is assessed for the isolated island in Greece. The economic viability of the system with the RE penetration greater than 30% is analyzed.
25	2013 [168]	PV-Battery	Nigeria	Adoption of RES for Nigerian community has been discussed. From the HOMER software analysis, it is understood that though adopting RES is possible but support from the Government would ease the RES adoption.
26	2008 [169]	PV-Diesel-Battery	Dhahran in Kingdom of Saudi Arabia	The study focus on integrating PV-Diesel-Battery showed that there are mutual benefits of the energy resources used for Tehran in terms of meeting the load demand. It suggests that the dependency of Diesel generator could be reduced greatly by increasing the PV capacity and introducing battery. This also resulted in lower CO_2 emissions.

27	2015 [170]	PV-Diesel-Flywheel-Battery	Makkah, Saudi Arabia	Stand-alone diesel generator, PV and diesel generator; PV, diesel generator and battery; diesel generator and fly wheel; PV, diesel generator and flywheel; and PV, diesel generator, battery and fly wheel are the six HRES configuration studied. The study results in the usage of diesel generator reduce and thus a reduction in CO_2 emissions when the PV and battery systems were introduced. There was a considerable reduction in COE for the system that consisted battery. IT was observed that the introduction of FW in the system had a similar effect on the CO_2 emission and COE, however, their presence in the system increased the battery storage timings. PV, diesel, battery-flywheel system was considered the more economically viable option and also mitigates CO_2 emissions compared to other models.
28	2011 [171]	PV-WT-Hydrogen Tank-Fuel Cell-Electrolyzer	Electrics & Electronics Faculty, Istanbul Technical University	Integration of Hydrogen system to the grid and stand-alone mode is studied for its economic viability after optimally sizing the system components using HOMER. The analysis resulted with grid connected system to be more viable than stand-alone system because the HOMER over-sizes the RES to make it 100% reliable to meet the load demand and thus results in high costs which are the biggest hurdle faced.
29	2016 [172]	Wind-photovoltaic-Hydrogen fuel cell- diesel -battery	Household in Tehran, Iran	Economic analysis was conducted for the HRES of WT, PV, FC, battery, diesel generators.The study suggests that wind, diesel, FC , battery results in the most economical option for the study case. The NPC of the chosen system was $63,190 with COE of $0.783/kWh. Amongst the HRES considered, WT had contributed the highest capital cost. Although, this system contributes to some emissions due to the consideration of diesel generator in HRES.
30	2012 [173]	Wind-Solar-battery	Remote village which lacks access to the utility grid - Mandapam in Ramanathapuram District, Tamil Nadu, India	The cost optimisation for a hybrid stand-alone network was considered in this study. The COE is $0.235/kWh and the costs of WT and converter being very high. Hence the study suggests in integrating Grid into the system would ease the economics of the HRES and the size of PV.

31	2010 [174]	PV-fuel cells	Brazilian Amazon region	Considering PV, FC, electrolyser, battery and hydrogen storage the HRES is analyzed to cater to a load of a small community in Amazon. The above-considered HRES were technical feasibility, its financial feasibility has been a questionable option. However, the most feasible technology for adoptability is found to be PV-Battery system and this system could be economically comparable with PV-Fuel cell-Battery system if the cost of Fuel cell drops by 50% to make adoptable to Brazilian Community.
32	2013 [175]	Wind turbines for Wind Power plants	Al-Wajh, J Jeddah, Yanbu and Jizan of the Kingdom of Saudi Arabia (K.S.A.)	Techno-economic feasibility by understanding the COE, NPC have been studied to explore wind energy through wind farms at Al-Wajh, J Jeddah, Yanbu, and Jizan. CFD (cumulative frequency distribution of wind energy has been analyzed using HOMER for these places
33	2016 [176]	PV-Wind-Diesel generator-Battery	Rural Community, Bangladesh	A stand-alone HRES like PV and wind has been studied for Baultali Muslim Para under Kalapara sub-district of Pathuakhali district, Bangladesh. The PV and WT are solely used to meet the load, after meeting the load if the energy produced in excess, then it is used to charge the batteries and used as dump load if the energy is excess. The diesel generator presence is only for load following strategy. With the COE \$0.161/kWh the considered system is techno-economically a feasible option.
34	2014 [177]	PV-Battery	Orphanage in Nsukka (Enugu State, Nigeria)	Energy consumption of the orphanage was calculated according to the electrical appliances used over time and adoptation of PV connected to the battery system was considered for the analysis. 1.4 kW PV, 48 Surrette 6CS25P battery, and the 1kW inverter were resulted as the optimized size for the load demand for orphanage using HOMER.
35	2012 [178]	Hydro-wind-PV -hydrogen storage	A rural community, Iran	Using GA using MATLAB and HOMER software the optimized solution for the chosen HRES is studied. The COE of the HRES with and without hydro energy system was found to be nearly the same of about 0.2\$/kWh. Using LPSP as the criteria to size the HRES the optimum size was reached.
36	2015 [84]	PV–Wind–Diesel–Battery	Southern Algeria	Proven 15 WT and The PV module of type KD 180 GX-LP from KYOCERA have been included in the study in sizing HRES. The considered HRES system meets the load demand with 43% of energy contribution from WT and 26% from PV panels. 7500 kW h/month of

				load demand is met by this HRES and thus mitigating about 70% of GHG compared to diesel alone system.
37	2010 [179]	PV–Wind–Diesel–Battery	Remote community: The four locations are Addis,Ababa, Mekele, Nazret and Debrezeit in Ethiopia	An assumed load for a community consisting 200 families, each comprising of five family members are used for the study. The desire to adopt RE in Ethiopia comes with a bigger challenge with respect to the NPC which in turn depends on the cost of the system was concluded.
38	2012[133]	Wind-PV-diesel	Village in Saudi Arabia	The study aims at designing HES to mitigate the CO_2 emissions and reduce the reliability of the available generator sets to source the electricity load of 17,043MWh/year. When PV and WT were introduced along with the generator, HOMER sized HRES consisting of 3 WT of 600 kW capacity, 1000 kW of PV panels and 4 diesel generators of 1120 kW capacity. This HRES reduced the GHG emissions along with 35% of energy contributing from PV and WT. The COE for this system was 0.212 US$/kWh.
39	2007 [180]	Diesel generator-wind turbine	A village, Saudi Arabia	The primary electrical load of the village, the contribution of wind energy source using WT was studied by performing the feasibility analysis using HOMER. The study was aimed to include the existing diesel generator grid connected system with a WT. It was found that, when the available wind speed of 4.95 m/s was included, the HOMER did not give a feasible solution. However, a feasible solution using HOMER was for HRES with wind speed greater than 6 m/s and the fuel price is lesser than 0.1 $/litre.
40	2014 [181]	PV-Wind-Diesel generator-Battery	Hargeisa, Somaliland	Integration of RE to Hargeisa has been studied as the electrical grid present in the location has not been much developed. Economic analysis was performed using HOMER with the diesel only system as the base case and comparing this system with the hybrid energy system consisting of PV-Wind-Diesel and battery. I was observed that for the diesel price considered, the HRES was a more economically feasible option by considering the NOC and COE of the systems. Wind energy proves to be a better option compared PV.

41	2012[182]	Hydro/PV/Wind	Dejen district, Ethiopia	Using GIS, empirical formula and NASA database the flow head, solar radiation and wind speed data were calculated. The load for the community was estimated according to the activities of the people in the village with an assumption of a total of 10,500 families with an average of six members in a family the primary load for the community was considered as 561kWh/day. Diesel price and capital and replacement cost of PV were used for sensitivity cases. Hydro-Diesel Generator-Battery system was considered as the most feasible option for considering COE and NPC.
42	2015[183]	Wind-Hydrogen fuel cell-Diesel generator	Grimsey Island, Iceland	The peak electrical load was for the island was analyzed to be 175 kW. The average daily energy consumption of 2.4 MWh. Three system configurations were studied: wind, diesel; wind, diesel, hydrogen; and wind, hydrogen systems connected to the grid. Amongst the three models proposed, the HRES consisting of wind, hydrogen, diesel system was found to be the most economically feasible option.

2. Literatures on the Case studies conducted using iHOGA software

Sl No	***Year***	***Energy system studied***	***Location***	***Comments***
1.	2016[90]	PV, Wind, battery	Community in Yavatmal district, Maharashtra, India	The HRES is connected to meets the load when the energy output is higher. If the output from the HRES is less the battery meets the load demand. In this study for different sensitive variables like solar radiation, wind speeds the LCOE was. The results infer that the iHOGA gives the best designed optimized HRES for the given location.
2.	2017[184]	Wind Turbine	Pianu in Alba country	The Skystrem 3.7 wind turbine performance for smaller windspeed was experimentally measured and the results were compared with the results obtained from iHOGA simulation. The inference from the results obtained showcasing a difference between the measured and simulated values could be due to the stochastic behavior of the wind energy

3.	2016[185]	PV and Battery stand alone	North India, Central India, South India, North Pakistan, South Pakistan, Kalimantan Java, Tanzania, and Spanish Pyrenees	The economic and environmental analysis was performed for the aforementioned developing countries. PV and Li-Ion batteries were considered as energy sources and storage option for the LED lit homes. The economic analysis was carried out for 2015,2020, 2025, 2030. The result analyses the economic and environmental feasibility of houses adopting LED lights which are sourced by PV. This option has been inferred to be more a feasible even with respect to the environmental emissions.
4.	2015[186]	PV-Wind-Battery-hydrogen fuel cell, electrolyser-grid	Cluj-Napoca	The performance of PV+battery, Wind+ battery, Fuel cell + hydrogen, PV+WT+FC+hydrogen, PV+WT+FC+electrolyser-hydrogen energy systems were individually studied through simulation using iHOGA. Unmet load, carbon dioxide emissions, total system cost were considered as the multi-objective functions for the analysis. The results highlight the Solar and Wind energy systems were the most feasible options for a house in the city of Romania and the Hydrogen energy technology needs a compromise with respect to the cost of the system to be adoptable.
5.	2016[124]	PV, Wind turbine, Battery (stand-alone)	Sirte, Libya	Cost analysis was conducted using three software: HOMER Pro, HOMER Beta and iHOGA software. A stand-alone HRES has been studied considering PV and wind turbine connected to battery storage to provide water pumping facility in Sirte, Libya. The three software was used to size and economically optimize the HRES. The size of HRES though are similar, there is a small difference in their NPC an LCOE. iHOGA had the highest LCOE, HOMER Pro had the highest NPC and HOMER Beta provided highest COE. The study concluded that the HOMER Beta to the best software as it provides the best of NPC and COE of HRES compared to the results from HOMER or iHOGA
6.	2016[86]	PV, Wind, battery	Community in Yavatmal district, Maharashtra, India	The HRES is connected to meets the load when the energy output is higher. If the output from the HRES is less the battery meets the load demand. In this study for different sensitive variables like solar radiation, wind speeds the LCOE has been examined. THE LCOE from the optimally sized HRES was $0.41 with 99% of the load being met and 1% of the load was unmet by the system.

7.	2016 [187]	PV-Battery	Developing countries	Considering the PV and battery setup for the off-grid system has been analysed for a set of developing countries. Different types of PV panels were considered for the analysis. The study suggests that an off-rid system for developing countries is though environmentally a viable option, it is an expensive setup for the developing countries. However, an efficient utilisation of these energy sources is considered as an alternate option.

APPENDIX B

1. Regulatory Policies of Denmark

Policy	Year	Description
Regulation on Net-metering for the Producers of Electricity for Own Needs	2012	This policy includes exclusion from paying tariffs, duties, and VAT for the quantity of electricity exported to the grid. This applies to both partially and totally complete electricity producers. Self-producing electricity generators with the exemption of geothermal energy are eligible for this exemption. The self-producing installations are to be connected to the grid and are owned by the consumer and installed in the place of electricity consumption. To benefit from net metering regulation, installation of self-producing locations must be registered with Energinet.dk. To avail this policy, generators under 6 kW are eligible. Net metering is calculated on an hourly basis. Two levels of benefits from net metering are outlined: i. Full exemption from sharing for public use under the following conditions. • PV < 50kW, • Wind < 25kW, and • Other types of installations < 11kW ii. These installations are not required to pay RE subsidy.
Danish Energy Agreement for 2012-2020	2012	Focus on the orchestration for the policy on climate and energy up to 2020 and outlines the course Denmark will take until 2050. According to this policy, wind power provides 35% of gross energy consumption in 2020 in addition to the reduction in energy consumption of more than 12% by 2020 compared to 2016. This policy also highlights: i. Energy-efficiency

		ii. Green Heating iii. RE in buildings iv. RE in industry v. Deployment of Smart Grids vi. Electricity and biomass in transport vii. Research, development and demonstration and financing
Energy Strategy 2050	2011	For 100% RE deployment Danish government is aiming at a few strategies: i. Introducing building code and forbidding the use of oil boilers in all new constructions and, by 2017, in all houses. ii. Encouraging the use of biomass, biogas and solar thermal appliances iii. Denmark's main objective lies in the large-scale deployment of offshore wind, improving the wind manufacturing and fund for projects to deploy solar and wave power, large heat pumps intended to be used in district heating plants, geothermal energy research projects. iv. Introduction of public service obligation tax on electricity and gas and also increased taxation of oil, gas, and coal to discourage their use. v. Denmark has banned nuclear power programme and the country lacks large hydropower projects thus it focuses on deploying RE.

National Renewable Energy Action Plan (NREAP)	2010	EU Directive 2009/28/EC member countries of the European Union are bound to submit a draft/proposal/ roadmap to European Commission National Renewable Action Plans (NREAPs) which will allow them to meet their 2020 targets, energy efficiency and aims to mitigate GHG emissions. This includes: i. Proof of investments in R&D and demonstrate the possibility of use of RE by virtue of demo projects. ii. Increase efforts to improve energy efficiency in buildings. iii. Efforts to save energy at all levels iv. Provide subsidy and tax relief to the generation of energy from RES. v. Provide financial support for installations of RES at the micro and mini scale. vi. Introduce obligations to blend biofuel
Promotion of Renewable Energy Act	2009	Promote the use of new wind turbines on land by introducing new schemes: i. Provide local citizens the option to purchase shares in wind turbine operations, ii. Create green schemes to improve local scenic and recreational values. iii. Provide suitable funds to support preliminary investigations of setting up wind farms by local wind turbines owners.
Feed-in premium tariffs for renewable power (Promotion of Renewable Energy Act)	2009	i. Wind power generated onshore which are not used by the owner of the wind turbine benefits from a feed-in tariff of DKK 0.25 per kWh of electricity produced for the first 22,000 peak load hour of the wind turbine being connected to the grid. Turbine owners also benefit from a refund of DKK 0.023 per kWh towards the price paid for electricity consumed. ii. Offshore wind farm installations are installed by following a tender process and have incentives different that the onshore ones. The huge wind farm at Horns Rev 2 was provided with a feed-in premium and when included with the market price of electricity amounted to DKK 0.518 per kWh. For the wind farm at Rodsand 2, the total tariff amounted to DKK 0.629 per kWh. iii. Supplement to all this, a part of the price is some amount of money which are towards the supply of the electricity supplied to the grid.

		iv. The premium price is paid for even the wind turbines which are less than 25kWwhich are installed for personal use. The price is set at DKK 0.60 per kWh.
National RD&D Strategies for Renewable Energy Technologies	2003	Integration of renewables into the grid needs to be done by having a consistent strategy. This strategy has been developed by the collaboration between The Danish Energy Authority and the two main utilities. The strategy elaborated has strategies for R&D of fuel cells, wind energy, biomass and solar cells. This also covers how these discrete types can be used in conjunction with each other and create an integrated system.
Energy Research Programme	1976	This programme supported projects there were practical in nature and the projects selected were implemented over a tow to there year timeframe. All technologies were welcome except nuclear power. Some of the technologies covered were wind energy, solar cells, biomass, wave energy and hydrogen technologies. Also available was financial support, in some circumstances almost 100% of Financial support was available, however, average support level was around 50%.

2. Renewable Energy Policy Framework of Germany

Policy	Year	Description
2017 Amendment of the Renewable Energy Sources Act (EEG 2017)	2017	On 8th of July 2016, Germany adopted an amendment to the Renewable Energy Act (further: EEG 2017). The amendment came into effect on 1st of January 2017. The reform introduces public tender procedures for onshore wind, offshore wind, solar and biomass projects in the country's efforts to shift from FiT support RE deployment to market-orientated price finding mechanism. With that, projects

		will no longer be eligible for statuary FiT remuneration but will have to bid for it in public auctions organized and monitored by the Federal Network Agency (Bundesnetzagentur). Successful projects will receive contracts for the duration of 20 years for sale of the produced electricity at the price that they bid during the auction process. Germany has been aggressively looking at increasing the share of the renewables use. By 2025, Germany is looking at increasing the share to 40%-45%, by 2035 55%-60% and by 2050 they plan to reach a minimum of 80%. However, in the EEG 2017 amendment, it has been stipulated to control the capacity of deployments every year similar to how it was done in 2014.
Ground-mounted PV Auction Ordinance	2015	Germany has recently introduced a pilot version of auctioning installation of ground-mounted solar PV. The aim of this exercise is to achieve expansion of solar installations in a cost-effective manner. This auctioning process has ensured that installation of new ground-mounted PV installations are built with maintaining a high level of public acceptance and diversity of stakeholders. This process is helping capture learning for future auctions of other RE types. The auction system is for ground-mounted solar installations between 100kW and 10MW.
2014 Amendment of the Renewable Energy Sources Act (EEG 2014)	2014	The objective of an amendment to the EEG in 2014 is to continue the steady deployment of renewables by integrating more RES into the market. This share is set to increase to 40%-45% by 2025, 55% - 60% by 2035 and increasing up to 80% by 2050. The following are the RES technology expansion plans – 1. Wind Energy a. Onshore – Annual net addition of about 2.5 GW. b. Offshore – Average of 800MW per year totaling about 6.5 to 7.7 GW. 2. Solar PV's – Annual addition of 2.5 GW. 3. Biomass – the Annual addition of 100MW. Tracking of these RES investments will be done by the Federal Network agency using a register created for this very purpose. Mandatory direct marketing:

		Better integration of RE into the market will depend on how the operators market it. This will be done by imposing obligations to market the electricity generated. This can be accomplished either by marketing directly, independently or using a direct marketing agency. The EEG 2014 listed the two ways in which direct marketing could be achieved : i. Subsidised direct marketing – This is a way of marketing the product with the sole reason to receive a market premium. ii. Direct marketing without receiving a subsidy. As of EEG 2104, the direct marketing subsidy known as EEG surcharge or green energy privilege has been removed. Market premium: RE generated was a subject of a market premium pricing when it was directly marketed. The premium pricing consists of a statutorily fixed tariff for a particular RE plant minus the market value of the specific technology. Direct marketing of wind and solar generators are exempt from receiving any management premium. Not all the RES plants are obligated to follow direct marketing, they are : ➢ RES plants commissioned before 1st January 2016 with a capacity less than 500kW. ➢ RES plants commissioned before 31st December 2015 with capacity under 100kW. Tenders: From 2017, RE generators will be able to start raising funds via tenders. The rules governing this have not yet been agreed upon. Feed-in tariffs for small-scale generators: RES generators installed before the 1st of January 2016 will be supported by the implementation of feed-in tariffs, however, this will be limited to installations with a capacity up to 500 kW. RES plant operators are allowed the flexibility to switch between receiving benefits from feed-in tariffs and market premium tariffs. This switching is allowed only once a month.

		Domestic consumption surcharge: As per EEG 2012, the energy produced in generators owned by the consumer, termed as “auto supply”, did not have to pay any charges but others did not have to pay charges. Such auto supply plants which are already in use will be protected from any charges. Any new auto supply plants will have some EEG charges imposed on them.
Energy Concept	2010	The Energy Concept was coined to group together several policy goals 1. Securing the supply of power. 2. Protecting the growth and competitive nature of German industry Energy Concept also has stipulated climate protection targets. With the 1990 emissions as the base, the plan is to achieve a 40% cut in greenhouse gas emission by 2020, by 2030 reduction up to 55%, by 2040 reduce to 70%, by 2050, reduce it to between 80% and 90%. The energy concept also defines a strategic approach to switch to renewables and the energy efficiency that’s needed to secure supply of energy that is environmentally compatible i.e. the 80% carbon emission reduction by 2050 and affordable. As per the Energy Concept, the renewables should account for the major share of the energy supply The Energy Concept also contains a large number of specific financial measures such as the Energy and Climate Fund. The Energy Concept describes the below specific targets and development paths through to the year 2050: i. Cutting of greenhouse gas emissions to the rates listed above as compared to the 1990 levels. ii. A portion of RE among the total energy consumption to increase to 60% by 2050 from the current share of 10%. iii. Reduction of primary energy consumption – Reduce base 2008 consumption to 20 % in 020 and further reduced to 50% by 2050. iv. The double annual rate of building renovation from 1% to 2% per year in order to improve energy performance. To aid in implementing these targets, The Energy Concept consists of wide array of specific measures. It also consists of an immediate action programme to help kick-start these processes. One of these, in particular, is the extension and upgrading of the existing power grids and expansion of offshore wind power.

		In order to track the progress of the Energy Concept, from 2013, the Federal Government will carry out a monitoring process which is very scientific in nature. This will happen every 3 years. To top it all off, the Energy Concept programme has the necessary funding in place to implement the measure over the long term.

3. Renewable Energy Policy framework in the USA

Policy	Year	Description
US Climate Action Plan	2013	In June 2013, the US president at the time, Barack Obama, presented the US Climate Action Plan which called for a steady and responsible national and international action to cut GHG emissions which were responsible for climate change and caused a threat to public health. The plan was a 3 step plan. • Reduction in carbon pollution. • Equip the US for impacts arising out of Climate Change. • Lead the global efforts to help combat climate change and prepare for the impacts. These identified pillars each contain wide-ranging provisions for Executive actions that Presidents can take. The mitigation elements are as follows. 1. Reduce CO_2 pollution from coal plants by directing the Environmental Protection Agency to update the acceptable pollution level standards for existing and new power plants 2. Unlock the potential of clean energy innovation by making available USD 8 billion in loan guarantee for energy projects that use fossil fuels.

		3. Accelerate clean energy creation by directing the US Interior Department to permit the use of public lands for installation of 10GW of renewables by 2020. 4. Setting goals to install 100 MW of renewables in Federal Housing by 2020. Additionally, the US Department of Energy has recently announced its RE expansion of providing low and moderate income housing with 300MW energy and they have also agreed to deploy about 3GMW of renewables in military installations. They have also announced the expansion of the Federal Government's Better Building Challenge which focuses on helping industrial, multi-family buildings and industrial installations become at least 20% more energy efficient in the near to medium term.
Smart from the Start Initiative	2010	To promote the development of the wind potential, the Smart from the Start initiative was established. One of the goals of this initiative is to issue leases for RE development on the Outer Continental Shelf (OCS) and to promote environmentally feasible renewable development. The steps to accomplish this is as follows 1. Implement comprehensive and expedited leasing framework for harnessing Atlantic Wind potential. 2. Simplification of the approval process for individual projects and elimination of regulatory requirements were not necessary. Aggressively moving to process the build of offshore transmission lines.
American Recovery and Reinvestment Act of 2009: Tax-Based Provisions	2009	In 2009, the American Recovery and Reinvestment Act (ARRA), was signed into law. This was a supplemental spending bill that earmarked over USD 80 billion to support the research and development and deployment of clean energy. Out of this money, about USD 30 billion was available through tax-based incentives. The provisions included a Production Tax Credit (PTC) for implementation of renewable energy technologies. The average taxpayer investing in these facilities could claim a tax credit of about 2.1cents per KWH of energy produced in such facilities. AARA extended the financial facilities for wind farms through till 2012 and for other renewable types such as irrigation, closed-loop biomass, open-loop biomass etc till 2013. AARA also allows for claiming Investment Tax Credit (ITC) instead. Taxpayers who invest in these energy properties could claim about 30% ITC. ARRA will increase funding for CREB by USD 1.6 billion for the RE entities that are owned by Governmental entities such as municipal utilities, cooperatives, and tribal entities.

		For manufacturing facilities located in the US will be provided with a form of tax credit called the Manufacturing Tax Credit (MTC). ARRA has also created a new incentive scheme for creation or expansion of manufacturing facilities that produce components and systems for renewable energy systems. The incentives set aside for these total about USD 2. 3 billion. MTC applicants also receive tax credits which cover Capital Costs worth about 30% of Capital Costs for approved projects. ARRA also has set up provision for Alternate Refuelling Tax Credit (ARTC). As per this, ARTC provides gas station businesses credits to install alternate fuelling points such as E85 Fuel, hydrogen fuelling, and natural gas fueling. For the years 2009 and 2010, the ARRA bill provided 30% credit for up to a maximum of USD 30,000. In the case of hydrogen pumps citing the cost of setting them up, the tax credit was up to a maximum of USD 200,000.
Credit for holders of Clean Renewable Energy Bonds (CREBs)	2006	CREB's are financial products which are used by public sector entities to finance RE projects. These provide interest-free type loans to Municipal Electric Utilities and Rural Electric co-ops for financing qualified energy projects. These include closed-loop biomass, open loop biomass, small irrigation projects, landfill gas, hydropower, trash combustion and marine renewables.

APPENDIX C

1. Electricity Consumption Data of 70 houses in Aralvaimozhi, India

Number of Houses	***Electricity Consumption in kWh***												
	Billed date 4/07/2016	3/05/2016	3/03/2016	6/01/2016	4/11/2015	4/09/2015	6/07/2015	10/05/2015	6/03/2015	5/01/2015	4/11/2014	4/09/2014	**TOTAL**
1	150	200	130	130	120	70	110	170	100	80	90	110	**1460**
2	80	628	470	370	470	470	360	240	260	250	260	250	**4108**
3	370	300	180	380	320	380	390	250	290	345	350	350	**3905**
4	190	180	170	140	150	140	120	150	120	120	130	120	**1730**
5	350	480	390	390	520	150	260	260	180	180	220	360	**3740**
6	230	280	220	200	270	270	190	200	90	180	260	260	**2650**
7	780	720	710	590	660	590	580	680	620	660	600	700	**7890**
8	220	230	190	240	220	190	220	240	210	200	200	210	**2570**
9	90	120	80	70	60	90	90	100	70	80	80	90	**1020**
10	100	140	110	140	140	140	130	180	100	120	140	150	**1590**
11	140	120	110	110	110	110	80	120	90	130	160	170	**1450**
12	240	140	20	10	20	20	20	40	20	20	20	40	**610**
13	60	40	40	60	50	50	20	80	60	20	50	80	**610**
14	140	90	150	160	100	100	110	100	80	70	40	170	**1310**
15	100	100	60	100	130	120	130	170	150	150	180	160	**1550**

16	40	40	70	160	60	40	30	40	60	20	110	210	**880**
17	20	70	50	40	30	50	40	170	50	50	40	40	**650**
18	130	120	120	140	140	120	120	200	130	120	140	150	**1630**
19	70	100	50	30	40	80	40	50	40	30	30	30	**590**
20	10	5	10	80	30	50	50	90	50	60	60	60	**555**
21	210	330	220	260	270	330	295	250	250	260	290	270	**3235**
22	140	160	140	150	150	170	120	360	160	160	110	110	**1930**
23	210	200	280	330	270	210	230	120	90	200	90	160	**2390**
24	340	390	190	150	200	330	600	160	160	190	240	230	**3180**
25	160	180	120	120	120	120	110	130	110	120	150	160	**1600**
26	50	50	20	30	30	30	30	50	20	20	30	70	**430**
27	30	120	40	40	80	150	160	200	140	80	140	110	**1290**
28	140	160	130	100	140	130	130	150	120	110	110	140	**1560**
29	210	160	160	180	170	150	150	170	140	140	170	160	**1960**
30	410	370	280	300	300	240	240	270	220	240	300	250	**3420**
31	260	300	240	430	220	220	230	250	210	190	230	310	**3090**
32	210	260	170	180	170	180	170	290	250	190	40	60	**2170**
33	300	320	260	280	290	280	275	270	270	270	310	320	**3445**
34	80	110	80	240	240	230	130	200	70	0	130	80	**1590**
35	140	170	150	220	300	280	280	380	260	260	340	350	**3130**

36	140	140	140	80	110	40	55	80	80	70	140	140	**1215**
37	230	240	310	430	350	350	290	300	280	280	330	290	**3680**
38	40	50	20	40	75	80	80	50	50	140	50	110	**785**
39	100	130	240	200	190	150	130	200	360	320	300	380	**2700**
40	240	290	220	250	250	240	200	250	210	200	210	200	**2760**
41	220	220	190	210	200	220	190	240	180	200	210	200	**2480**
42	70	150	90	90	100	110	180	70	90	70	80	70	**1170**
43	0	10	0	10	30	30	10	35	80	50	0	100	**355**
44	70	80	60	70	60	110	110	130	100	80	90	90	**1050**
45	330	270	300	130	260	260	210	230	260	270	260	270	**3050**
46	330	200	120	151	180	180	60	130	120	140	170	190	**1971**
47	230	200	460	0	290	260	200	220	160	210	240	220	**2690**
48	300	310	260	300	260	300	260	320	270	260	290	300	**3430**
49	240	260	230	240	250	260	210	300	230	210	220	200	**2850**
50	90	150	90	80	90	120	100	130	90	110	110	100	**1260**
51	120	210	120	140	110	180	160	180	110	110	130	130	**1700**
52	50	33	40	40	40	30	30	40	30	40	50	40	**463**
53	170	170	120	130	110	130	100	100	120	110	190	170	**1620**
54	230	160	150	160	160	180	140	180	130	130	150	150	**1920**
55	110	130	200	230	150	200	140	230	170	170	110	90	**1930**

56	130	150	130	100	90	60	40	20	30	20	30	20	**820**
57	170	160	150	200	92	170	140	200	140	130	130	120	**1802**
58	30	50	0	0	20	20	30	30	30	30	20	40	**300**
59	320	280	290	330	390	480	280	240	160	240	340	180	**3530**
60	230	130	130	160	170	130	140	130	140	160	240	250	**2010**
61	20	30	20	20	20	30	20	40	10	30	20	20	**280**
62	40	60	40	30	40	50	40	70	50	50	80	50	**600**
63	130	320	100	120	111	150	100	230	150	110	120	100	**1741**
64	140	190	190	190	190	140	150	240	160	130	140	150	**2010**
65	20	50	20	20	30	30	30	30	30	20	20	40	**340**
66	200	190	180	170	180	160	170	200	170	150	190	190	**2150**
67	160	190	140	170	160	160	150	200	130	140	160	170	**1930**
68	110	90	80	0	30	120	30	0	30	0	120	130	**740**
69	110	130	120	110	140	110	120	130	90	100	90	240	**1490**
70	50	50	40	31	50	45	0	60	20	20	20	55	**511**

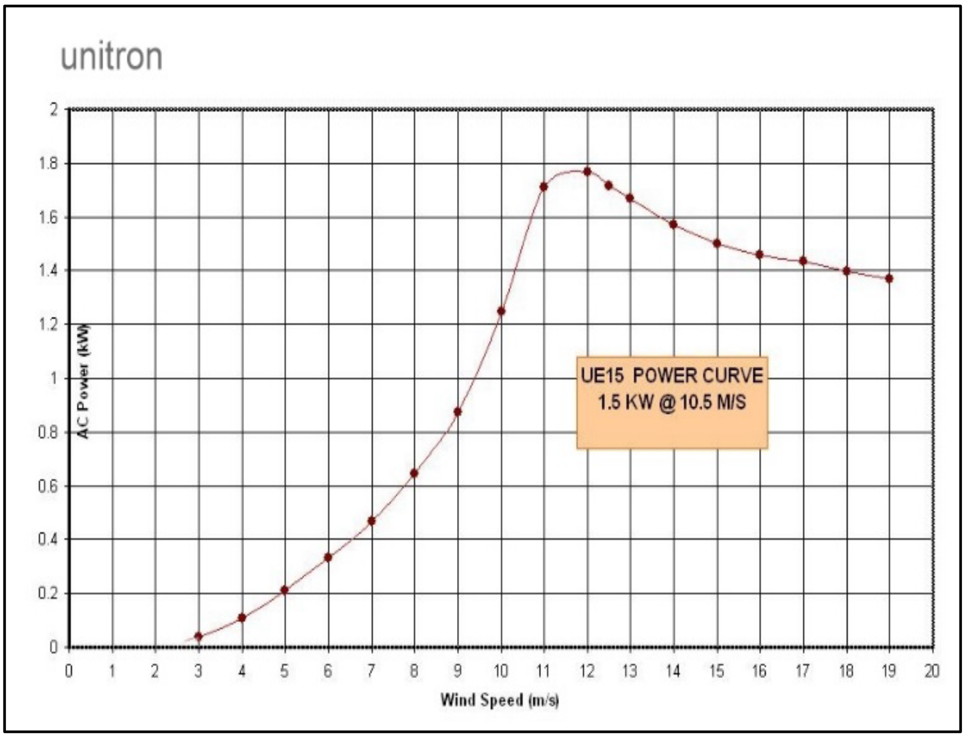
2. Energy consumption of the university in Warrnambool, Australia

Month	Energy Consumption in kWh
Mar-14	220,558.87
Apr-14	196,130.30
May-14	203,301.18
Jun-14	200,457.33
Jul-14	215,580.13
Aug-14	208,148.48
Sep-14	206,927.75
Oct-14	210,207.45
Nov-14	190973.78
Dec-14	193558.7
Jan-15	205,835.11
Feb-15	200664.66
Mar-15	217595.69
Apr-15	202262.54
May-15	214124.58
Jun-15	212,457.68
Jul-15	226,076.14
Aug-15	222,825.84
Sep-15	212,800.36
Oct-15	219116.91
Nov-15	212,876.80
Dec-15	234605.32
Jan-16	221619.44
Feb-16	207,321.40

3. **Technical details of the HRES considered for Aralvaimozhi, India**

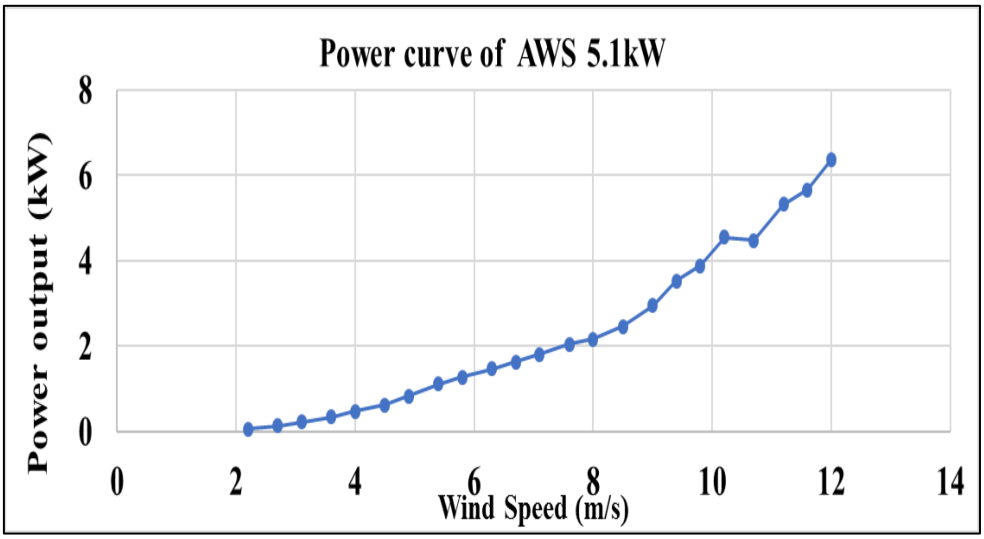
Solar Panels	Panel Type	Flat plate
	Rated Capacity	1kW
	Temperature Coefficient	-0.5
	Operating Temperature	470C
	Efficiency	13%
	Panel slope	60degree
	Temperature Effects on Power(%/0C)	-0.500
	Nominal Operating Cell Temperature	470C
	Ground Reflectance	20%
	Lifetime	25 years
Wind Turbine	Manufacturer	Unitron energy
	Rated Output	1500W
	Rated Wind Speed m/s / mph	10.5 / 24
	Peak Output	1700W
	Cut In m/s / mph	2.7 / 6
	Yaw System	Passive by tail Vane
	Yaw / Tower Cable	N x 360° Freedom
	Generator	PM 3 phase alternator (variable speed)
	Max Stator Core Temperature	180° C
	Poles	16
	Rpm	50hz/60hz 375 / 450
	Number Of Blades	3
	Blade Material & Cp	Carbon Fiber composite, ~ 0.37
	Warranty	2 yrs.
	Operating Life	20 yrs.
	Survival Wind	55 m/s
Batteries	Manufacturer and Model	Trojan-105
	Nominal Voltage	6V
	Nominal Capacity	1.52kWh
	Maximum Capacity	254Ah
	Capacity Ratio	0.447
	Rate constant	0.455/hr
	Round trip Efficiency	80%
	Maximum charge current	45A
	Maximum discharge current	300A
	Maximum Charge rate	1A/Ah
	Initial state of charge	100%
	Minimum State of charge	20%

4. Power curve Unitron 1500 (U1500)



5. Technical details of the HRES considered for Warrnambool, Australia

Solar Panels	Panel Type	Flat plate
	Rated Capacity	1kW
	Temperature Coefficient	-0.5
	Operating Temperature	470C
	Efficiency	13%
	Panel slope	60degree
	Temperature Effects on Power(%/0C)	-0.500
	Nominal Operating Cell Temperature	470C
	Ground Reflectance	20%
	Lifetime	25 years
Wind Turbine	Manufacturer	AWS
	Rated Output	5100W
	Rated Wind Speed m/s / mph	11/25
	Peak Output	5700
	Cut In m/s / mph	2.7 / 6
	Yaw System	Passive by tail Vane
	Yaw / Tower Cable	N x 360° Freedom
	Generator	PM 3 phase alternator (variable speed)
	Max Stator Core Temperature	180° C
	Poles	16
	Rpm	50hz/60hz 375 / 450
	Number Of Blades	3
	Blade Material & Cp	Carbon Fiber composite, ~ 0.37
	Warranty	2 yrs.
	Operating Life	20 yrs.
	Survival Wind	55 m/s
Batteries	Manufacturer and Model	Trojan-105
	Nominal Voltage	6V
	Nominal Capacity	1.52kWh
	Maximum Capacity	254Ah
	Capacity Ratio	0.447
	Rate constant	0.455/hr
	Round trip Efficiency	80%
	Maximum charge current	45A
	Maximum discharge current	300A
	Maximum Charge rate	1A/Ah
	Initial state of charge	100%
	Minimum State of charge	20%



6. Power curve of AWS 5.1kW Wind Turbine

APPENDIX D

1. Summary of D.C. and history of the micro-grid

D.C. history	Battery input energy	Previous day	1.6kWh
		7 Day total	9.2kWh
		30 day total	49kWh
		365 (year to date) total	254kWh
		7 day daily average	1.62kWh
		Daily average	1.55kWh
		30 day total	49kWh
		365 (year to date) total	254kWh
		7 day daily average	1.62kWh
		Daily average	1.55kWh.
	Battery output Energy:	Previous day	1.3kWh
		7 day total	8.7kWh
		7 da y daily total	1.18kWh
		30day Total	43kWh
		30 day daily total	43kWh
		365Year to Date total	254kWh
		Daily average	1.55kWh
		Previous day Peak power	1.39kW
		Previous day total	2.3kWh

	Solar shunt energy	7 day daily average	2.1kWh
		30day total	72kWh
		30 day daily average	2.63kWh
		365 day total	401kWh
		365 day daily average	2.44kWh
	Inverter energy Details	Previous day	2kWh
		7 day total	14.1kWh
		7 day daily average	1.99kWh
		30 day total	75kWh
		30 day daily average	2.44kWh
		365 day total	540kwh
		365 day daily average	3.25kWh
		Year to date Total	540kWh
		Daily average	3.25kWh
history	Load energy	Previous day load	3.5kWh
		7 day total	24.2kWh
		7 day daily average	3.45kWh
		30 day total	112kWh
		30 day daily average	3.73kWh
		365day total	719kWh
		Year to Date Daily average	4.37kWh
		365 day daily average	4.37kWh
		Year to Date Total	719kWh

	input energy	7 day total	0.1kWh
		7 day Daily average	0.0kWh
		30 day Total	1kWh
		30 day daily average	0kWh
		365 day total	38kWh
		365 day daily average	0.21kWh
		Year to Date Total	38kWh
		Year to Date Daily average	0.21kWh
		Hours of input Is	24h
	Export energy	Previous day	0.1kWh
		7 day total	0.2kWh
		30 day total	1kWh
		365 day total	38kWh
		365 days daily average	0.21kWh

2. Summary of Overall Performance of the micro-grid (Daily Performance)

Date/Time Stamp [dd/MM/yyyy]	D.C. Input Total Accumulated (Sample) [kWh]	D.C. Output Total Accumulated (Sample) [kWh]	Battery In Total Accumulated (Sample) [kWh]	Battery Out Total Accumulated (Sample) [kWh]	Input kWh Total Accumulated (Sample) [kWh]	Load kWh Total Accumulated (Sample) [kWh]	Shunt 1 kWh Total Accumulated (Sample) [kWh]	In Hours Total Accumulated (Sample) [Hours]	Export kWh Total Accumulated (Sample) [kWh]	Inverter D.C. KWh Total Accumulated (Sample) [kWh]	Modulation Hours (Sample) [Hours]	Float Hours Today (Sample) [Hours]	Battery Charge Efficiency Index (Sample) [Units]
18/01/2018	0.8	0.7	0.7	0.6	1.8	1.5	-0.1	14.58	0.6	1.4	13.77	7.1	0.979
19/01/2018	0.1	0.2	0.8	0.7	2	1.5	-0.2	38.57	1.8	1.6	37.75	23.98	0.979
20/01/2018	0.2	0.2	0.9	0.8	2.1	1.5	-0.4	62.55	3.9	1.8	61.73	23.98	0.979
21/01/2018	0.1	0.2	0.9	0.9	2.1	1.5	-0.5	86.53	6.3	2.1	85.73	24	0.979
22/01/2018	0.1	0.1	1	1	2.4	1.5	-0.7	110.52	7.6	2.2	109.72	23.98	0.979
23/01/2018	0.1	0.1	1	1	2.6	1.5	-0.8	134.52	9.4	2.4	133.7	23.98	0.979

24/01/2018	0.1	0.2	1	1.1	2.7	1.5	-0.9	158.5	11.3	2.7	157.68	23.98	0.979
25/01/2018	0.1	0.1	1	1.3	3	1.5	-1	182.48	13.2	2.8	181.67	23.98	0.979
26/01/2018	0.1	0.2	1.1	1.3	3.1	1.5	-1.2	206.47	15.1	3	205.65	23.98	0.979
27/01/2018	0.1	0.3	1.1	1.5	3.1	1.5	-1.3	230.45	17.6	3.3	229.63	23.98	0.979
28/01/2018	0.1	0.2	1.1	1.6	3.3	1.5	-1.3	254.43	19.2	3.5	253.62	23.98	0.979
29/01/2018	0.1	0.1	1.1	1.8	3.7	1.5	-1.4	278.42	19.9	3.7	277.6	23.98	0.979
30/01/2018	0.1	0.1	1.2	1.8	4.4	1.5	-1.6	302.4	20	3.8	301.6	23.98	0.979
31/01/2018	0.1	0.1	1.3	1.8	4.9	1.5	-1.7	326.38	20.3	3.9	325.58	24	0.979
1/02/2018	0.1	0.1	1.3	1.9	5.3	1.5	-1.8	350.38	21.5	4.1	349.57	23.98	0.979

2/02/2018	0.1	0.1	1.4	2	5.5	1.5	-1.9	374.37	23.1	4.3	373.55	23.98	0.979
3/02/2018	0.1	0.3	1.4	2.1	5.6	1.5	-2.1	398.35	25.1	4.5	397.53	23.98	0.979
4/02/2018	0.1	0.2	1.4	2.2	5.7	1.5	-2.2	422.33	27.4	4.8	421.52	23.98	0.979
5/02/2018	0.1	0.1	1.6	2.3	6.5	3.1	-2.3	444.97	28.8	5	444.28	21.73	0.989
6/02/2018	0.1	0.1	1.6	2.4	8.5	6.8	-2.4	468.97	28.8	5.2	468.28	24	0.989
7/02/2018	0.1	0.1	1.6	2.4	10.4	10.4	-2.5	492.97	28.8	5.2	492.28	24	0.989
8/02/2018	0.1	0.1	1.7	2.4	12.3	14	-2.7	516.97	28.8	5.4	516.28	24	0.989
9/02/2018	0.1	0.1	1.8	2.4	14.1	17.6	-2.8	540.97	28.8	5.5	540.28	24	0.989
10/02/2018	0.1	0.1	1.9	2.5	16	21.2	-3	564.97	28.8	5.6	564.28	24	0.989
11/02/2018	0.1	0.1	2	2.5	17.9	24.9	-3.1	588.97	28.8	5.7	588.28	24	0.989
12/02/2018	3.9	4.4	2.1	3	18.9	28.5	-7	612.97	32	10.1	612.28	23.98	0.989

13/02/2018	1.4	2.1	2.4	4	18.9	32	-8.4	636.95	32	12.1	636.27	2.62	0.989
14/02/2018	1.7	2	3.2	5.1	18.9	35.6	-10	660.93	32	14.1	660.25	0	0.989
15/02/2018	1.8	2	4.1	6.1	18.9	39.1	-12	684.92	32.1	16.1	684.23	0	0.989
16/02/2018	1.8	2	4.9	7.1	19	42.7	-13.7	708.9	32.1	18.1	708.22	0	0.989
17/02/2018	1.8	2	5.8	8.1	19	46.2	-15.6	732.88	32.1	20.1	732.2	0	0.989
18/02/2018	1.9	2	6.6	9.1	19	49.7	-17.5	756.87	32.1	22.1	756.2	0	0.989
19/02/2018	1.7	2	7.4	10.1	19	53.2	-19.2	780.87	32.2	24.1	780.18	0	0.989
20/02/2018	2.2	2.1	8.5	11.2	19.1	56.6	-21.4	804.5	32.4	26.2	803.82	0	0.989
21/02/2018	5.9	7.9	9.8	14.6	25.3	71.5	-27	828.48	32.4	34.5	827.8	0	0.989

22/02/2018	6.4	6.2	11.4	16	32.4	85.1	-32.6	852.47	32.4	41.5	851.78	0	0.989
23/02/2018	4.8	4.6	12.7	17	41.8	99.5	-36.6	876.45	32.4	46.9	875.77	0	0.989
24/02/2018	2.5	1.7	14.3	17.7	42.7	103.1	-38.7	900.43	32.6	49	899.75	0	0.989
25/02/2018	2.3	2.1	15.6	18.8	42.7	106.5	-40.9	924.42	32.7	51.1	923.73	0	0.989
26/02/2018	10.6	11.3	16.8	20.7	50.4	126	-51.1	948.4	32.7	62.8	947.72	0	0.989
27/02/2018	10.4	10.4	18	21.9	58.8	144.8	-60.8	972.38	32.8	74.1	971.7	0	0.989
28/02/2018	1.3	0.1	19.2	21.9	69.5	156	-61.1	996.37	32.9	75.1	995.68	8.98	0.999
1/03/2018	3.5	3.7	19.6	22.5	73.6	163.8	-64.4	1019.3	33.7	79.1	1018.82	22.02	1.008
2/03/2018	7.9	12.3	19.8	27.1	79.8	182.5	-72.2	1043.22	34	91.5	1042.8	15.07	1.008

3/03/2018	10	16.8	20.6	34.6	79.8	199.1	-82.3	1067.2	34	108.2	1066.78	0	1.008
4/03/2018	10.2	1	30.2	35.1	79.8	200.9	-92.4	1091.18	34	109.2	1090.77	0	1.008
5/03/2018	2.5	1.3	32.1	35.8	80.7	204.2	-94.9	1115.17	34	110.6	1114.75	0	1.008
6/03/2018	7.2	12.4	33.2	42	81	216.4	-101.9	1139.15	34.5	123.2	1138.73	2.15	1.018
7/03/2018	10	15.6	34.9	49.4	81	231.9	-111.9	1163.15	34.6	138.8	1162.73	0	1.018
8/03/2018	1.3	1.8	35.7	50.7	81	234.1	-113.2	1173.32	34.6	140.6	1185.35	0	1.018
9/03/2018	0.1	1.1	35.8	51.8	81.1	235.8	-113.2	1185.25	34.6	141.7	1209.33	0	1.018
10/03/2018	0.7	0	36.6	51.8	83.1	237.8	-113.4	1209.23	34.6	142.3	1233.32	0	1.018
11/03/2018	1.8	1	38.3	52.6	83.8	239.9	-115	1233.22	34.6	143.5	1257.3	0	1.018
12/03/2018	0.1	1.5	38.3	53.9	83.8	241.9	-115.1	1257.2	34.6	145	1281.28	0	1.018
21/03/	0.3	0.6	38.5	54.5	84.5	243.3	-115.1	1274	34.6	145.7	1298.05	0	1.018

201 8													
19/ 04/ 201 8	13.3	1.7	50.4	54.8	97.4	247.9	-117.6	1297.65	34.6	158.3	1321.7	8.85	1.008
20/ 04/ 201 8	4.1	4.8	50.8	55.8	98.6	253.6	-121.4	1322.48	35.8	163.4	1346.5 5	22.02	1.018
21/ 04/ 201 8	2.2	2.1	52.1	57.2	98.6	256.9	-123.6	1346.47	36	165.6	1370.5 3	0	1.018
22/ 04/ 201 8	1.9	2.1	53.3	58.5	98.6	260.2	-125.5	1370.45	36.1	167.6	1394.5 2	0	1.018
23/ 04/ 201 8	8.3	11.6	55.1	63.6	100.3	273.1	-132.9	1394.43	36.1	180.2	1418.5	0	1.018
24/ 04/ 201 8	2.4	1.9	56.8	64.8	101.7	276.2	-133.9	1418.42	36.1	183.4	1442.4 8	0	1.018
25/ 04/ 201 8	4.6	1.9	60.6	66	103.2	279.7	-137.2	1442.4	36.1	186.6	1466.4 7	0	1.018
26/ 04/ 201 8	2.1	2	61.9	67.1	103.2	283.1	-139.3	1466.37	36.1	188.7	1490.4 5	0	1.018
27/ 04/	4.7	6.1	65.1	71.6	105.7	290.5	-142.1	1489.88	36.1	196.7	1514.4 3	0	1.018

2018													
28/04/2018	3.8	2.1	68.1	73	105.8	293.8	-145.9	1513.85	36.1	198.7	1538.42	0	1.018
29/04/2018	2.4	2.1	69.6	74.3	105.8	297.2	-148.2	1537.83	36.2	200.9	1562.38	0	1.018
30/04/2018	6.5	6.9	70.6	75.8	105.8	305.2	-154.7	1561.82	36.2	207.8	1586.37	0	1.018
1/05/2018	7.5	8.6	73	79.2	107.1	315	-161.4	1585.8	36.3	217.3	1610.35	0	1.018
2/05/2018	3.4	2	75.6	80.4	108.6	318.3	-163.4	1609.78	36.3	220.7	1634.33	0	1.018
3/05/2018	1.3	2	76	81.6	108.6	321.5	-164.7	1633.77	36.3	222.7	1658.32	0	1.018
4/05/2018	1.8	2	77.1	82.9	108.6	324.5	-166.5	1656.05	36.3	224.7	1680.62	0	1.018
5/05/2018	2.4	2.2	78.6	84.1	108.6	327.7	-168.9	1680.03	36.5	226.9	1704.6	0	1.018
6/05/2018	3.1	2.1	80.9	85.4	108.6	331.1	-172	1704.02	36.5	228.9	1728.58	0	1.018
7/05/2018	2.4	3.4	81.4	86.9	108.6	335.6	-174.4	1728	36.5	232.3	1752.57	0	1.018

8/05/2018	4.9	5.4	82.4	88.5	108.6	342.1	-179.3	1751.98	36.5	237.7	1776.55	0	1.018
9/05/2018	4.9	9.7	85.4	96.2	111.4	352.8	-181.8	1775.95	36.5	249.9	1800.53	0	1.018
10/05/2018	2.7	1.9	87.4	97.4	111.4	356	-184.6	1799.93	36.5	251.8	1824.52	0	1.018
11/05/2018	0.6	1.9	87.4	98.8	111.4	359.2	-185.1	1823.9	36.6	253.8	1848.5	0	1.018
12/05/2018	4.6	1.9	91.2	99.9	111.4	362.5	-189.7	1847.88	36.6	255.7	1872.48	0	1.018
13/05/2018	4.3	1.9	94.8	101.2	111.5	365.7	-193.9	1871.87	36.6	257.6	1896.47	0	1.018
14/05/2018	7.6	11	97.6	107.4	114.2	377.8	-199	1895.85	36.6	271	1920.45	0	1.018
15/05/2018	1.1	2.1	98	108.6	114.2	381.1	-200.2	1919.83	36.7	273.1	1944.43	0	1.018
16/05/2018	2.1	1.9	99.3	109.8	114.2	384.3	-202.3	1943.82	36.7	275	1968.4	0	1.018
17/05/	2	1.9	100.6	111.1	114.2	387.5	-204.3	1967.8	36.7	276.9	1992.38	0	1.018

2018													
18/05/2018	3.1	1.9	103	112.3	114.3	390.8	-207.3	1991.78	36.8	278.9	2016.37	0	1.018
19/05/2018	2.4	1.9	104.6	113.5	114.3	394.2	-209.7	2015.77	36.8	280.9	2040.35	0	1.018
20/05/2018	0.5	1.9	104.6	114.9	114.3	397.3	-210.3	2039.75	36.8	282.8	2064.33	0	1.018
21/05/2018	2.3	1.9	106.2	116.1	114.3	400.6	-212.5	2063.73	36.8	284.7	2088.32	0	1.018
22/05/2018	3.4	1.8	108.9	117.3	117.2	404	-213.3	2087.72	36.8	289.1	2112.3	0	1.018
23/05/2018	1.5	1.9	109.8	118.6	117.2	407.3	-214.8	2111.7	36.8	291.1	2136.28	0	1.018
24/05/2018	6.4	5.7	114.9	123	122.6	414.6	-216.2	2135.68	36.8	301.6	2160.27	0	1.018
25/05/2018	4.9	2.1	119	124.4	122.6	418	-221.3	2159.67	36.8	303.7	2184.25	0	1.018
26/05/	3.1	2.1	121.3	125.6	122.7	421.6	-224.3	2183.65	36.9	305.7	2208.23	0	1.018

2018													
27/05/2018	2.4	2.1	122.9	126.9	122.7	425.1	-226.7	2207.63	36.9	307.9	2232.22	0	1.018
28/05/2018	1.3	2.1	123.4	128.2	122.7	428.5	-228	2231.62	36.9	310	2256.2	0	1.018
29/05/2018	6.8	9	126.1	133.1	125.4	438.7	-232.3	2255.6	37	321.5	2280.18	0	1.018
30/05/2018	3.3	2.1	128.6	134.3	125.4	442	-235.6	2279.57	37	323.5	2304.17	0	1.018
31/05/2018	3.4	2.1	131.2	135.5	125.5	445.5	-239.1	2303.55	37	325.6	2328.15	0	1.018
1/06/2018	7.2	8.8	133.9	140	128.2	455.5	-243.7	2327.53	37	337	2352.13	0	1.018
2/06/2018	4.3	2.1	137.4	141.3	128.3	458.9	-247.9	2351.52	37	339.1	2376.12	0	1.018
3/06/2018	2.7	2.1	139.3	142.5	128.3	462.5	-250.7	2375.5	37	341.2	2400.1	0	1.018
4/06/2018	2.1	2.1	140.7	143.9	128.3	466	-252.8	2399.48	37.1	343.3	2424.07	0	1.018

5/06/2018	6.9	8.9	143.3	148.6	131.1	476.1	-257.2	2423.43	37.1	354.7	2448.02	0	1.018
6/06/2018	4.3	2.1	146.8	149.9	131.1	479.5	-261.4	2447.42	37.1	356.8	2472	0	1.018
7/06/2018	1	2.1	147.1	151.2	131.1	482.9	-262.4	2471.4	37.1	358.8	2495.98	0	1.018
8/06/2018	0.5	2	147.2	152.8	131.1	486.2	-262.9	2495.38	37.2	360.8	2519.97	0	1.018
9/06/2018	2.4	2.1	149	154.2	131.2	489.5	-265.4	2519.37	37.2	362.9	2543.95	0	1.018
10/06/2018	4	2	152.2	155.5	131.2	492.9	-269.3	2543.33	37.2	364.9	2567.93	0	1.018
11/06/2018	2.6	2.1	154.1	156.9	131.2	496.4	-271.9	2567.32	37.2	367	2591.92	0	1.018
12/06/2018	6.1	6.9	157.1	160.7	134.1	504.6	-275.4	2591.3	37.2	376.5	2615.9	0	1.018
13/06/2018	2.1	2.1	158.6	162	134.1	508	-277.5	2615.28	37.2	378.6	2639.88	0	1.018
14/06/2018	2.5	2.1	160.3	163.3	134.1	511.5	-280	2639.27	37.2	380.6	2663.87	0	1.018

15/06/2018	1.8	2	161.3	164.6	134.1	514.9	-281.9	2663.25	37.3	382.7	2687.83	0	1.018
16/06/2018	2.2	2.1	162.8	165.9	134.1	518.3	-284.1	2687.23	37.3	384.7	2711.82	0	1.018
17/06/2018	1.9	1.9	164.4	167.5	135.8	521.7	-284.5	2711.22	37.3	388.2	2735.8	0	1.018
18/06/2018	1.6	2.1	165.3	168.8	136.3	525.1	-285.7	2735.2	37.4	390.7	2759.78	23.5	1.027
19/06/2018	6.3	12.7	167.7	177.7	139	538.6	-289.5	2759.18	37.4	405.7	2783.77	2.88	1.027
20/06/2018	3	1.9	169.9	178.9	139	541.8	-292.5	2783.17	37.4	407.7	2807.75	0	1.027
21/06/2018	4.1	2	173.4	180.3	139.1	545	-296.6	2807.15	37.4	409.7	2831.73	0	1.027
22/06/2018	5.3	7.5	176.3	185.3	141.7	553.6	-299.5	2831.13	37.5	419.7	2855.72	0	1.027
23/06/2018	0.7	2	176.4	186.7	141.7	556.7	-300.2	2855.12	37.5	421.6	2879.7	0	1.027

24/06/2018	1.6	1.9	177.2	188	141.7	559.8	-301.7	2879.1	37.5	423.6	2903.68	0	1.027
25/06/2018	4.6	1.9	181.1	189.1	144.4	563.1	-303.8	2903.08	37.5	428	2927.67	0	1.027
26/06/2018	2.7	2.1	183.2	190.5	144.5	566.3	-306.6	2927.07	37.5	430	2951.65	0	1.027
27/06/2018	3.6	4.7	185.9	194.4	147.2	572.2	-307.7	2951.05	37.5	437.2	2975.63	0	1.027
28/06/2018	1.3	1.9	186.4	195.6	147.2	575.4	-308.9	2975.03	37.5	439.2	2999.62	0	1.027
29/06/2018	1.1	2	186.8	196.9	147.2	578.5	-310.1	2999	37.5	441.1	3023.6	0	1.027
30/06/2018	5	1.9	191.1	198.1	150	581.8	-312.5	3022.98	37.6	445.6	3047.58	0	1.027
1/07/2018	3	2	193.5	199.4	150	585.1	-315.6	3046.97	37.6	447.6	3071.57	0	1.027
2/07/2018	4.4	2.1	197.1	200.8	150	588.6	-319.9	3070.95	37.6	449.7	3095.55	0	1.027

3/07/2018	4.2	7.2	200.4	207	152.7	596.9	-321.7	3094.93	37.6	459.4	3119.53	0	1.027
4/07/2018	2.2	2.1	201.8	208.4	152.7	600.1	-323.9	3118.92	37.7	461.4	3143.5	0	1.027
5/07/2018	1	2	202.4	209.8	152.7	603.3	-325	3142.9	37.7	463.3	3167.48	0	1.027
6/07/2018	3.8	2	205.6	211.1	152.7	606.6	-328.9	3166.88	37.7	465.3	3191.47	0	1.027
7/07/2018	3.9	2	208.7	212.5	152.8	610	-332.7	3190.87	37.7	467.4	3215.45	0	1.027
8/07/2018	1.9	2.1	210	213.8	152.8	613.4	-334.6	3214.85	37.7	469.5	3239.43	0	1.027
9/07/2018	7	9	214.6	220.5	157.4	623.5	-337.4	3238.83	37.7	482.7	3263.42	0	1.027
10/07/2018	1.2	2	215.1	221.8	157.4	626.7	-338.6	3262.82	37.7	484.7	3287.4	0	1.027
11/07/2018	1.8	2	216.2	223	157.4	629.9	-340.5	3286.8	37.7	486.7	3311.38	0	1.027
12/07/2018	3	2	218.5	224.3	157.4	633.1	-343.5	3310.78	37.8	488.7	3335.37	0	1.027
13/07/	2.5	2.1	220.2	225.5	157.4	636.4	-346	3334.77	37.8	490.7	3359.35	0	1.027

2018													
14/07/2018	4.7	1.9	224.2	226.7	157.4	639.8	-350.8	3358.75	37.8	492.7	3383.33	0	1.027
15/07/2018	2.9	2	226.4	228	157.5	643.3	-353.6	3382.73	37.8	494.7	3407.32	0	1.027
16/07/2018	1.5	1.9	227.2	229.2	157.5	646.7	-355.2	3406.7	37.9	496.6	3431.3	0	1.027
17/07/2018	2.6	2	228.9	230.5	157.5	650.1	-357.7	3430.68	37.9	498.6	3455.28	0	1.027
18/07/2018	2.1	2	230.3	231.7	157.5	653.5	-359.8	3454.67	37.9	500.6	3479.27	0	1.027
19/07/2018	2.1	2	231.7	232.9	157.6	656.9	-362	3478.65	38	502.5	3503.25	0	1.027
20/07/2018	1.8	2	232.7	234.2	157.6	660.4	-363.7	3502.63	38	504.5	3527.23	0	1.027
21/07/2018	2	1.9	234	235.4	157.6	663.8	-365.7	3526.62	38	506.5	3551.22	0	1.027
22/07/	2.1	2	235.4	236.7	157.7	667.2	-367.8	3550.6	38	508.5	3575.18	0	1.027

2018													
23/07/2018	2.1	2.1	236.7	238	157.7	670.7	-369.8	3574.58	38	510.5	3599.17	0	1.027
24/07/2018	1.8	1.9	237.8	239.4	157.7	674.1	-371.6	3598.57	38	512.5	3623.15	0	1.027
25/07/2018	2.6	2.1	239.6	240.5	157.7	677.6	-374.2	3622.55	38	514.5	3647.13	0	1.027
26/07/2018	2.2	1.9	241.1	241.7	157.7	681.1	-376.4	3646.53	38	516.4	3671.12	0	1.027
27/07/2018	4.4	5.6	241.5	243.4	157.7	687.9	-380.8	3670.52	38.1	522.1	3695.1	0	1.027
28/07/2018	3	2	243.6	244.5	157.7	691.4	-383.7	3694.5	38.1	524.1	3719.08	0	1.027
29/07/2018	2.5	2	245.3	245.7	157.7	694.8	-386.2	3718.48	38.1	526.1	3743.07	0	1.027
30/07/2018	1.7	2	246.2	247	157.8	698.3	-387.9	3742.47	38.2	528	3767.05	0	1.027
31/07/	2.1	2.1	247.6	248.2	157.8	701.7	-390	3766.45	38.2	530	3791.03	0	1.027

2018													
1/08/2018	2.1	2	248.9	249.4	157.8	705.2	-392.2	3790.43	38.2	532.1	3815.02	0	1.027
2/08/2018	2.5	2.1	250.6	250.7	157.8	708.8	-394.7	3814.42	38.2	534.2	3839	0	1.027
3/08/2018	1.8	2	251.6	251.9	157.9	712.1	-396.5	3838.4	38.2	536.2	3862.98	0	1.027
4/08/2018	2	2	252.9	253.2	157.9	715.6	-398.5	3862.38	38.2	538.2	3886.97	0	1.027
5/08/2018	2.3	2	254.5	254.4	157.9	719	-400.8	3886.37	38.3	540.2	3910.95	0	1.027

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