Investigation of a Hybrid Control Scheme for the Optimized Operation of a Virtual Power Plant

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Abstract

Climate change concerns due to the rising amounts of carbon gas in the atmosphere have in the last decade or so initiated a fast pace of technological advances in the renewable energy industry. Such developments in technology and the move towards cleaner sources of energy have made renewable resources based Distributed Generators (DGs) more desirable. However, it is a known fact that rising penetrations of DGs have adverse impacts on the grid structure and its operation. The smart grid concept has been used as a good solution to control the impact of DGs and make conventional grids more suitable for large scale deployments of DGs.

Unlike conventional utility grids, a smart grid is an advanced electricity distribution network with sophisticated communication, control, metering, and analysis capabilities. The smart grid is used to improve the efficiency of the overall system by maximizing the throughput of the system and reducing the energy consumption. To achieve this requires the integration of distributed renewable energy resources (DERs) to form a Virtual Power Plant (VPP). A VPP is a cluster of Distributed Energy Resources (DERs) integrated to form a system that can be controlled from a central control entity. A VPP system improves the economics and effectiveness of DGs by making it more cost effective and reliable. A VPP system may be disconnected from the utility grid and continue its operation under islanding conditions.

One of the key factors to achieve a maximum efficiency of operation of a VPP system is an advanced control techniques. In addition, the maximum power output cannot be achieved without extensive use of control technologies at all levels. There are different

types of control schemes such as: Direct Load Control (DLC), Price Signal Control (PSC), and Internal Exchange Control (IEC).

There are two main aspects of developing control models and optimization algorithms which are as follows:

- Planning the energy generation by DERs to minimize the cost of producing energy and maximize the profit of the VPP.
- Optimized operation and dispatch of electrical energy to the grid with maximum profit achieved in trade with the national power market.

Studies so fardeveloped have used each one of the individual scheme on its own, to optimize the operation of a VPP system. However, using individual schemes separately lead to some challenges:

- Uncertainties about load forecasting
- Considering the contractual relationship between the DERs and the VPP

In this thesis, a novel hybrid control scheme is proposed to achieve a cost-effective power generation by overcoming challenges stated above caused by utilizing an individual control scheme. The main contribution to knowledge presented in this research is design and development of a new control scheme using Five Layered Model of a VPP (FLMVPP) to optimize the operation of a VPP system .In this manner, an appropriate scheme must be developed to optimize the operation of the FLMVPP. In doing so, an Artificial Neural Network (ANN) algorithm is developed and simulated to manage the optimal operation of the system.

This study also creates a new modeling technique for a VPP system. This approach is designed to model a VPP system using a five layered architecture (FLMVPP) as it gives a better understanding of the system operation as well as a clear separation of the function of each layer by adding flexibility to the system. Furthermore, it is worthy to highlight that the proposed scenario does not depend on any particular communication standard or modeling.

The proposed technique is very versatile as it gives the VPPs' participants a freedom of choice when making a decision for their operations.

Declaration of Originality

“I, Mahtab Zaerilolmani, declare that the PhD thesis entitled “Investigation of a Hybrid Control Scheme for the Optimized Operation of a Virtual Power Plant” is no more than 100,000 words in length including 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”.

Signature [redacted] Date: **31/03/2016**

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List of Publications

Conference Paper

[1] Mahtab Zaeri, Nalin Sharda, Ahmad Zahedi, ―*A five layer model for simulating a virtual power plant".* In: Proceedings of the IEEE Innovative Smart Grid Technologies Conference, ISGT Asia, pp. 435-440, 20-23 May 2014, Kuala Lumpur, Malaysia.

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[1] Mahtab Zaeri, Nalin Sharda, Ahmad Zahedi, Modelling and Controlling of a Virtual Power Plants – A Review‖ in Renewable and Sustainable Energy Reviews, Elsevier.

Presentation

[1] Mahtab Zaeri, Nalin Sharda, Modelling of a Virtual power Plant‖, VU FOHES postgraduate research conference, platform presentation, Jun, 2012

[2] Mahtab Zaeri, "From Dirty Coal-Fired Generators to Virtual Power Plants'' to College of engineering and science, Postgraduate Research Conference; poster, Victoria University, July, 2011.

[3] Mahtab Zaeri, ―investigation of a Hybrid Control scheme for the optimized operation of a Virtual Power Plant, AUPEC, 2012, Bali, Postgraduate Research Conference; poster, Victoria University ,July-2011.

Table of Contents

List of Figures

List of Tables

List of Graphs

List of Abrreviations

DG	Dispersed Generator
DER	Distributed Energy Resource
VPP	Virtual Power Plant
DLC	Direct load Control
PSC	Price signal Contral
FLMVPP	Five Layered Modeling of a Virtual Power Plant
ANN	Artificial Neural Network
PHS	Pumped Hydroelectric Storage
FF	Fossil Fuel
GT	Gas Turbines
FC	Fuel Cell
PV	Photovoltaic
WT	Wind Turbines
ICT	Information and Communication Technology
DDG	Domestic Distributed Generators

PDG	Public Distributed Generator
CVVPs	Commercial Virtual Power Plants
TVVP	Technical Virtual Power Plant
CCC	Central Coordination Centre
EMS	Energy Management System
DCS	Decentralized Control System
LC	Local Controllers
DEM	Decentralized Energy Management
µCHP	Micro Combined Heat and Power
PDF	Probability Density Function
V	Voltage
I	Current
STC	Standard Test Condition
PR	Performance Ratio
ZBB	Zinc Bromine Battery
SOC	State of Charge

ISO	International Standard Organization
OSI	Open System Interconnection
PL	Physical Layer
NL	Network layer
CL	Control layer
OL	Optizization Layer
HBL	Human Behaviuor Layer
BOM	Bureau of Meteorology
AFC	Alkaline Fuel Cell
PEMFC	Proton Exchange Membrane Fuel Cell
PAFC	Phosphoric Acid Fuel Cell
SOFC	Solid oxide fuel cell
OCV	Open Circuit Voltage
CCS	Combined Control Scheme
FL	Fuzzy Logic
ES	Expert System

DSM	Demand Side Management
DSO	Distributed System Operator
ISO	Independent System Operator
TOU	Time-of-Use
CPP	Critical Peak Pricing
RTP	Real-Time Pricing
CSIRO	Scientific and Industrial Research Organization
NEM	National electricity Market
AEMO	Australian electricity Market
WF	Wind Farm
PVF	PV Farm
E_{wt}	Total Energy produced by Wind Farm
E_{wind}	Energy in the Wind

Chapter.1 Thesis overview

1.1 Introduction

The global climate change phenomenon and increasing concerns about the need for a sustainable energy supply have created global sensitivity to energy production methods. Consequently, interest in finding pollution-free and sustainable solutions has increased. Researchers around the world are approaching these issues from different perspectives, and one such perspective is the seamless integration of distributed renewable energy resources. These imperatives have led to the novel concept of a smart grid [1, 2].

1.2 Smart grid

A smart grid concept is an emerging technology that refers to a more sustainable electricity network.Furthermore, smart grids use distributed energy resources (DERs), and advanced communication as well as control technologies, to deliver electricity more cost-effectively, and with lower greenhouse intensity than that of the current practice [3].In other words, a smart grid is an amalgam of various traditional and renewable DERs, which are small-scale power plants, typically much smaller than fossil fuel or nuclear powered generators. In addition, a smart grid includes monitoring systems, communication & control elements, demand-side energy management, and energy efficiency options [3, 4].

A conceptual model of smart grid architecture is shown in Figure 1.1. In this Figure, six important domains: bulk generation, transmission, distribution, customers, operations, and service providers have been depicted. It shows the communications among each aspect and how they are interconnected .Each individual domain is connected to the others via two-way communications. These connections are the basis of the smart power grid.

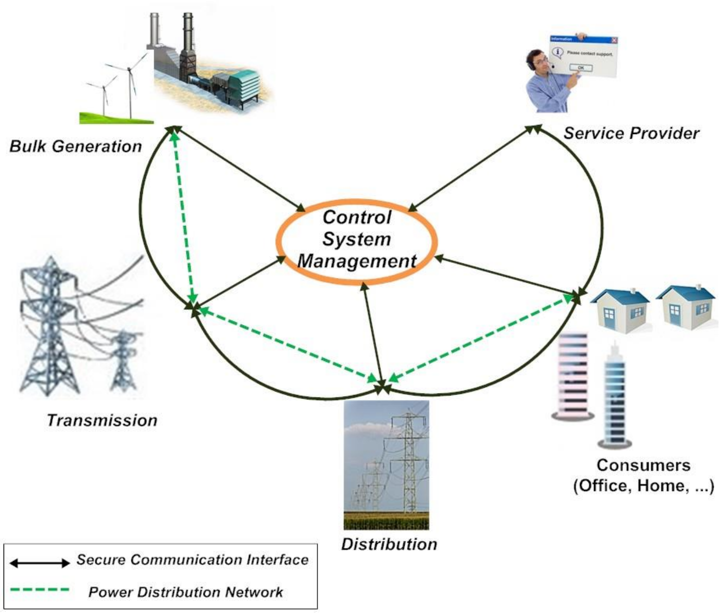


FIGURE 1.1CONCEPTUALMODELOF A SMART GRID

The bulk generation system generates electricity from renewable sources such as solar and wind and also from non-renewable energy sources such as coal and nuclear in bulk quantities. The bulk energy storage systems such as Pumped Hydroelectric Storage (PHS) are also included in this domain [5]. The power distribution network distributes the electricity to and from users into the power grid. It connects to intelligent devices such as smart meter to manage and control them through a two-way communications network. It also connects to energy storage systems and distributed energy resources [5, 6].

The consumer includes all users, such as domestic, and industrial, connected to the distribution grid through smart meters**.** The smart meters control and manage the electricity flow to and from the end users and provide energy flow information. Consumers are also able to produce, store and control the usage of electricity, and connect to plug-in vehicle [5, 7]. The control and management system manages and controls the power flow through the network. It provides monitoring, reporting and controlling by gathering data from each aspect [8]. The service provider handles all third-party operations among the domains by providing energy management services to the consumers and exchanging data between users and utilities. The service provider also manages other processes for the utilities, such as demand response, and outage management [5].

Due to high cost of individual high voltage transformers and switchgear, the DERs cannot be connected to the transmission system easily [9,10]. These small generators connected to the distribution system are therefore known as Distributed or Dispersed Generators (DGs). DGs are not necessarily powered by renewable energy sources, e.g. a DG could be a small gas turbine or a fuel cell [9].

1.3 Virtual Power Plant

The popularity of generating electric power in very large steam-powered central power stations seems to have ended. The global climate change phenomenon and increasing concerns about the need for a sustainable energy supply have created a global sensitivity to energy production. Consequently, interest in finding pollution-free and sustainable solutions has increased. Researchers are approaching these issues from different perspectives; and one of such key perspectives is seamless integration of distributed renewable energy resources. These imperatives have led to the novel concept of a VPP [11, 12].

A VPP is a multi-technology unit which includes both renewable and non-renewable generators as well as storage systems connected with smart devices. Furthermore, it includes consumers who often use smart appliances, such as smart meters. This has been made possible by the availability of advanced communication and Information Technology (IT) systems. The motivation behind creating VPP technology is to coordinate the various types of energy resources to minimize the cost of power generation and maximize the profits received from the sale of that power [2].

To achieve cost-effective generation, a control scheme is needed to optimize the operation of a VPP. Various control models and optimization algorithms have been developed and simulated to manage the optimal operation of a VPP [11, 13-17]. Yet, there are still many research and development needs associated with the optimized operation and integration of VPPs. These shortcomings are explained in further detail in the forthcoming sections. Thus, advanced control models and optimization algorithms are required to overcome these challenges and make the VPP concept a reality. The objective of the proposed research is to contribute to that accomplishment through investigating the use of a hybrid control scheme to mitigate the downsides of control approaches so far outlined in the literature.

1.4 Aims of the Research

The proposed research aimed to investigate an appropriate control scheme combined use of various control schemes to optimize the operation of a VPP .In order to eliminate the various weaknesses of the individualistic control schemes so far developed in the literature for controlling VPP systems a hybrid control scheme is considered as a novelty of this research. The main outcome of this research is the development of a hybrid control scheme to get the maximum profit out of renewable generation, and reduce the cost of generation as well as the peak load through demand side management measures.

The specific aims of this study can be summarized as follows:

- Model a VPP system using five layer technique
- Introduce an overarching control system to manage the dispersed local control systems
- Investigate, develop and analyze the use of a combined control scheme
- Optimize the operation of a VPP using an appropriate algorithm technique

1.5 Research questions

The investigation of control schemes to control the operation of a VPP system is vital to achieve maximum profitability in a VPP, thereby enhancing the attractiveness of renewable energy technologies leading to greater uptake. This would make it possible to scale up the implementation of renewable energy systems giving them recognition and equal status in energy sector investment process. The proposed study intends to investigate the use of a combined control scheme in a VPP to control the energy generation produced from renewable system, storage and sale to the market. Therefore, the overall research question is: How to achieve the balance between generation and consumption by minimum costs of renewable generation as well as maximum utilization of renewable resources. This question can be divided into the following sub-questions:

- What is the concept of the VPP?
- How to develop a modeling system to better understanding of its function as well as minimizing the complexity of the system?
- What type of control scheme should be used to efficiently control the operation of the DERs?
- What methods should be used to optimize the operation of a VPP?

1.6 Overview of the thesis

This thesis contains of six chapters in total and it is organized as follows:
Chapter one gives an overview of the thesis, the aims of the research and its contribution to knowledge. It also consists of the research methodologies used in current research. Chapter two provides a comprehensive literature review that specifically addresses VPP concept in further detail. Moreover, this chapter reviews the new concepts in the power engineering field such as smart grid, DGs, VPP, and their implementations, interactions with one another and the larger power network. The literature review is carried out in order to analyze the topic and understand the viewpoints of researchers in smart grid area.

Following the literature review, chapter three represents the details of a conceptual design of a VPP system using new method in MATLAB environment. This method is defined as a Five Layered Model of a Virtual Power Plant (FLMVPP) system. It exposes the connection among layers following by VPP components modeling in MATLAB-Simulink, while processing the real data and its analysis, the mathematical calculation of each component and updating them in relevant grid components. Furthermore, it is also mentioned how this new method keep the system flexible and is easy to modify.

Chapter four focuses on investigation and integration of various control algorithms to optimize the operation of a VPP by introducing direct control and price signal control scheme. Major contributions to knowledge has been made here as the control algorithms developed is a combination of those used in the marketplace and thus the various shortcomings of individual control approaches h eliminated. This is achieved by proposing a new scenario as a combined control scheme in a VPP system with five layered model to fill the knowledge gap which is earlier outlined in the literature review.

Chapter five depicts the optimization operation of a FLMVPP system using combined control scheme by considering an Artificial Neural Network (ANN) system as an appropriate algorithm technique. Furthermore, the ANN architecture network is also introduced in details and modeled in MATLAB environment. The significant outcome during this research is addressed in this chapter followed by summarizing the whole research work, draws the conclusions and some recommendations for future work in chapter six.

Chapter.2 Litrature review

2.1 The Virtual Power Plant Concept

This chapter presents an extensive review of various aspects of Virtual Power Plants has been done and research and development needs have been identified. This has made it likely to further define and limit the problem that the proposed study is to address. The traditional, vertically-integrated electricity generation, transmission, distribution, and customer energy services have been changing radically for over a decade. The distribution grid has been opened to independent power producers who offer competitive smaller-scale power plants [9, 10]. In addition to the economic benefits, the increased concern for the environmental impacts of Fossil-Fuel (FF) fired generation is also driving this transition. The smaller-scale power plants are commonly referred to as DERs, which are typically much smaller than FF or nuclear powered generators. However, these cannot be connected to the transmission system easily, due to the cost of individual high voltage transformers and switchgear. These small generators connected to the distribution system are therefore known as DG [87,89].

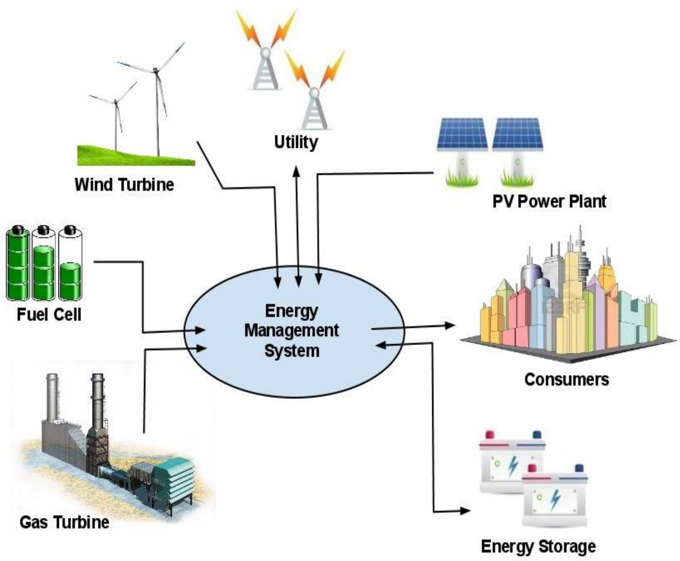


FIGURE 2.1.STRUCTURE OF A VIRTUAL POWER PLANT

As shown in Figure 2.1, DGs are not necessarily sourced by renewable energy sources, e.g. a DG could be a small gas turbine or a fuel cell. However, increased penetration of DERs can lead to major disturbances on the distribution grid. This is due to the fact that the traditional grids have been designed as passive networks, and are not suitable for the integration of DERs at a large scale [9, 11,88]. The power exchange between DGs and the network must also be handled properly for which the standard paradigm of centralized control will no longer be sufficient, thus a distributed control mechanism must be considered [6, 18].

The main drawback of DERs is their failure to compete with conventional units and the ineffectiveness of their market integration. The rapidly reforming power industry has a market-based structure and in such structure, DGs cannot be viable on their own, being small and only able to supply power irregularly [6,90].These plants can be operated more efficiently and more economically in a network to the benefit of the operators of DGs. This can be achieved aggregated together to virtually act as a conventional power plant having an amply large size for market integration. This aggregation is commonly referred to as a Virtual Power Plant (VPP) system [11, 16,92].

As can be seen in Figure 2.1, a VPP is a multi-technology unit that includes both renewable and non-renewable generators as well as storage systems connected with smart devices. Various types of DG units, such as Gas Turbines (GT), fuel cells (FC), storage battery, Photovoltaic (PV) systems, and wind turbines (WT) can be connected to form a VPP system [2, 10, 17]. Furthermore, it includes consumers who often use smart appliances, and smart meters [2,90,91]. The ability to create VPPs has been made possible by the availability of advanced Information and Communication Technology (ICT) systems. The motivation behind creating the VPP technology is to coordinate the various types of energy resources to minimize the cost of power generation and maximize the profits received from the sale of that power [2, 18,92].To better understanding of conceptual meaning of the VPP the components of the system is explained in details in the following section.

2.2 Components of a VPP

The VPP technology becomes more important by maximizing the power output of renewable energy resources and minimizing the cost of generation [8, 18,94]. The core components of a VPP system includes: distributed low-emission and renewable energy sources, smart grid, smart metering technologies, as well as energy storage systems. A VPP also includes some operational enhancements, such as load management, peak electricity shaving, and a range of demand side energy efficiency measures [7, 11,96]. Each component is explained individually in below subsections.

2.2.1 Generation

In a VPP, various DG systems such as engine-based heating power plants, Wind Turbines (WT), Photovoltaic (PV) systems, block heating power plants; produce both heat and electricity in a compact unit ,are combined into a network and controlled as a single power plant as shown in Figure 2.1. These DGs can be classified into two categories as follows [2, 13,93]:

2.2.1.1 Domestic Distributed Generator

A Domestic Distributed Generators (DDG) is a small DG unit that serves an individual residential, commercial, or industrial consumer. A DDG can typically serve a well-defined load; however, for flexibility it may include energy storage ability and a low voltage (e.g. 240 V) distribution network. The surplus power production of a DDG may be injected into the main power grid, and any shortage may be compensated by the grid. The rooftop solar systems widely installed these days fall under this category [2, 19,94,95].

2.2.1.2 Public Distributed Generator

Public Distributed Generators (PDGs) are DG units with the primary aim of injecting power into the grid. In other words, a PDG refers to a generator and an energy storage system that can only be connected to the medium voltage (e.g. 22 kV) distribution network [2, 13].

2.2.2 Storage System

Although energy storage in utility grids has existed for many decades, the impact of storage in future grids is receiving more attention than ever before, from system designers, grid operators and regulators. Energy storage technologies help a utility grid to cope with imbalance between generation and demand [17, 20].These energy storage systems are designed to tackle load balancing issues, such as: relieving overload on a section of the grid, restoring power to customers during an outage, and allowing utilities to take power from customer-controlled generators [96,97] . There are many types of energy storage systems, such as: batteries and pumped water [8, 17]. Due to the relatively high cost of current electricity storage technologies, the challenge for utilities is to enhance the cost vs. benefit factor for these systems [20]. For instance, by storing electricity in storage systems in an area with limited generation capacity, the need to purchase the additional power will be decreased [17, 21].

2.3 Operation of a VPP

One of the main aims of a VPP is to control and manage the electrical energy that flows into the main grid [6, 18]. According to the FENIX project [9], there are two types of VPPs: Commercial Virtual Power Plants (CVPPs) and Technical Virtual Power Plants (TVPPs)which are as follows [97,98]:

2.3.1 Commercial Virtual Power Plants

A Commercial Virtual Power Plant (CVPP) is the aggregated capacity of a number of DER units. The CVPP essentially optimizes the production from the DER portfolio, where the output is based on the predicted needs of consumers. The main functions of a CVPP are [2,9,22]:

- The estimation of revenue and consumption based on weather forecasting and historical demand data

- The sale of energy to the market
- The collection of DER energy offerings, and passing this information to the electricity market

2.3.2 Technical Virtual Power Plants

A Technical Virtual Power Plants (TVPP) is composed of DERs from the same geographic site, and has a real-time impact on local network [98,99]. One of the main functions of the TVPP is to optimize the DERs' operation, according to the data received from the CVPP by using an appropriate monitoring system [22, 23].

2.4 Control of a VPP

One of the crucial aspects of a VPP is its efficient control; and a variety of control models have been developed to date. A classification of models and schemes to control a VPP is shown in Figure 2.2. At the top level, these can be classified as centralized or decentralized control models. In the centralized control model, the various control schemes can be classified as direct control or price signal control [13, 18, 24]. The decentralized model consists of these two stated schemes, and an additional internal exchange scheme.

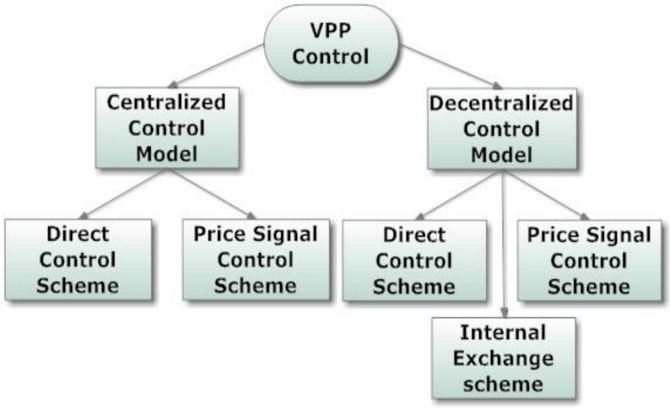


FIGURE 2.2. CLASSIFICATIONS OF VPP CONTROL MECHANISMS

2.4.1 Centralized Control Model

In the centralized control model, DGs are often controlled by a Central Coordination Centre (CCC) also known as an Energy Management System (EMS). The EMS connects to all DGs in a centralized fashion, as shown in Figure 2.1, and makes all decisions [8, 25].

2.4.2 Decentralized Control Model

In the Decentralized Control System (DCS), DGs are controlled by Local Controllers (LCs), which are linked to each other via communication links to create a data network. These LCs are responsible for making the operational decisions for the individual DERs [8, 18]. Figure2.3 illustrates the DCS concept.

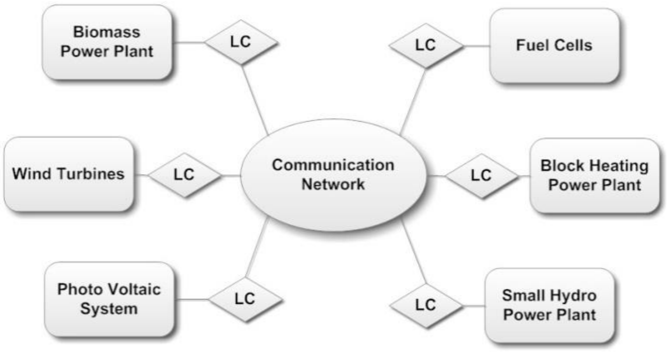


FIGURE 2.3. DISTRIBUTED CONTROL SYSTEM (LC= LOCAL CONTROLLER)

The main aim of control operation is to get the maximum profit out of renewable generation, and reduce the cost of generation as well as the peak load through demand side management [12, 18]. The control function can be accomplished through several methods depending on the type of the scheme used [89, 97]. These schemes are: Direct Control, Price Signal Control or Internal Exchange Control [1, 13]. Table 2.1 lists these control schemes; the first two schemes are common to both models whereas the Internal Exchange Control scheme is used only in decentralized control model.

TABLE 2.1.VARIOUS VPP CONTROL SCHEMES

Name	**Description**
Direct Control	A direct load control (DLC) scheme, determines an optimal control schedule to be applied to controllable devices. In this strategy, the VPP has direct access to all DERs. It will generate and submit its bids/offers based on generation schedules and location in formation .Therefore, the approved bids and offers will be sent to the generation & consumption schedules for every DER [13, 15].
Price Signal Control	Price signal control is a method that indicates the marginal price of electricity at network buses. By sending price signal to DREs, the VPP will regulate the operation of individual DERs. Under this scheme, the VPP defines the generation & consumption pattern of DERs according to different price signals. In other words, this scheme is based on demand and generation forecasting techniques [13, 16].
Internal Exchange Control	In this scenario, a VPP just operates an internal exchange electricity market and delivers some supportive information such as market price to the DERs. Based on this information, bids and offers are made by DERs, to be sent to the internal market. These bids and offers are first cleared internally and then submitted to the external market for clearance [13].

Researchers have often used each one of these schemes on its own, to optimize the operation of a VPP [12,13,15,16]. Using these individual schemes separately lead to some challenges; e.g. any error in load forecasting lead to extra load balancing cost [13,15,18]. A good solution to cope with this challenge is to use a hybrid control scheme, which is the main aim of our research. A hybrid control scheme is a blend of different schemes combining the favorable attributes of various schemes; therefore it will give the VPP participants the freedom of choice in optimizing their operation [13, 18, 26].

2.5 Energy Management

The number of DGs used – such as wind, photovoltaic, and fuel-cell system is expected to increase incessantly over the coming years [16, 23]. As outlined previously, VPPs could deliver cleaner electric energy at competitive prices when the operation of the VPP is scheduled and optimized by a central energy-management system [99, 100]. This would lead to numerous advantages, such as; optimized local energy exchange, better energy balance between generation and supply, and these benefits make VPPs a viable alternative to the traditional generators [12, 13, 16, 17].

The Siemens's Decentralized Energy Management (DEM) system is one of such systems, that helps to increase the efficiency of the power output [27].By using the DEM system an operator could carry out [27]:

- Intelligent forecasting and planning of generation and consumption;
- Real-time optimization; and
- Minimization of operation costs by considering the interconnections between the various energy resources.

These features can be implemented by smart technologies as explained in the following sections.

2.6 Smart Measurements

To automate the measurement of the power consumption in a grid, smart meters can be used. These smart devices will send the required information back to the grid for monitoring and billing purposes [98,100]. Moreover, these can connect to the control center via two way communication links, in order to collect data from various DERs. Therefore, smart measurements provide the utilities with real-time information of the demand [18, 28, 29]. Furthermore, on the demand side, consumers can also add intelligent management systems to their small DGs, such as PVs or wind turbines, to track their efficiency. In this scenario, to achieve load reduction the smart meters should be installed for all customers with controllable devices [10,13,15,18].

2.7 Current Research on VPP Modeling

When a real system is not easily accessible for experimentation it can be modeled, simulated, and analyzed using underlying mathematical principles. It then becomes possible to use the simulation results to predict the performance of the real systems [30, 31].Since models only approximate natural phenomena, and they are not accurate. The mathematical parameters used in models to represent real processes are often uncertain because these parameters are empirically determined. Additionally, the initial or starting conditions and/or the boundary conditions in a model may not be well known .Despite these weaknesses, models are very powerful tools to represent natural processes [100,101].

Often models are the only mean which will be concluded to large spatial scales or predict the future. Because of their importance, the accuracy of the models must be assessed by calibrating and validating them [98,102]. Current research and development is taking place in the VPP area with a major focus on control models and algorithms developed to optimize the operation of a VPP, thereby making the VPP concept a profitable reality [31-34].This section presents a literature review of the VPP models developed worldwide to illustrate the various aspects of the VPP concept.

2.8 Modeling VPP Components

Depending on the purpose of modeling, the developed models will be different in terms of complexities [34, 35]. Since photovoltaic systems and wind turbines have intermittent generation, it is important to use their models to develop control techniques to make their operation more efficient and cost effective within a VPP. The following subsections present current research on modeling VPP components, such as: WT system, photovoltaic PV system, µCHP generator, as well as energy storage in VPP systems.

2.8.1 Modeling a Wind Turbine system

Wind energy is a valuable resource since it is free and renewable. Moreover, at locations with high wind resource a wind energy system will have an effective impact on a utility system by providing additional power to the local consumers [36]. It is notable that besides the positive impacts of the WT machine such as: free and renewable resource, it also has some negative points such as: bird kills, noise and construction site disturbances which cause noise, dust and annoyance to local residents.

Since a wind turbine is one of the major components of a VPP, many researchers have previously developed WT models to simulate its behavior [36-39]. According to these studies there are many factors affect the power output of a WT system, such as: height of tower, location, and wind velocity. The power in the wind represented as:

$$P_{wind} = 1/2\ \rho A\, V^3 \tag{2.1}$$

Where, P_{Wind} is power in the wind, ρ is air density (Kg/m^3), A is the cross-sectional area of the wind turbine (m^2) and V is the wind speed (m/s).

To determine the power output of WT there are different methods that must be considered:

If site data is available by using hourly data for hours throughout the year at each wind speed the output power can be calculated, as shown in Equation (2.2) [39]:

$$P_{out} = 1/2\ \rho A\, V^3 c_{p1} c_{p2} \tag{2.2}$$

Where , A is the cross-sectional area of the wind turbine, ρ is air density, C_{p1} is wind energy conversion efficiency (maximum 59%) and C_{p2} is the device efficiency, and V is the wind speed [38, 39].

1. Equation 3 is used to determine the output power of the WT, if only annual average wind speed is available:

$$P_{Ave\_out} = {}^{1}\!/_{2}\, \pi \rho A (Average) 3 c_{p1} c_{p2} \tag{2.3}$$

According to the Equations (2.2) and (2.3), wind velocity has the most significant effect on the power output as it is proportional to cubed of wind speed.

The other important factor that must be considered is the capacity factor. The capacity factor presents the energy delivered by WT at its rated power [38].

$$Cf = \frac{average\ power}{rated\ power} \tag{2.4}$$

Where, Cf is the capacity factor and the rated power is the maximum power (kW) that can be produced at full load.

Many studies have conducted to show the important parameters of WT and connection between them with different approaches. A. Zahedi used Mont Carlo method for different types of wind turbine to generate wind speed data. In his study, he also presented the capacity factor of each case and showed that a smaller wind turbine has the higher capacity factor for the same average wind speed [39]. In case of lacking wind data, performance estimation can be conducted by using Weibull probability density function (PDF) which is described in the following section:

2.8.1.1 Data generation using Weibull PDF

If only annual average site data is available, Weibull statistics is used to estimate the energy delivered. The Weibull PDF is used to characterizing the statistics of wind speed. The PDF expressed in mathematical form as shown in the Equation (2.5) [34, 38]:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{(k-1)}.\exp(-\left(\frac{v}{c}\right)^{k}) \tag{2.5}$$

Where k is the shape parameter, c is the scale parameter.

The output power is estimated by considering site data and assuming the Weibull statistics, with an appropriate shape and scale factor. Rayleigh statistics is an option to estimate the power delivered by wind turbine. The Weibull PDF for k=2 is known as Rayleigh PDF [38, 39]. As shown in the Equation (2.5) , If only the average wind speed is available, then by using Rayleigh statistics the output power can be calculated as shown in Equation (2.6):

$$f(v) = \left(\frac{2v}{c^2}\right).\exp(-\left(\frac{v}{c}\right)^2) \quad (2.6)$$

Average of wind speed $V_{ave} = \int_0^v vf(v)dv = \left(\sqrt{\pi}/2\right).c$

$V_{ave} = (\sqrt{\pi}/2).c$ and $c = 2V_{ave}/\sqrt{\pi}$c = 2 $V_{ave}/\sqrt{\pi}$

Equation (2.6) depicts the relationship between scale factor (c) and average of wind speed (V_{ave}). By replacing c in Equation 6 with its expression, the Equation 4 is given to determine the probability of wind speed and hours per year for a given average wind speed. The Equation (2.7) shows the Rayleigh's PDF in terms of average wind speed [34, 39].

$$f(v) = \left(\pi.\frac{v}{2(V_{ave})^2}\right).\exp((-\frac{\pi}{4})(\frac{v}{V_{ave}})^2 \quad (2.7)$$

Due to the competition among the various renewable resources, one of the main factors that should be considered is the cost of generation. To achieve a more cost effective outcome, wind turbine models are used to study and to improve their ability to capture wind energy and optimize it for a given wind speed and rotor angular velocity [38].

Moriarty and Butterfield presented a set of models and programs to determine the load and output power for a given wind turbine design [36]. In this study, they focused on modeling the different aspects of turbine, including external conditions, turbulent inflow, aerodynamics, applied loads and the wind energy versus electrical power output.

Cultura and Salameh have also presented an electrical model of a wind turbine system. They have used MATLAB-Simulink tool in their study to predict the steady state response of the wind power system. They believed that computer simulation is a valuable tool to predict some characters of the system such as: system's transient behavior and the power output [37]. Modeling wind turbine behavior gives a better understanding of the physical mechanisms behind the operation of the wind turbine. Furthermore, improvement the modeling of wind turbine by integrating it with other generation systems such as PV, leads to better result in real systems [36, 39]. In this research two different types of WT systems is considered; Vestas and Suzlon. These two systems are efficient systems as these are capable of producing power even in the low wind speed site.The WTs model is created using MATLAB software. The model is based on Equation (1).

2.8.2 Modeling a Photo Voltaic system

A PV system consists of a solar panel that converts the sunlight to electrical energy. Due to the low voltage output of each solar cell, they are aggregated to obtain more voltages [24]. Over the years, many studies have been done on the characteristics of PV systems and the factors that affect their performance [24,35,40,41]. Patel and Agarwal have used MATLAB based model to predict the Current-Voltage (I-V) and Power - Voltage (P-V) characteristics of large PV arrays. One of the advantages of their study is that the modeled PV system is close to a real-life system, and can also interface with other systems, such as wind turbines [42].

The power output in a PV system can be calculated as [34]:

$$P_{ac=Rated\ power\cdot PR} \qquad (2.8)$$

Where, P_{ac} is the output power of the PV system, rated power is dc power of the array under Standard Test Condition (STC), and PR is performance ratio; which is explained in the next sub-section.

Furthermore, the STC defined as 1000(W/m^2) of sunlight, reference temperature at 25(ºC), and air mass of 1.5 (AM). The air mass is the optical length through the atmosphere [34].

Since shading has significant effects on the output of a PV system, the incident irradiance and cell temperature are two major parameters to determine the solar cell efficiency. By increasing temperature the rate of photon generation increases therefore reverse saturation current increases; which leads to reduction in band gap. Consequently, this leads to minor changes in current but major changes in voltage [43]. As stated earlier in this section, one other important factor that must be considered to model a PV system is Performance Ratio (PR); which evaluates the efficiency of the PV system.

2.8.2.1 Performance ratio

Performance ratio (PR) and also called derated factor (in Europe), presents the number of hours that PV arrays performed at rated power; typically for monthly or yearly basis. With this factor, operators are able to monitor the performance of systems in order to increase the energy efficiency and reliability of system [34]. In mathematical form, PR is the ratio of actual ac power output (after inverter and before injecting to the grid) and the nameplate dc power and can be depicted by the following Equation [34, 40]:

$$PR = \frac{ActualoutputPower\,(kWhp.a.)}{Nominalpoweroutput\ (kWhp.a)} \tag{2.9}$$

The PR of real systems reach to up to 80% due to some heat losses caused by conduction or wiring.

2.8.3 Modeling Energy Storage System

The energy storage systems store the excess energy to the electricity storage to perform useful operation at a later time. E.g.it can be used as a temporary producer when the generation output is low or the demand is high [17, 44]. Different types of energy storage systems are available in the market such as: lead-acid batteries, sodium sulfur, and zinc bromide, which are explained briefly in the following paragraph [20, 21]:

-The lead-acid battery is the oldest form of a rechargeable storage. This type of battery usually utilizes in electric vehicles to supply the current which is needed by starter motors.

-Sodium sulfur usually applied for large scale application such as power network for electricity storage.

-The zinc-bromine flow battery delivers up to 5 kW of power and 10 kWh of energy. It applies for large stationery application such as: load balancing, power conversion and power system. With the relatively high cost of current electricity storage technologies, the challenge for utilities today is to learn how to realize multiple values in the storage value stream .In this study, the zinc-bromine battery is utilized as a storage system. Reasons to choose the zinc-bromine battery are the following primary features [21, 44]:

- The ability to provide energy storage at a lower cost
- 100% depth of discharge
- No shelf life limitations
- More than 2000 cycles life at 100% depth of discharge

All of the energy storage technologies are targeting to help the utility grid cope with balancing generation and load in the optimal ways. As mentioned earlier in this section the zinc-bromine storage system has high efficiency, power density, and longer life than other batteries. The energy stored in a battery will be measured based on its voltage and capacity. In addition, the state of charge (SOC) should be considered as one of the important assets of a battery operation. The SOC is defined as a ratio of its available capacity [44].

$$SOC = \frac{C_{nom} - \int idt}{C_{nom}} \qquad (2.10)$$

Where, C_{nom} is nominal battery capacity and i is an operating current.

$$V_b = V_0 - R_b . i_b - K\frac{Q}{Q - \int i_b dt} + A.\exp(-B\int i_b dt) \qquad (2.11)$$

Where, R_b is the internal resistance of the battery, V_0 is the open circuit potential (V), K is the polarization voltage (V), Q is the battery capacity (Ah), A is the exponential voltage (V), and B is the exponential capacity (Ah).

By considering the stated formula the zinc–bromine flow battery in this study is modeled in MATLAB environment.

2.8.4 Modeling a Micro Combined Heat and Power

A µCHP system is a distribution generator that supplies both heat and electrical power. It has the potential to supply up to 40kW thermal energy as the primary output and about 10kW electrical power as the secondary output [13]. However, due to the low capacity of the µCHP, it is mainly used for household and small commercial building [13].As µCHP systems are not suitable for large scale systems so, fuel cell system has been considered in this thesis.

2.8.5 Modeling a Fuel Cell

The FC produces electricity through a chemical reaction therefore; there is significantly cleaner emission than from a fuel combustion process. Some advantages of FC system over µCHP are; no moving parts, less maintenance, and quieter operation [45]. In this study, the fuel cell technology is considered in modeling a VPP. In order to model a fuel cell some parameters should be considered, most of them are acquired from the manufacturer's data sheet, others are obtained from the available literature [34, 45].

The Nernst equation can be calculated to determine the average voltage magnitude of the FC stack. Hence, applying Nernst's equation and terms of voltage loss, the output voltage of FC can be modeled as follows [34, 45]:

$$v_{out} = E_{nerst} - V_{act} - V_{conc} - V_{ohm} \quad (2.12)$$

In Equation (2.12) E_{Nernst} is the thermodynamic potential of the cell and it represents its reversible voltage V_{act} is the voltage drop due to activation of the anode and cathode, V_{conc} shows the voltage drop resulting from the concentration of the reacting gases,

V_{ohm} is the ohmic voltage drop [34, 45]. Further details of modeling the FC system in MATLAB software is explained in chapter 3.

2.9 Modeling VPP Operation

Combining different types of dispersed resources as a VPP make it a viable entity to the conventional generators by raising the efficiency of the system and reducing the cost of maintenance as well as operation. To maximize the generation of the VPP and minimize the cost of generation from renewable resources an appropriate control method, is needed. Many studies have already been completed, and various control models as well as optimization algorithms have been developed, to optimize the operation of a VPP [12, 18, 25].However, there are still many research and developments need associated with the optimized operation and integration of the VPPs. Furthermore, some shortcomings such as: uncertainties about load forecasting and the contractual relationship between DERs, and the VPP need to be considered [13].Thus, advanced control models and optimization algorithms are required to overcome these weaknesses. In order to achieve a better control method a combined control scheme has been considered as a feasible solution to mitigate the weaknesses thus far outlined [1, 13, 22,87]. As outlined previously, the combination of price signal control and direct load control approaches is considered in our study.

2.10 Summary

Smart Grid technology aims to achieve reductions in energy consumption and generation, as well as CO_2 emissions by establishing a synergy between energy generation, consumption, and distribution. It can be achieved by linking these three elements via an advanced metering, communication, and decision making process [10].

In this chapter a review of modeling and controlling of a VPP is presented. One of the main features of a VPP is to achieve more cost effective and reliable electrical energy. To tackle this target, a suitable control method is needed. One necessary control strategy is the generation schedule which optimizes the operation of a virtual power plant for DG units. In this study the FLMVPP system in MATLAB-Simulink software has been modeled and developed to optimize the operation of the system. In this regard, different types of DGs such as: PV system, WT, FC, and ZB battery storage system has been considered. Each element is modeled in MATLAB-Simulink. Finally, an appropriate control algorithm is used to optimize the operation of a VPP. The focus of this research is to use the combined control scheme to achieve a better control method as a feasible solution to mitigate the weaknesses thus far outlined.

Chapter.3 Developing a Five Layered Model of a Virtual Power Plant

The purpose of this chapter is to propose a new modeling technique of Five Layered Model for a Virtual Power Plant (FLMVPP) system. The layered model is used to characterize the internal task of a communication system by dividing it into abstraction layers. Each layer is in a correlation with other layers; it serves the layer above it and is served by the layer below it [46].The FLMVPP architecture is designed to employ a strategy to summarize the complexity from one level to another. This chapter covers two parts: Theory of layered model and architecture of the FLMVPP system.

3.1 Theory of layered model

In the middle 1980 The International Standard Organization (ISO) developed networking model to provide standards to design network, this is the Open System Interconnection (OSI) model [46].

This standard dividing a system tasks into different individual layer, therefore developers are able to modify or add a specific layer to the system instead of changing the entire system. Layered modeling is an adaptation of queue models for systems with software resources [47].It makes models easy to develop and more understandable by providing a representation of the architecture. Each layer represents a specific task and each task can be performed by either hardware/software or a single program [48].

As outlined previously, in this study a five layered model has been considered to model a VPP. A five layered architecture in this work is composed of Physical Layer (PL), Information Layer (IL), Control Layer (CL), Optimization Layer (OL) and finally Human Behaviour Layer (HBL).

In the following subsection some advantages of the layered structure which are applicable in this VPP system are described:

3.2 Advantages of layered Model

There are many benefits of layering model of the big size system. Some of them that are applicable in this study are [46-50]:

- Strong separation of concerns: Each layer can be dealt with the little concern for the other layers. Layers independency is an essential factor that causes organizational modularity; each layer can be organized without dealing with other layers. In a structured model each layer uses the elements of the layer below and offers elements or services to the next layer

- System flexibility*: To* modify each part of the system there is no need to modify the whole system. Since each layer has its own task adding or omitting one or more elements, would not affect other layer's function.
- Interoperability: Layering promotes greater interoperability among devices and different generations of the same type of device from the same manufacturer.
- Greater Compatibility: One of the greatest benefits of using a hierarchal approach is the greater compatibility between devices, systems and networks that this delivers.

3.3 Architecture of FLMVPP

As stated earlier in this chapter, using layered model gives the developers the ability to modify the desired layer instead of whole network which makes models more clear and understandable.The five layered network classification of the proposed model is depicted in Table 3.1.Each layer represents a specific function .Each function can be performed by either hardware/software or a single program. Our five layers, from the lowest to the highest, are the PL, IL as a second layer following by the third layer; which CL is, OL as forth layer and finishes at HBL.

TABLE 3.1. DIFFERENT LAYERS OF THE NETWORK

HBL is the highest level in this hierarchy. Regulatory and pricing methods lead to a wider behavior change policies that integrate public knowledge and engagement campaigns [51].
OL is used to optimize the operation of a system. In this regard, an appropriate algorithm technique must be chosen to get the maximum benefit of the system's operation. More detail is explained in following subsection.
CL controls load flow and error checking by using different control mechanisms to obtain optimal control of a system under different operating conditions [52].
IL is used to exchange information through the system. The main objective of this layer is to allow end systems, connected to different networks [2].
PL is the lowest layer of the model. The initial data for the second layer is provided in this layer [50]. This layer represents the individual elements of a VPP which is modeled in MATLAB-Simulink software.

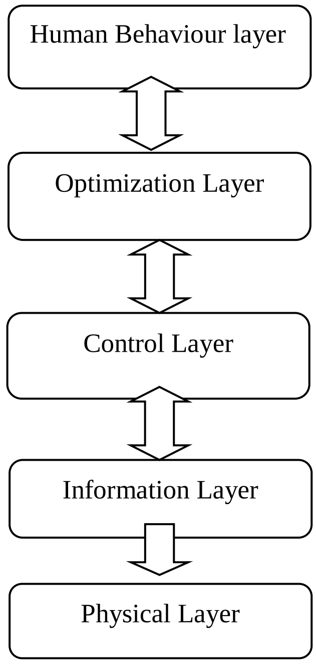


FIGURE 3.1. INTERFACE BETWEEN LAYERS

The connection among five layers in the VPP system is also illustrated in Figure 3.1; it starts with PL at the beginning and proceeding to the HBL. At the beginning all elements are modeled individually in MATLAB software and results are transferred to the next layer; which is the IL. In this layer, the whole network is modeled as a VPP to produce power electricity by considering a set of data and exchanging information among different elements. The CL, as a third layer, is used to control and coordinate the power output of a VPP from previous layer by choosing a suitable control scheme. In OL the output power is optimized by considering an appropriate algorithm technique to get the best result from available data. The last one is HBL Layer. In this layer people's behavior and their response to price changing of electricity is briefly investigated. Each layer is explained in detail in the following sections.

3.4 Physical Layer

The PL is the lowest one in this hierarchy. In this layer each component is simulated individually in MATLAB-Simulink software. For VPP system in this study, four different component is considered; PV system, WT, system, ZBB storage system and FC. The FLMVPP system has been developed in MATLAB software. The specific reasons to use MATLAB are that, this software is widely used tools in the electrical engineering community, user friendly as well as easy to access data [48].As stated in chapter 2, the mathematical relationship between power output of each element and the factors that effect on it, is considered to develop the FLMVPP system. Then, MATLAB-Simulink is used to simulate each component. In the following subsection each component and its mathematical formula is explained in MATLAB-Simulink.

Furthermore, depending on the size and efficiency of devices selected for this system it is possible to predict the system's performance over different time interval as well as overall system efficiency, the percentage of energy generated by each element.

3.4.1 Wind turbine modeling

Australia has high potential capacity for large development of wind power generation. Although wind energy is a free resource, it is challenging to integrate this resource to the power grid due to the intermittent nature of the wind [57]. Combining the smart grid technology with storage systems would provide a resource that meets both the needs of peak reduction and shaping of wind power [58]. Nearly all technologies are available these days to tackle these goals. These technologies are also available in Australia, as currently it has the wind generation capacity of more than 3 GW, while it was about 2,000 MW in 2010 [38]. To model a WT system in PL, 60 WT systems has been considered which have been modeled in MATLAB environment by considering in two different scenarios [57,58].

In scenario 1, the system is modeled with 60 types of $WT_{1,}$ while two different types of WT systems with 2 and 2.1 MW capacity respectively is modeled in scenario 2. The reason to choose two different scenarios to model WT systems is comparing results of these two scenarios in MATLAB-Simulink. Each type of WT is briefly explained in the following paragraph:

-WT_1 with 2 MW capacities is strongly reliable turbine, and known for its strong availability and performance with the lighter structure. Some other features of this system are:

- Resistance in extreme conditions
- Control strategy such as reduce load
- Produces power even by opening up low-wind sites

-The WT_2 system with 2.1 MW capacity provides an efficient control of load and power. In this study the 2.1 MW is modeled in MATLAB-Simulink. The reasons to use this system are:

- Resistance in extreme conditions
- Low maintenance costs
- Optimal power generation

The technical specification of each system is also represented in Table 3.2.

TABLE 3.2.WT_1&WT_2TECHNICALSPECIFICATION [57,58]

Technical Specification	WT1	WT2
Rated power	2000 KW	2100 KW
Cut-in wind speed	4 m/s	3.5 m/s
Rated Wind Speed	14 m/s	11 m/s
Cut-out Wind Speed	23 m/s	25 m/s
Rotor Diameter	90m	95 m
Swept Area	6361.73 m^2	7,085m^2

Both WTs have similar output power ranges, with a maximum output of around 2 MW. To produce a model can output the total energy produced with the given inputs and variables. To model WT systems in MATLAB the average yearly wind speed is generated from the BOM and NASA website [68, 69] as well as the following formula:

$$v = \frac{2vave}{\sqrt{\pi}}(-\ln(1-x))^{.5} \quad (3.1)$$

V_{ave}=8 m/s

The wind speed is measured based on 10 meter above the ground however, each WT system in this modeling has 90 and 95m height respectively, so the new wind speed is calculated based on below formula [57,58]:

$$V_{avenew} = V_{aveold}\left(\frac{WTtowerheight}{10}\right)^{.15} \quad (3.2)$$

Based on Equation (3.2) V_{ave} for each system is 11.12 and 11.21 m/s respectively. Now power in the wind is calculated from [57,58]:

$$P_{wind} = {}^{1}/_{2} * {}^{6}/_{\pi} * \rho A(\upsilon_{ave})^{3} C_{p1} C_{P2} \quad (3.3)$$

Then the Mont Carlo formula has been used in this modeling to calculate wind speed for 12 months from Equation (3.4):

$$\upsilon = {}^{2(\upsilon_{ave})}\Big/_{(\pi)\,{}^{1}/_{2}}\,(-Ln(1-x))\,{}^{1}/_{2} \quad (3.4)$$

Eventually, according to power curve of each WT system the power output of each WT system is calculated from (3.5):

$$P_{out} = \frac{P_{rated}(v^3 - v_{CI}^3)}{(v^3{}_r - v_{CI}^3)} \quad (3.5)$$

To produce a model, can output the total energy produced with the given inputs and variables; the model uses Equations (3.1)-(3.5).In fact, the equations represent the Simulink implementation of the mathematical equations of the WT module such as output power, energy of WT systems as well as energy from the wind.

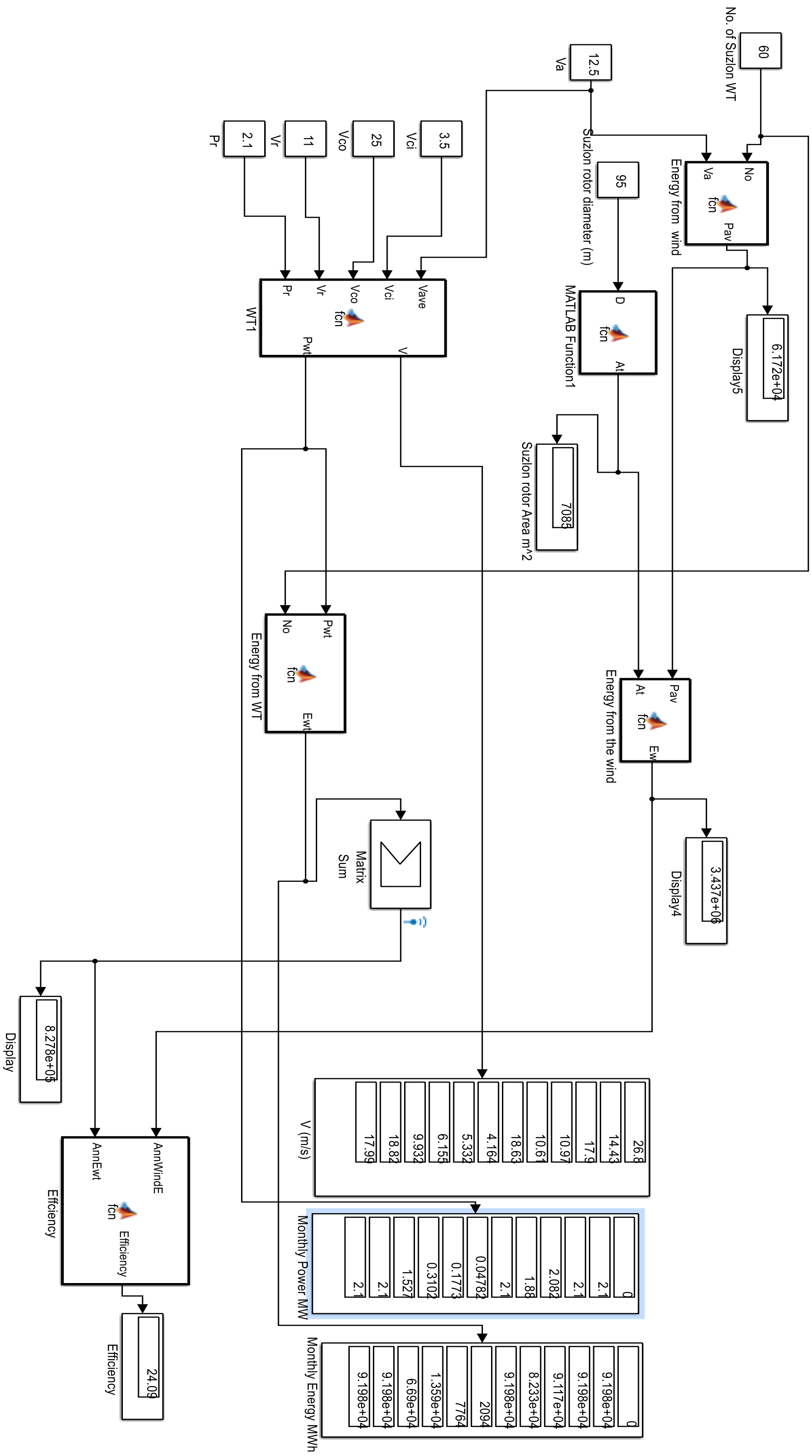


FIGURE 3.2. SCENARIO 1,WT_1 MODELING IN MATLAB-SIMULINK

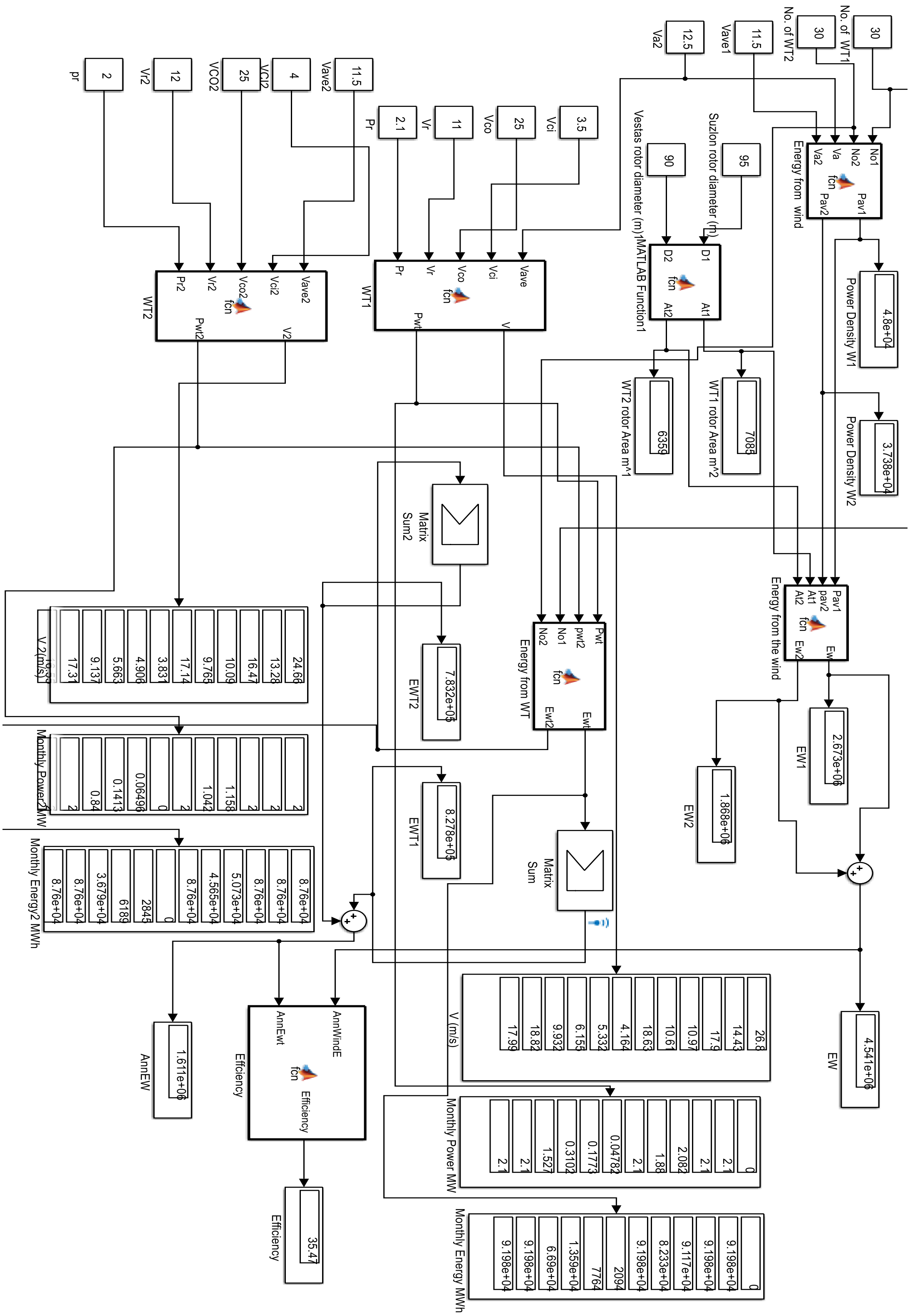
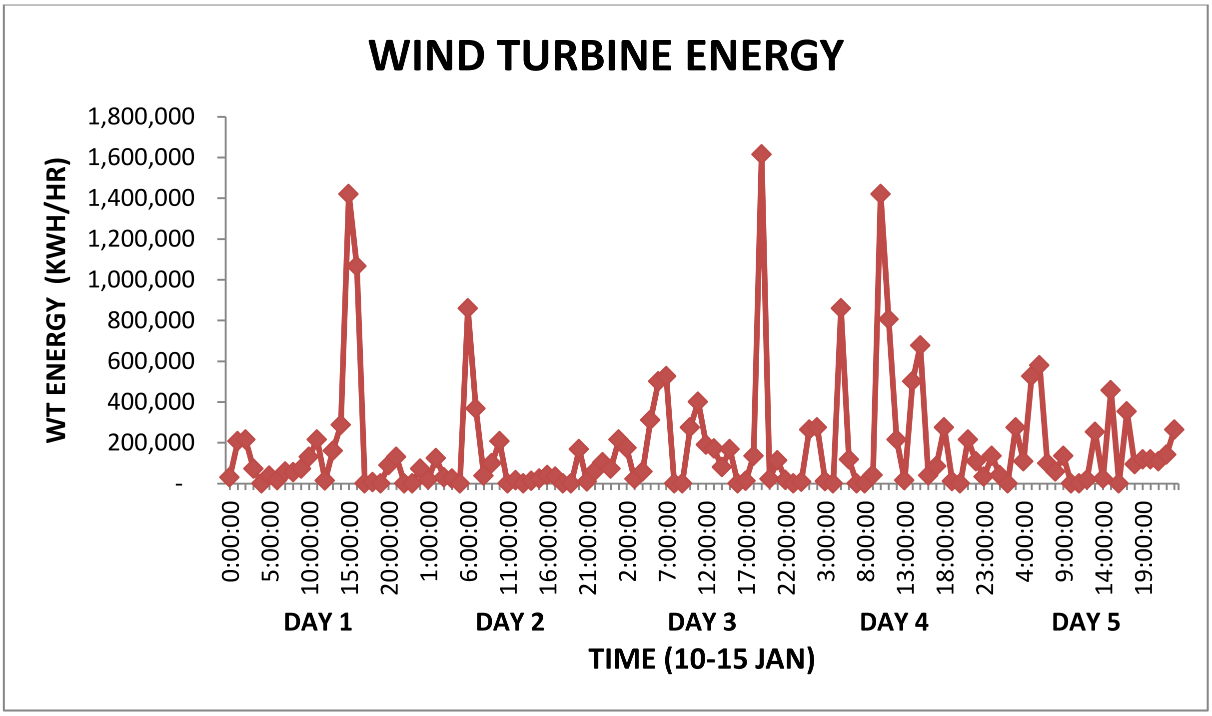


FIGURE 3.3. SCENARIO 2,WT_1 AND WT_2 MODELING IN MATLAB-SIMULINK



GRAPH 3.1. ENERGY GENERATION OF WIND FARM FOR FIVE DAYS

Furthermore, all input in this simulation have been considered as hourly bases. However, as shown in Figure 3.2and Graph 3.1 the output of energy generated from wind farm are presented for the period of one year and five days respectively. Since showing the hourly bases of the power generation for the whole year is not feasible to illustrate in one single diagram here. So, for visualizing purpose the output of the simulation has been shown for different period of time.

As shown in Figure 3.2 and 3.3 60WT systems are modeled in different scenario to form a wind park. To model WTs in each scenario the capacity factor is considered in a range of 35% to 45%. Indeed, the system is modeled with three different capacity factors; 35%, 45% and 50% as shown in tables 3.3 and 3.4.The model then generated with power generation at average speed for 12 months, total power generated in a year 1as well as the power from wind.

TABLE 3.3.CAPACITY FACTOR FOR 60 WT_1

Capacity Factor	E_{wind} (MWh/yr)	E_{wt}	Power density (kW/m^2)	Efficiency
35%	$2.6*10^6$	$8.2*10^5$	$4.8*10^4$	30.97
40%	$3.05*10^6$	$8.2*10^5$	$5.48*10^4$	27.1
45%	$3.43 *10^6$	$8.2*10^5$	$6.17*10^4$	24.09

TABLE 3.4.CAPACITY FACTOR FOR 30 WT_1& 30 WT_2

Capacity Factor	E_{wind} (MWh/yr)	E_{wt} (MWh/yr)	Power density $WT_1(kW/m^2)$	Power density $WT_2(kW/m^2)$
35%	$4.5*10^6$	$1.61*10^6$	$4.8*10^4$	$3.7*10^4$
40%	$5.19*10^6$	$1.61*10^6$	$5.2*10^4$	$4.2*10^4$
45%	$5.83*10^6$	$1.61*10^6$	$6.17*10^4$	$4.8*10^4$

As illustrated in table 3.3 and 3.4, combination of two different types of wind turbines is more efficient than using only one type wind turbine. As combination of systems optimize the wind farm output and improve the generation significantly by increasing the efficiency of the system .As outlined previously the average yearly wind velocity for Melbourne area, rotor diameter and power curves of each WT take as inputs. To predict the WT generation at any given time an accurate and sufficient information are needed to integrate the wind generation system into the power grid [39], afterward the WT system model is created using MATLAB-Simulink. Due to the competition among renewable resources, one of the main factors that should be considered is the cost of generation. To achieve a cost effective outcome the WT models are required, such that the wind energy capture of such systems, can be optimised versus wind speed or rotor angular velocity [37, 38].

Eventually the WTs outputs along with other components' outputs have been used in layer four, OL, to optimize the operation of a VPP system.

3.4.2 Photovoltaic modeling in solar farm

Solar farms can be located close to infrastructure, forests and houses as these parks are noise free with very little risk to flora and fauna. PV parks are being built all around the world. The leading countries in terms of installed solar capacity are Germany, Spain, Japan and the United States and Australia. As Australia is the sunniest continent on the earth planet, it receives more sun energy than European countries. For instance, the annual sun exposure in Melbourne is 1500kWh/$m^2$and 2200 in Brisbane, while it is 1100 kWh/m^2in south of Germany and 800 kWh/m^2in north Germany [53] .In Australia the Bureau of Meteorology (BOM)is one of the good sources of solar data. According to the BOM, the Northern Territory and Western Australia have the best solar exposure. As solar energy has huge potential in Australia the main requirements of sunshine and lands are abundant making it an ideal place for PV systems installation [70].

In Victoria, the largest solar farms are in Bendigo and Ballarat with a capacity of 300 kW solar parks produce 420 MWh solar power per year, which is enough to provide clean electricity for 150 households [71].

PV systems have a number of desirable features which lead to the cost effectiveness of those systems. Some of these attributes are as follows:

- High reliability
- High PV efficiency
- No additional costs for land by integrating it into the building
- Deliver power during high demand especially in summers

The main difference between solar park and rooftop's PV system is the size of the park which is too large. Parks are often mounted near the ground in some un-shaded area such as a field more easily and cheaply. Furthermore, location and the local meteorology have the biggest influence to produce energy from sun in a solar farm as well as rooftop's one [56]. Although the solar farm rating is in power, kW or MW, the energy produced in kWh or MWh is more attracted. The common measure of a solar farm is kWh/kW per year - or K watt-hours per K watt-peak per year [43].

In this study 450 PV systems have been considered to form a solar park. As outlined previously in section 3.3.1, the PV system is modeled in MATLAB-Simulink based on mathematical equations. To model PV system in MATLAB the average hourly temperature and insolation data for Melbourne area have been collected from BOM and NASA website [54, 55].

In this study the PV system with below specification has been considered to model in MATLAB environment. Table 3.5 shows the specification of the system [56,59,71].

TABLE 3.5.ELECTRICAL SPECIFICATION OF PV SYSTEM

PV system	Specification
P_{max}	200 kW
Temperature coefficient	0.065
Manufacturer tolerance	.97
Dirt	.97
Efficiency	80%

The model is created using Equations (3.6) and (3.7) to calculate energy produced from PV farm within a year as well as the performance ratio of the system.

$$E = p_{max} * insolation * PR \qquad (3.6)$$

Where, E is energy produced from PV farm, insolation is solar irradiance which gets from table 3.5 and PR is performance ratio which is calculated based on Equation (3.7+) [53]:

$$PR = \frac{Real\ produced\ power}{Nominated\ power} \qquad (3.7)$$

The model is presented in Figure 3.4; in this figure the Simulink implementation of the mathematical equations of the PV module such as output power and energy of the PV farm as well as the effective cell temperature and PR has been illustrated. As shown in the below figure, the park produces $1.76*10^{\wedge 6}$ MWh per year which is almost the same amount of energy produced by wind farm. Indeed, the solar park is able to compensate the energy and meet the demand in absence of wind in Melbourne.

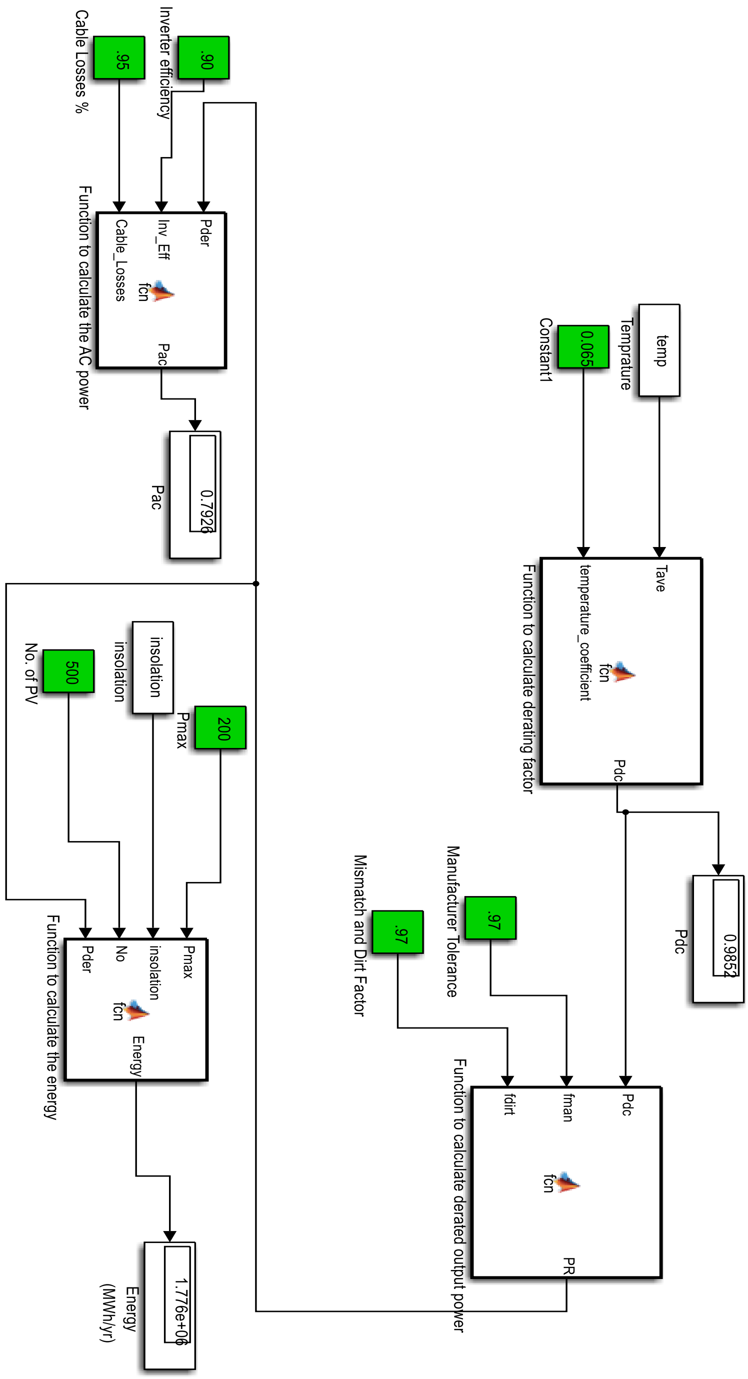
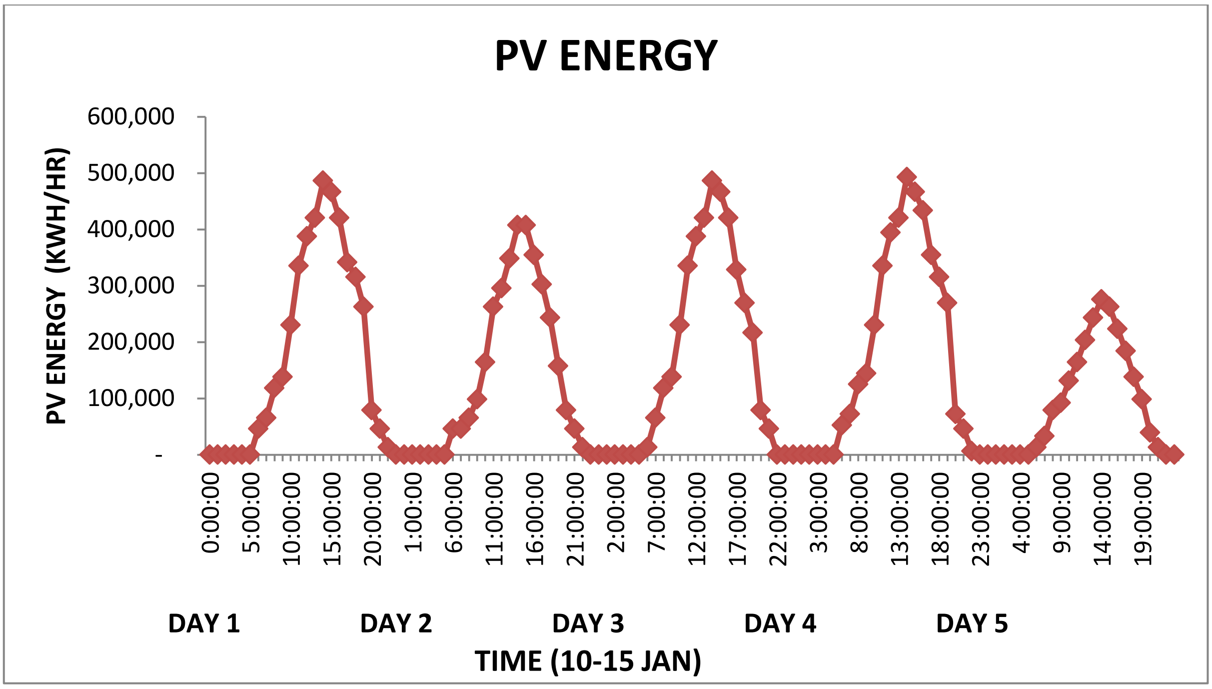


FIGURE 3.4. MODELING OF PV SYSTEMS IN MATLAB



GRAPH 3.2. POWER GENERATED FROM PV FARM FOR THE PERIOD OF FIVE DAYS (10^{TH}-15^{TH}JAN 2015)

As previously stated in section 3.4.1 illustrating the hourly bases of the output for the whole year is not feasible in one single diagram. So, the power output has been shown for the period of one year in Figure 3.4 as well as five days in Graph 3.2.

Because of the large size of the model, modeling a solar farm in a separate layer helps to modify and change each part easier without modifying or changing other components' parts. Therefore, modeling layer of components is an easy and reliable way to model a VPP system.

3.4.3 FC modeling in FLMVPP

A FC system generates thermal and electricity by transmitting a chemical energy of fuel through a chemical reaction. This system is an environmental friendly technology with almost zero gas emission that can be used for distributed power generation with high efficiency and no moving parts which makes it quiet and reliable [57].In addition, these systems are economics for their high performance and low cost. There are some different types of FC systems such as: Alkaline Fuel Cell (AFC), Proton Exchange Membrane (PEM) Fuel Cell, Phosphoric Acid Fuel Cell (PAFC), and Solid Oxide Fuel Cell (SOFC). The SOFC system has been chosen to model in the FLMVPP system in this study. The reason to choose this system in this study is that the system has a higher operating temperature (800 ^oC-1000 ^oC) compare to other types of FC which make it more efficient and reliable. The SOFC system uses hydrogen as fuel and can also consist of combination of CH_4, H_2O, CO, CO_2, O_2, and N_2 to produce protons, electrons, heat and water. The electrochemical reaction occurs in SOFC utilize fuel (hydrogen) and air (oxygen) as follows [34]:

$H_2 + O_2- \rightarrow H_2O + 2e-$ Anode

${}^{1}/_{2} O_2 + 2e- \rightarrow O_2-$ Cathode

$H_2 + {}^{1}/_{2}\, O_2 \rightarrow H_2O$ Overall reaction

As it can be seen in Figure 3.4 hydrogen fuel is supplied to negative terminal (anode) of the cell whereas oxygen is supplied to the positive terminal (cathode). During this process, hydrogen splits into electron and proton, and moves to the cathode in a different path [34].

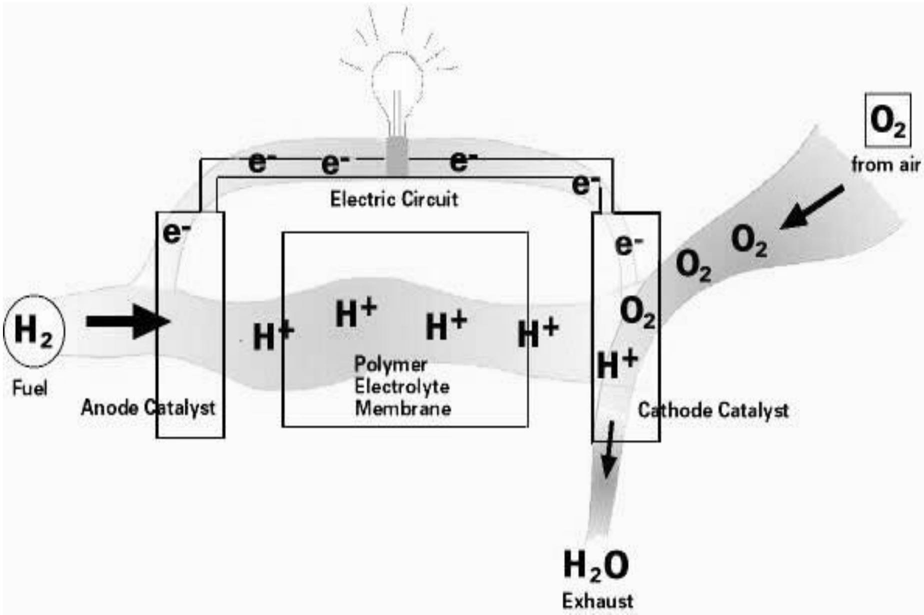


FIGURE 3.5.BASIC FELL CELL OPERATION [34]

The proton passes through the electrolyte and both are reunited at cathode. Eventually, the electron, proton, and oxygen combine to form water. Hydrogen fuel can be also supplied from a variety of substances if a fuel re-former is added to FC system. The FC therefore, produces electricity through a chemical reaction which is significantly cleaner emissions than a fuel combustion process [43].

3.4.3.1 SOFC Performance

There are some important factors that affect negatively on the performance of FC systems such as: pressure, partial pressure of the reactants, temperature, and impure gasses. In case of hydrogen, the partial pressure is equal to the pressure but for oxygen, the partial pressure is not the case as oxygen is a constituent of air [43]. By increasing the partial pressure, the reversible voltage increases as well, while it decreases the effect of activation and concentration losses [57]. Therefore, higher partial pressure of the fuel leads to a better efficiency and increasing the operating voltage of the stack. As outlined in the previous section, temperature is also another factor that effects on cell's performance. Increasing in stack's temperature causes higher cell efficiency that decreases the reversible voltage. However the overall efficiency could be improved by decreasing the activation loss and increasing exchange current [43, 57]. The other essential factor that should be considered on SOFC's performance is impure gasses which effects on the FC's generation .Impure gasses such as hydrogen sulfide (H_2S), hydrogen chloride (HCl) and ammonia (NH_3) may be harmful for the performance of SOFC systems [45].

3.4.3.2 Causes for Voltage Loss

Voltage losses of FC depend on some factors which are as follows:

3.4.3.2.1 Activation Losses

Activation losses of FC are related to slowness of the reactions that take place on the surface of electrodes. Three losses that occur at high temperature FC such as SOFC system is illustrated in Figure 3.6. A proportion of the voltage generated is lost in driving chemical reaction at the electrodes. It is called an activation loss as it is related to the activation energy required at both anode and cathode of FC system [34].

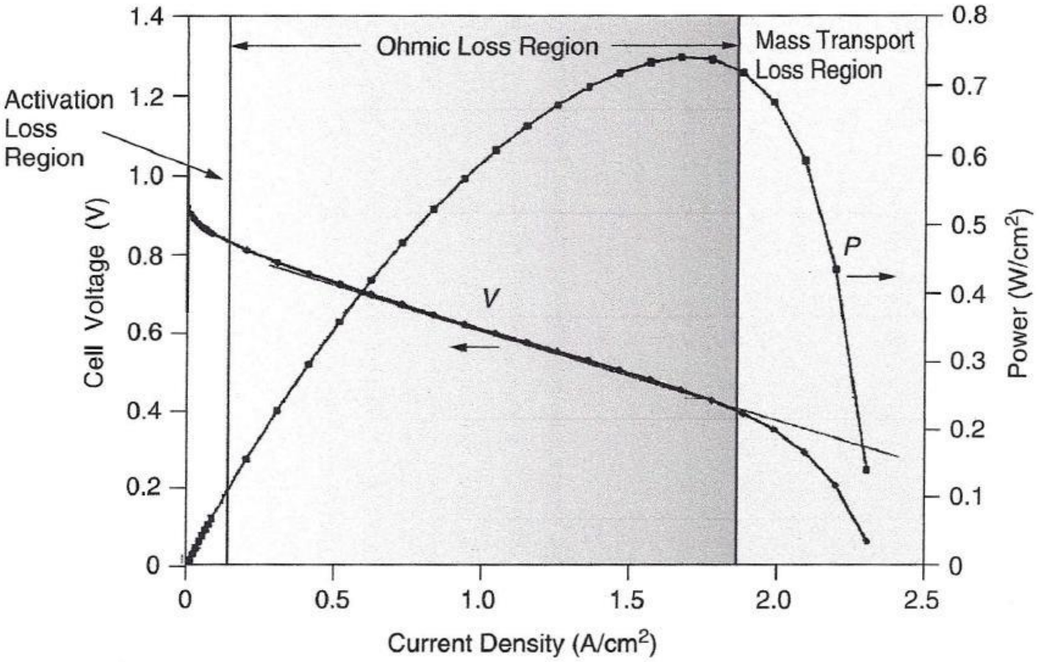


Figure 3.6. The voltage - current curve for a fuel cell with three different losses [34]

The loss of voltage that occurs in FC can be mathematically calculated from the following equation [57]:

$$\eta_{act} = \alpha + \beta \log I \quad (3.7)$$

Where; α is tafel constant (0.05), βis tafel slope and I is cell current, which can be calculated as follow:

$$I_{cell} = \frac{P_{cell}}{V_{cell}} \quad (3.8)$$

Where; V_{cell} is cell operating voltage, and P_{cell} is output power of the cell, which can be found as:

$$P_{cell} = \frac{P_{model}}{no\ of\ cells} \quad (3.9)$$

Where; P_{model} is rated power of SOFC system [58].

3.4.3.2.2 Concentration Losses

The concentration losses that occur in FC systems are directly related to the pressure. For instance, using the amount of hydrogen at a very vigorous rate at the anode makes the reaction rate slower by dropping the partial pressure of the hydrogen. This is the same process that happens at the cathode of oxygen [34].

The concentration loss becomes more significant at higher current when the fuel and oxidant are used at higher rates, while the gas channel concentration is at minimum. This loss can be declared mathematically from Equation (3.10) [57].

$$\eta_{con} = \frac{RT}{nF} \ln\left(\frac{I-I}{I_L}\right) \qquad (3.10)$$

Where; R is universal gas constant (8.314 J (mol.K) $^{-1}$), T is absolute temperature in Kelvin; 1273 K, n is the number of the electrode reaction, F is Faraday's constant (96485Cmol^{-1}), I is current (A) and I_L is the limiting current for the concentration loss.

3.4.3.2.3 Ohmic losses

The ohmic loss can simply occur due to the resistance to electron flow in bipolar plates. This loss can be considered as current density and area resistance. This allows for the ease of use in evaluating performance of the cell since most cells are rated in terms of the current density. It can be found in Equation (3.11) is as follows [57]:

$$\eta_{ohmic} = ixR_{ohm} \qquad (3.11)$$

Where; i is current density and R_{ohm} is the area specific resistance; 0.126 Ω for SOFC system. It is essential to use electrodes with higher conductivities or reduce the distance of traveler electrons to reduce the ohmic losses [57]. The slope of the cell voltage in the middle of the polarization curve as shown in Figure 3.5 is due to the ohmic loss. The loss in FC system is approximately linear after the activation loss levels out and before the concentration loss becomes significant.

3.4.4 SOFC in the FLMVPP system

To find the output voltage produced from SOFC the amount of hydrogen gas must be considered. To model a FC system the amount of hydrogen needs to be supplied to the fuel cell must take into account. Hence, the hydrogen rate for an ideal system with 100% efficiency is 30.35 gh_2/kWh [34]. Then for SOFC with 60% efficiency the hydrogen rate will be divided by the efficiency 30.35 / 60% = 50.58 gh_2/kWh. In the FLMVPP system the SOFC consists of 200 cells connected in series by adjusting the amount of fuel that enters into the system and controlling the output voltage [34].As outlined in section 2.9.4 the Nernst equation can be calculated to determine the average voltage magnitude of the SOFC stack. Hence, by applying Nernst's equation and terms of voltage loss, the output voltage of SOFC can be modeled as follows:

TABLE 3.6. DATA SPECIFICATION FOR FUEL CELL

Electrical output	System efficiency	Operating condition
1800Kw	60%	800-1000^{0c}

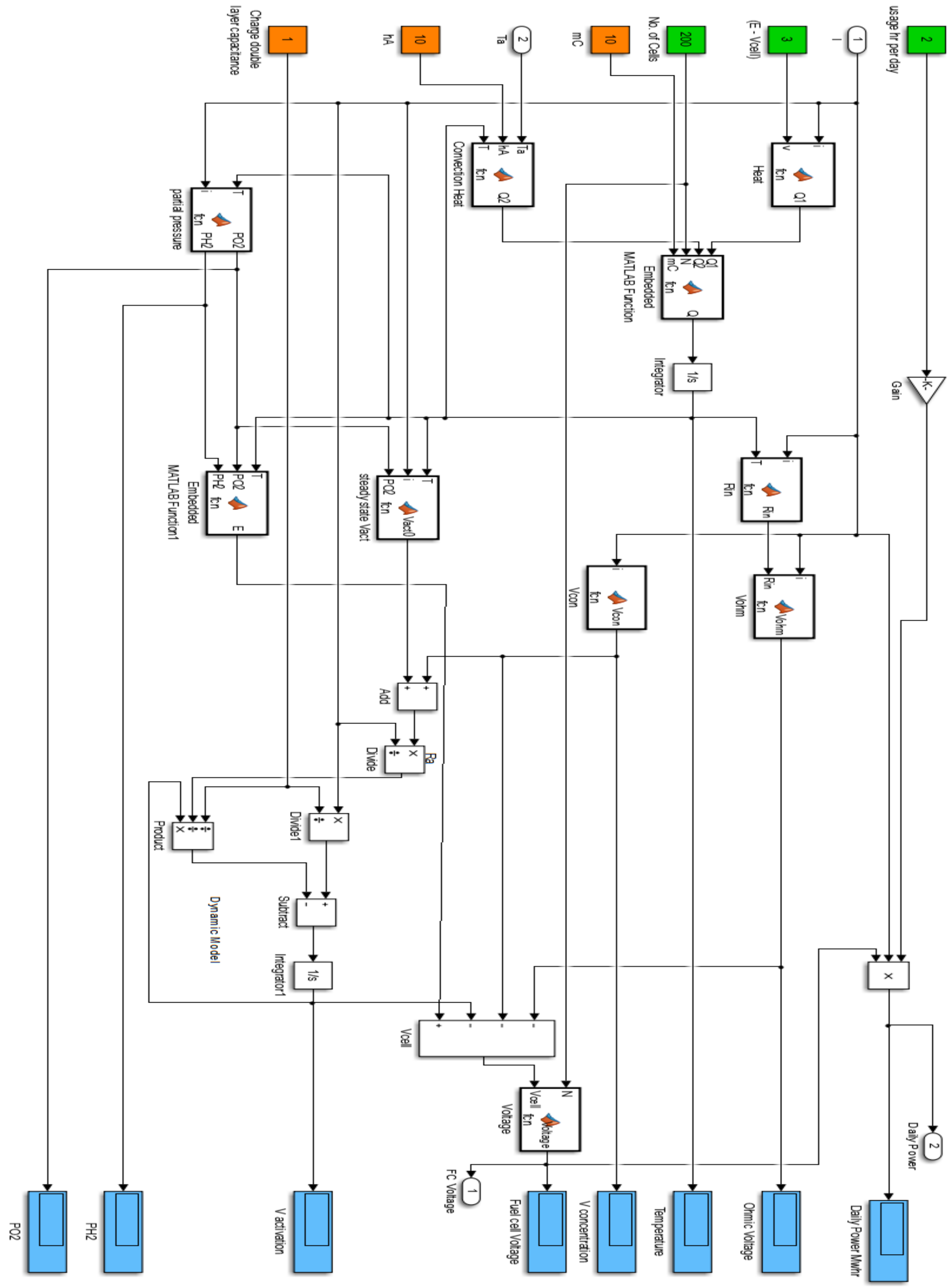
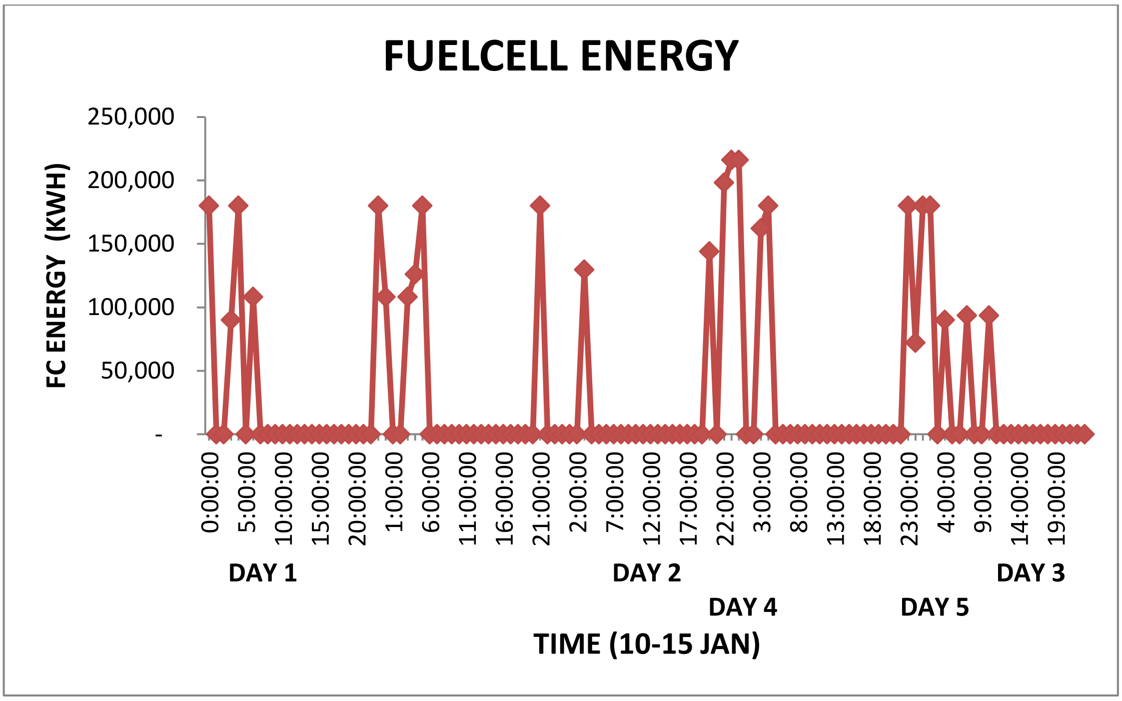


FIGURE 3.7. SOFC MODELING IN MATLAB

In this research study, to simulate the SOFC machine in the FLMVPP data have been considered as hourly basis, however only the period of five days (10-15Jan 2015) have been shown in Graph 3.3 as it is not feasible to show whole data in a single diagram in word document. In this simulation assumed that the SOFC system only runs for two hours a day and mostly act as system's back up. In case of there is no wind or sun the SOFC system will be run to meet the demand.



GRAPH 3.3. ENERGY OUTPUT OF SOFC FROM 10 TO 15 JAN 2015

From the FC simulation the actual cell potential V_{output} is lower than the stranded cell potential E^{o} because of cell losses while the cell voltage will be increased by increasing the operating cell temperature. This system has been integrated with other elements to form the FLMVPP system eventually, to optimize the operation of the whole system.

3.4.5 ZB Battery in the FLMVPP system

Due to the high cost of fossil fuels, concerns for environmental effects, energy security, and statewide regulations RES are experiencing a large growth [37, 38]. Among RES wind and solar energies are well advanced and are expected to play a major role in the future. Although renewable resources have many advantages, their utilization in the electrical grid is costly. The high penetrations of renewable resources lead to many technical and non-technical challenges. Power generation intermittence, power quality, reliability, safety, protection, load management, grid interconnection and controls new regulations and grid operation economics are active areas of research [17, 56]. By increasing the growth of the wind and solar energy in power grids the integration services required for reliable system operation. As shown in Figure 3.8, one solution to cope this challenge is to integrate an energy storage system with RES to alleviate these problems and facilitate higher penetration of RES [21, 59].

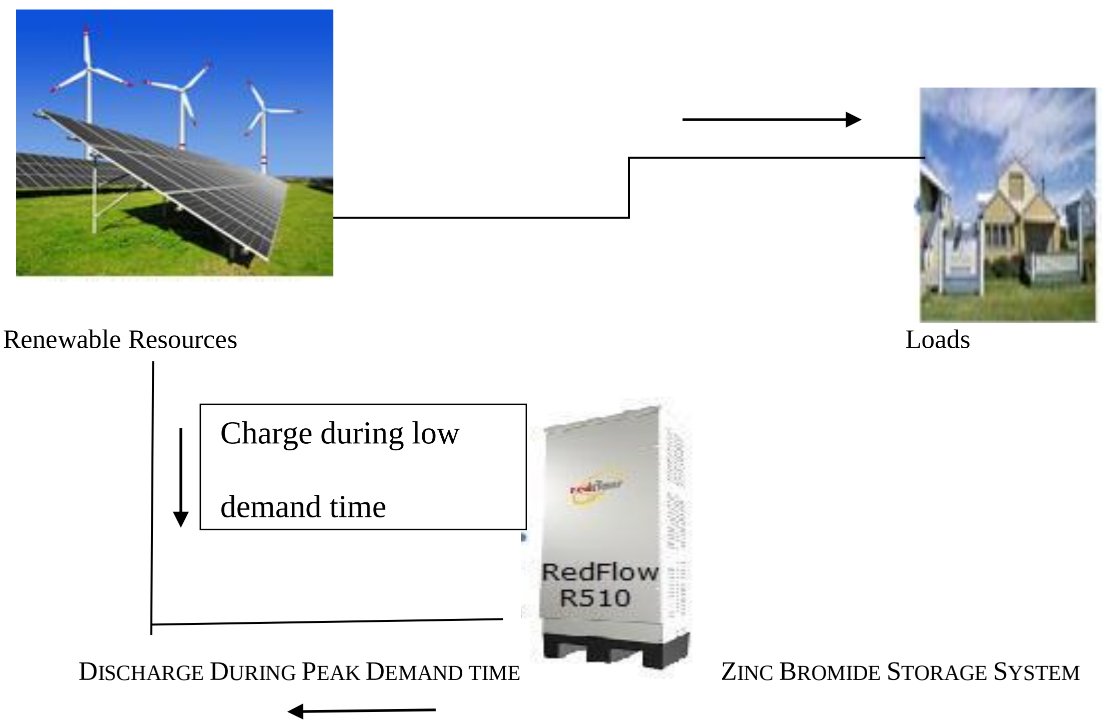


FIGURE 3.8.RENEWABLESOURCES WITH ZBB INTEGRATION [21]

Therefore, because of the intermittent nature of RES' and sudden variations of the power generated by these resources, having a storage system is essential. Integrating energy storage systems in to renewable resources lead to increase power dispatch as well as develop system stability by reducing the output intermittency of these sources [17]. As stated earlier in chapter 2, the Zinc Bromine Battery is used as a storage system in the FLMVPP system to use at the time of peak demand. The ZBB system acts based on the reaction between two metals, zinc and bromide, however its electrodes do not participate in the chemical procedure .It only plates zinc during battery charging and the metal dissolves back into the electrolyte during discharging [21, 60]. This storage system is suitable for deep cycling applications and long cycle life. Moreover, the ZBB system is capable to be widely used with renewable resources for large scale power utility and industrial applications while supporting smart grids at the times of peak load. It can be added to every renewable systems and charge or discharge to develop the output of RES'[21].Integrating intermittent energy resources such as solar and wind with energy storage system has several benefits for power grid. Some of these benefits are as follows:

- Help power grid during high demand
- Shifting the grid load from busy time to less demand time
- Smoothing the variations in power generation fed into the grid by intermittent renewable resources

As more renewable resources will be integrated into the electricity grid worldwide in the future, therefore the last feature is more essential than other features [59].

According to storage system modeling stated in section 2.8.3 it is important to calculate the SOC of the ZBB to model it in the FLMVPP system. There are some different techniques to estimate the SOC of ZBB while it is in operation. In this research the most common established techniques have been followed. The SOC of the ZBB system makes this storage system more unique than other types of batteries as it can be operated from 0% to 100% SOC and back to 0% at every operational cycle without loss of performance or damaging battery's life [59].

As the voltage of the battery is almost constant during charging period there is no estimation of available charge of the battery can be made, while there is a relation between SOC and open circuit Voltage (OCV)during discharging period [17].

3.4.5.1 SOC versus OCV

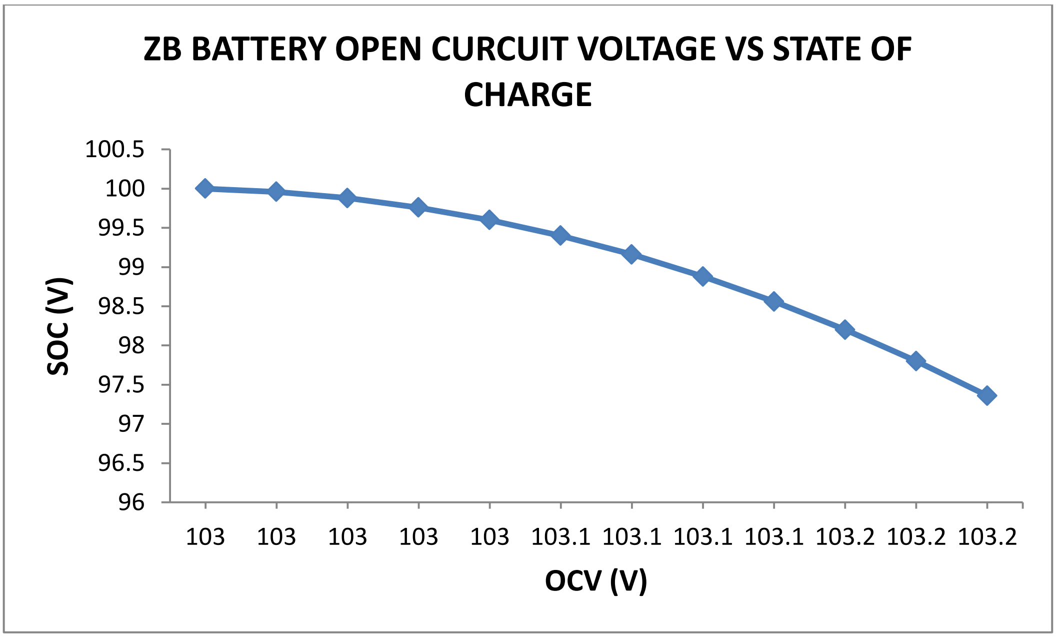
As stated earlier in chapter 2, the SOC of the battery is one of the important parameters that should be considered in modeling of battery storage system. An accurate model and the SOC values are essential to integrating the ZBB with renewable resources so that the controller can make a decision whether the battery should store or generate energy to/from the power. The correlation between OCV and SOC is crucial to model the ZBB storage system [59].It can be noticed that when the OCV reaches to its steady state value at different values of SOC, it takes more times to reach its steady state value of OCV when the battery is reaching to discharging period. The value of OCV at different values of SOC is shown in Table3.7 As mentioned in the previous section; there is a correlation between SOC and OCV during discharging which is shown in Equation (3.12) [59]:

$$OCV = -1.9e^{-6}SOC_4 + 5.3e^{-4}SOC_3 - 0.054e^{-2}SOC_2 + 2.4SOC + 63 \qquad (3.12)$$

FIGURE 3.9. SOC AND VOLTAGE OCV VALUES

SOC	OCV
100	103
99.96	103
99.88	103
99.76	103
99.6	103
99.4	103.1
99.16	103.1
98.88	103.1
98.56	103.1
98.2	103.2
97.8	103.2
97.36	103.2

The correlation of SOC VS OCV has been illustrated in Graph 3.4.



GRAPH 3.4.OCV VS SOC

In this research study, 300 batteries with 3MW capacity are integrated with renewable resources in the FLMVPP system in MATLAB-Simulink. The model uses all of the equations outlined in section 2.9.3 to produce a model that can output total energy with the given inputs and variables. As can be seen in Figure3.10, batteries with 80% efficiency are integrated to the grid with 8 hours daily operation time.

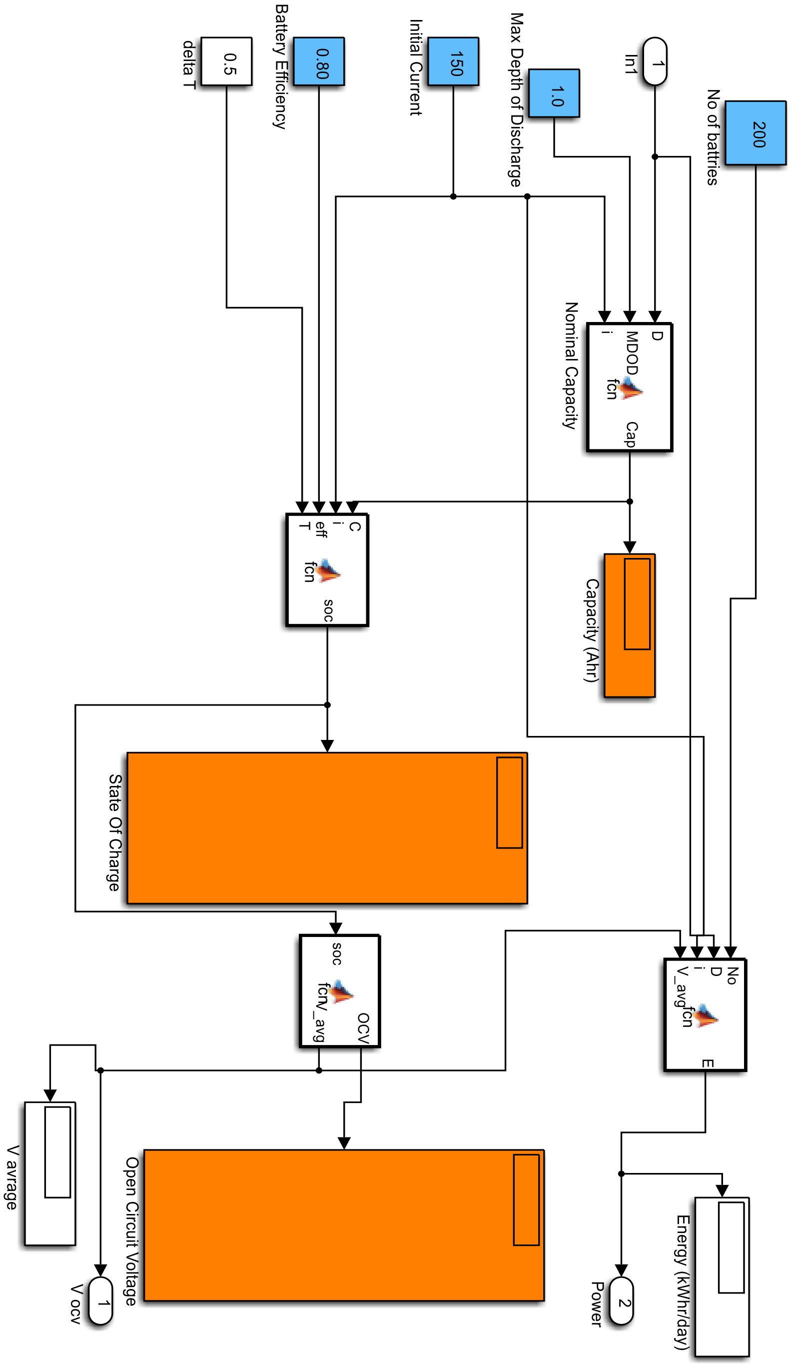
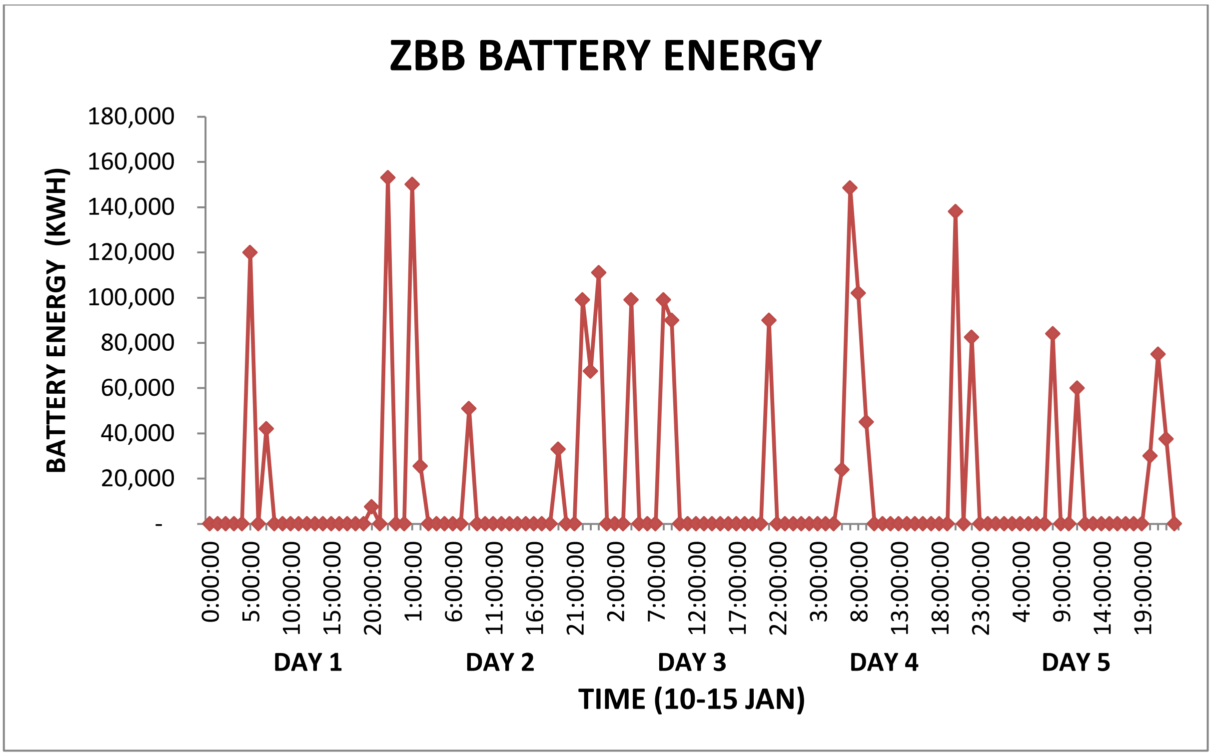


FIGURE 3.10.MODELING OF ZB STORAGE SYSTEM IN MATLAB



GRAPH3.5. POWER OUTPUT OF ZBB

The model takes in inputs for initial current, discharge rate, battery efficiency, and T as the period of the charge and discharge battery. Inputs into the model utilize the Simulink from file function; the function allows the model to read inputs from MATLAB files that are not part of the model. This allows the model to be used for numerous types of generator and site variables. The output of the model is also outputted to a separate file for further use in other modeling or further analysis.

After modelling all elements in PL, the second layer which is the Information Layer (IL), is used to exchange information through the system as described in the following section. The FLMVPP system proposed in this study follows the general concept considered for any VPP power station. The main components of this system are wind turbines, PV array, FC, and ZBB. In the FLMVPP system, as illustrated in Figure 3.11, electricity produced by WT and PV farms will be delivered directly to use by load if the power generated is enough to meet the demand. Otherwise, when the demand is less than the power generated by these two farms the excess power will be stored in batteries to use on peak period load to meet the demand.

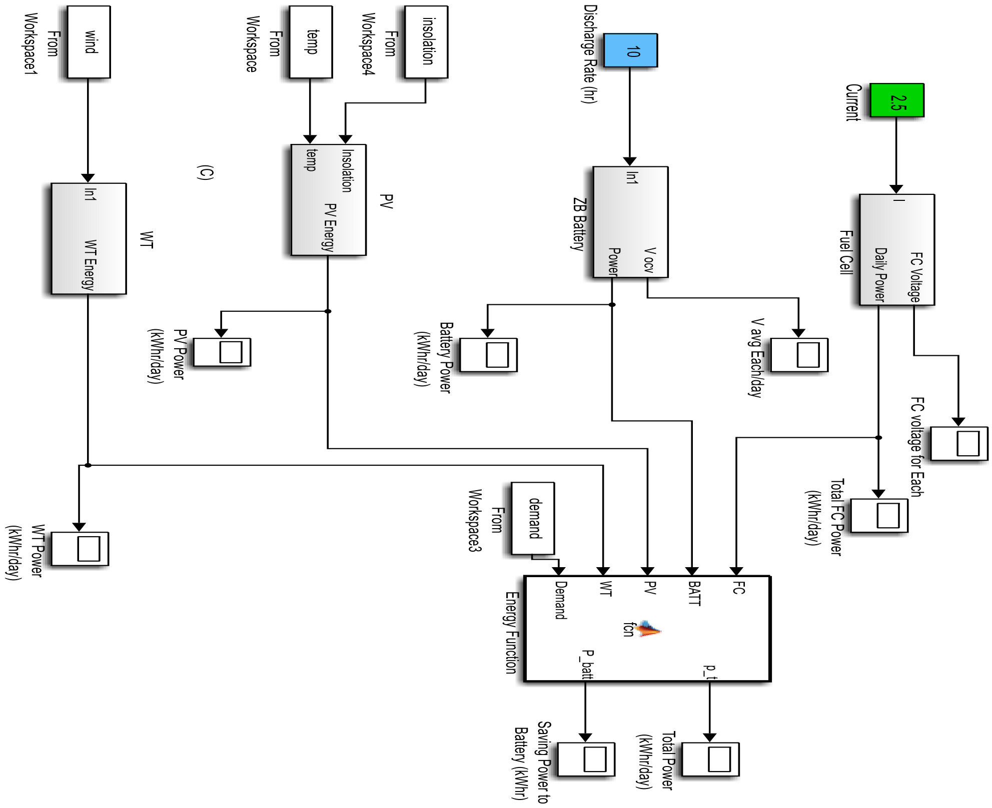
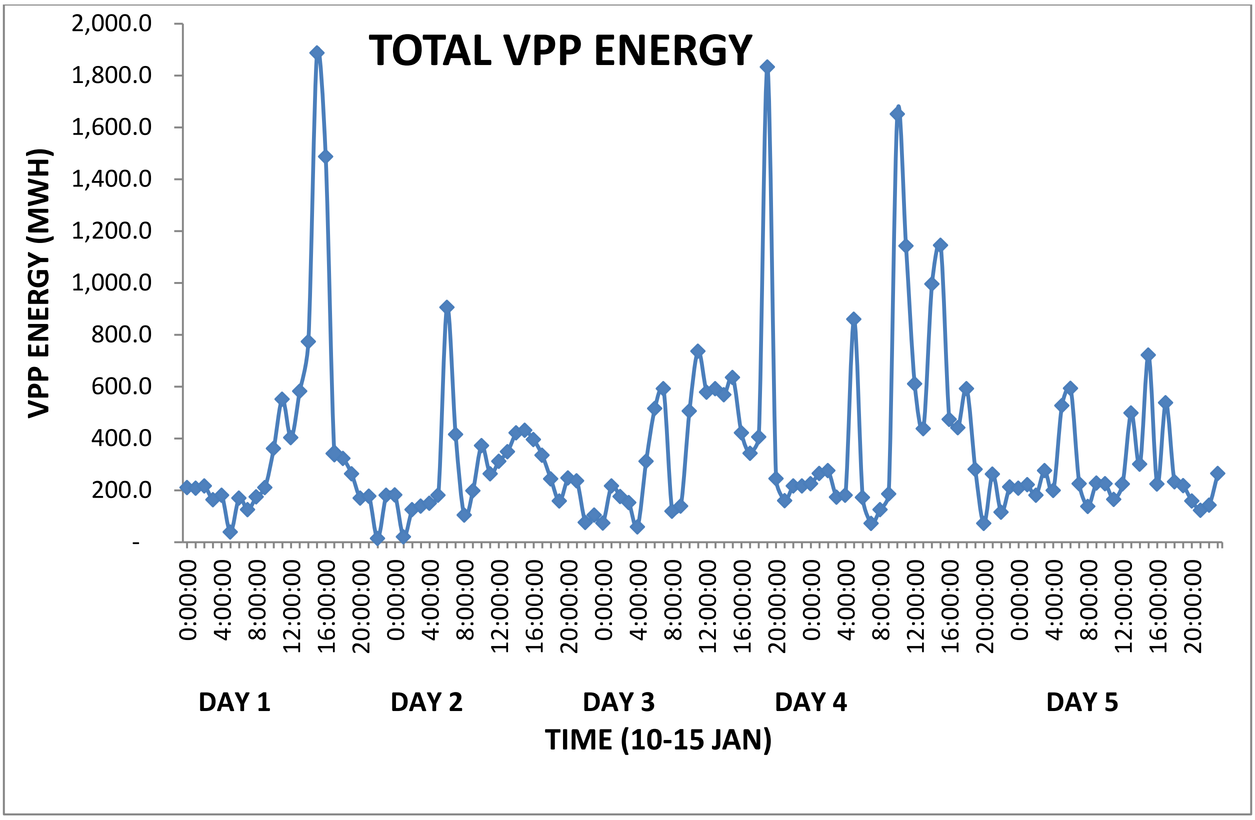


FIGURE 3.11.THE FLMVPP SYSTEM



GRAPH3.6.OUTPUT POWER OF THE FLMVPP SYSTEM FROM 10-15 JAN

Furthermore, in case of there is not enough wind or sun during the day, the system will use battery's stored power to compensate the demand by providing enough power to the grid. In this research study, it is assumed that in Melbourne there are not enough wind and sunshine for three days of the year. In this scenario batteries provide the amount of electricity that is needed to meet the demand. In this system, the FC system considered as a system back up, as in a large scale power grid using a large capacity fuel cell system is not safe as hydrogen gas is flammable and storing it as a FC fuel in bulk is not safe and reliable.

3.5 Information Layer

The proposed FLMVPP system emulates various activities in a VPP system. Exchanging information among different components of a VPP is an important aspect for any VPP's operation [61].The IL models how control and monitoring data flows over the communication network connected to various energy generating resources; which are modeled in the PL. The IL provides useful information through layers such as load and electricity demand for the whole network by interconnecting all elements in MATLAB software. Afterward, the output power of the VPP is calculated by considering the data for each element and information exchanged among different elements in the FLMVPP system. The output of this layer is used as one of the input data for the next layer which is the Control layer (CL).

3.6 Control Layer

The Control Layer (CL) is used to control the operation of the other layers. Optimal control of a VPP is crucial to minimize the costs of generation from renewable resources, and at the same time maximize utilization of the available energy; this could be achieved by managing energy balance obtained via an optimal dispatch methodology. To tackle this target control models and algorithms developed to optimize the operation of a VPP system, thereby making the VPP concept a profitable reality [2, 18].

In this layer a new control scheme have been proposed. The combined control scheme (CCC) have been modeled and developed to control and coordinate the system's operation as well as eliminate the various weaknesses of the individualistic control schemes. As outlined previously in section 2.10, the CCC is the combination of price signal control and direct load control scenario in this research study. This approach has been applied to the system by using an appropriate algorithm technique in the next layer, OL .More details of control scheme are stated in chapter 4.

3.7 Optimization Layer

Controlling a large number of geographically dispersed DERs in a large VPP network is a daunting challenge, vis-à-vis safe, reliable, and effective operation. Optimizing the operation of a VPP system can be done by choosing a suitable algorithm technique. There are many different techniques of algorithm such as: Fuzzy Logic (FL), Artificial Neural Network (ANN), and Expert System (ES) [62]. In my study the ANN is considered as an optimization algorithm technique. The reasons to choose ANN are:

- High level of accuracyfor load forecasting
- Learning ability and adapts to the data
- Easy computing
- Capability to solve complicated and non-linear problem
- Capability to process uncertain data

The technique is used to optimize the dispatch of controllable generators in order to track the production of intermittent sources and in that way make a VPP system to achieve desired output [63].This research study proposed a possible research solution to control the FLMVPP system using an appropriate algorithm technique to cope challenges caused by using individual control scheme. The ANN tool is available in MATLAB-Toolbox. By choosing a set of suitable data, the ANN is modelled in MATLAB software. Further details are explained in chapter 5.

3.8 Human Behavior Layer

Variety of social, political, and cultural aspects such as habits and technology affect human behaviors. This can add more complexity to the decision making behavior in human beings [63]. Human behaviors are influenced by the price of products, awareness of issues, trust on providers of information, and commitment to change.

3.8.1 Influences on energy behavior

Improving energy efficiency is the most cost effective technique to limit the universal warming. “It reduces demand, thereby reducing the cost of using energy services, and improves the security of energy supply”[63]. Humans and their attitudes is one of the main factors that affect energy usage patterns [51].Humans make decisions based on their personal actions, knowledge, abilities, and sometimes emotions. Emotions may affect the decision making by changing he insight of people about the environment and future [51].

Furthermore, the energy consumption decisions are not so complicated and do not require a lot of cognitive abilities, these often become embedded behavior patterns that are influenced by factors such as cost, comfort and environment [63]. Changes in consumer behavior can lead to vital saving in energy consumption such as: turning off the light when leaving the house or switch off some unnecessary appliances during peak time. Behavioral change can lead to more effective energy usage [63].To make decisions that maximize energy generation through renewable sources, consumers require market information [51, 63]. The regulation of Demand Side Management (DSM) of electricity is another factor that influences consumer’s behavior. Recently, the proponents of DSM have recognized its potential to change the pattern of energy usage, leading to demand reduction through behavioral change [51].Furthermore, using smart meters also give people an opportunity to be aware of electricity consumption by tracking electricity usage. They are able to reduce load at peak time by switching off some appliances like washing machine or air conditioning to avoid shocking bills.

3.9 Summary

A FLMVPP has been introduced in this chapter as a new modeling technique for simulating a VPP system. Using this technique gives a better understanding of the system operation as well as a clear separation of the function of each layer by adding flexibility to the system. In other word, each layer is separated from others and has its own function which makes the modification of each part easier. Therefore, there is no need to modify the whole system; only by plug-in or plug-off of each component the modeling system can be modified.

These five layers consist of PL, IL, CL, OL, and finally HBL. At the top layer, PL, each component of the VPP systems is modeled based on mathematical formula in MATLAB-Simulinkand results is transferred to the next layer by considering some information such as load and demand of the system. In layer three an appropriate control scheme is defined to control energy balance between supplier and consumer following by choosing an ANN as an optimization algorithm in layer four.To optimize the operation of the proposed FLMVPP an ANN algorithm technique is considered. The details of ANN algorithm is presented in chapter 5. Finally, at the top layer the HBL and people’s respond to price changing is briefly defined.

Chapter.4 Combined Control Scheme of a VPP

4.1 Introduction

These days different factors lead to uncertainties of power plants generation, such as technical limitations which is imposed mostly by power plant itself, the unstable power prices which make a problem to optimize the power generation [13]. From this point of view, the only difference between VPP systems and conventional power plants operation is the amount and type of data that is available to operators [13, 64].Controlling renewable energy systems require developed methods for high-performance and reliable operation. There are two main techniques that must be considered to aggregate DERs and controlling of a VPP system.

The objective of controlling a VPP system is to minimize the overall cost of the renewable system as well as providing the energy supply of every DER by using suitable methods [1, 13, 15, 18].These methods referred to as direct control and indirect control method (also known as price signal control) which is explained in this chapter.

4.2 Direct control

As stated previously in chapter two, distributed generation systems and controllable demand play an essential role to take a part in energy markets and also provide auxiliary services to system operators. However, integrating of these resources into power system requires a major change to the current control structure network [1,64,65]. This challenge can be met by using VPP system, which is based on DERs' aggregation, storage system, and demand to create an operating system [18, 65].DERs features are increasing the visibility and manageability to the system operators, as well as optimizing the generation and maximizing the profit opportunities of the renewable generation system. A DER equipped with a local controller to operate individually which is able to estimate the production/consumption of active/reactive power as well as remote controlled by receiving information from an external controller which allows aggregator to adjust the DER's flexibility [1, 13, 15].

A Direct control scheme is a two-way communication between VPP and DER sunder this scheme the operator of a VPP requires sufficient information for every single DER participant and their locations. These information help VPPs improve market-based decisions by characterizing the generation, as well as regulate its generation in real-time more accurately [13, 15].

In this method, VPP operators have direct access to DER participants, by assuming that the information and data communication are always available from/to the distributed system operator (DSO). By utilizing this data communication the DSO would be able to develop distributed power resources as well as exchange power within high voltage grid throughout the DSO's lines for the VPP system [1, 13].

Under this scenario the DER reports some information such as its local context to the VPP and the VPP operator controls the DER based on this data. Moreover, direct control scheme is based on an agreement between DER prosumers and the VPP to schedule the generation and consumption of each DER [1, 15].

In VPP systems the direct controlled strategy is operating same as in conventional power plants. A major drawback of this scheme in a VPP system is that is not suitable to use when a large number of DERs are aggregated [1, 13]. In other word, the VPP operator is not able to make a real-time decision under this scheme as informational and computational load will be quite heavy during the decision making process while DERs are waiting for commands. To model a direct control scheme in this study some variables such as cost of each element in VPP system is considered to optimize the operation of a VPP system. This model with more details is explained in chapter 5 along with an appropriate control algorithm [1, 15, 18].

Despite of the direct control method, the indirect control scheme is more about one-way signal that is sent from VPP operator to DER without any direct response from the DER prosumers [1]. More details of price signal control is explained in the following sub-section.

4.3 Price Signal Control

In early 1980s, “spot pricing” was developed by Fred C. Schweppes. The spot price which is also known as real-time pricing is developed based on energy marketplace and reflects the operation and capital costs of generation, transition and electricity distribution for a particular period of time. Later on, the topic of price signal control of power systems motivated parties in power system society such as utilities, system, and market operators. This method is based on clearance of a liberalized electricity market [1,13, 18].

Furthermore, the market clearing price is initiated based one quality between quantity of generation that is provided by suppliers and the quantity of consumption that is used by consumers. Indeed, both supply and demand act independently by responding to price changes according to their own price flexibility .In case of changing market price, the balance between supply and demand will be changed which states the probability of price signal control [18, 30].

4.3.1 Controlling power generation

The supply side in an electricity market is a number of generators based on different generation technologies. Since a single generator produces small power compared to the size of the market, its generation would not have serious effect on market price [24, 66]. Since all generators are capable of delivering electricity at any given time at the price which makes generation profitable, the decision making process can be considered by maximizing the difference between the revenue resulting from the sale of the power generated and the cost of generation. In fact, a big changing to electricity price will affect the decision made by suppliers [51].

The price responsiveness of a generator shows how suppliers respond to different market prices. Indeed, the spot pricing is correlated to some factors such as: cost of operation and technical issues which make generation difficult to control with price signal [13].

In this regard, some research studies have been done to investigate these possibilities from the perspective of independent system operator (ISO)by addressing some issues which occurred by using price signal control which are as follows [12, 13, 18, 25]:

1) The ISO can control the operation cost optimally by dispatching proper price signals based on his knowledge over cost operation. In fact, the ISO can get this knowledge by having adequate information about generators' respond to price signals when their operation cost is unknown.

2) Delays within system known as response dynamics of price signal control which is caused by either the price makers or generators. Eliminating delays is inevitable,

however by choosing an appropriate time cycle to adjust price, an optimal response would be gained by changing sequence of prices.

3) It is difficult for ISO to predict the generators' response to dispatched price signal when the operation costs changing over the time. There are two solutions to cope this challenge. One way is to find out more about cost structure of generator's model and related parameters. The second one is using feedback observations to identify which generator has non-stationary costs and when the data is updated, reassesses the price signal.

4) Under price control scheme, the generator keeps its capacity and waits for a higher price to make bids and offer into a market power. The consistency between predicted and actual behaviors for price-taking generators must be checked to identify the market power. So, it is important to integrate the market monitoring system into the price signal control method.

4.3.2 Controlling the demand side

Using time-based pricing to control electricity consumption in response to supply conditions and achieve more elasticity from demand side is widely used by utilities for many years. Time-based pricing is also called Time-of-Use (TOU) prices and dynamic prices. It determines for specific time of the day such as: peak shoulder and off-peak with the rates that adjusted few times per year. For example, throughout the whole season the price in a specific period of the day is same [13, 51].

Despite of pricing scheme some large consumers such as industrial and commercial usually adjust their consumption to the TOU prices. In doing so, they would be able to increase the price flexibility on demand side by changing the load from peak-time to off-peak periods. Dynamic prices, change more frequently compared to static prices. There are two different types of dynamic price methods that use more often; Critical Peak Pricing (CPP) and Real-Time Pricing (RTP) to support the demand elasticity and capture the electricity market changes [1, 18, 67].

In a limited time throughout the year, the CPP let the retailers state the high retail price for critical peak hours. Under this program, when the peak prices are approaching the consumers will be notified. The CCP can be any value to get the desired amount of load reduction as it is not the market value of the power. To increase the demand side elasticity and reasonable reduction of annual electricity bills for customers, it is better to utilize the CPP as it is more effective than TOU [27, 51].

As stated above, the second dynamic price scheme is Real-Time Pricing. By using this method the retail price can change in shorter time intervals that would be from a few minutes to a day. Indeed, the prices is more accurate when the lag time between dispatched and real-time price is short that shows the real condition electricity market and power system operation. Practically, the RTP can be utilized unaccompanied(one-part tariff) or with a standard energy price (two-part tariff).It used marginal generation cost of that moment when applied alone while the two-part tariff used by utilities that customers load is formed based on their historical load prior to RTP. The base line load will be charged at standard electricity rate and the difference between hourly and baseline load will be priced at RTP [12,13, 51].

Moreover, the real-time price in both cases must be calculated and dispatched before finalizing all computations to motivate customers responding to different price signals.

In doing so, retailers must have more accurate load forecast based on historical price responsiveness to reduce the error as much as possible. Retailers should add some expected revenue or costs used for false risk to RTP to make the higher value of it, even though to meet the real-time demand the RTP should be the real-time marginal generation cost. Furthermore, one advantage of using the RTP is to increase the demand side elasticity while reducing the electricity bills for consumers [12, 13, 18].

4.3.3 Price responsiveness of Distributed Energy Resources

As stated previously, DER is also controlled by price signals and there is no difference in conventional power plants. Although the control algorithms implemented by DERs manufacturers, in different DERs technologies, the short-term economics and price responsiveness are closely related. Furthermore, each DER technique has different price responsive characteristic that is classified into [5, 13, 18]:

- Cost based response like small generator which depends on some factors such as fuel price and efficiency of generators.
- Users' willingness such as freezer that users can switch consumption from peak load to off peak period.
- Intermittent resources like wind turbine and PV systems response to any price signals due to low operation cost.

Under this method some information such as price signal, generation of DERs and local demand will be recorded for calibration and prediction of the model that improve the accuracy of the model [13].

Compared to the direct control technique, the challenge for price signal control operating is more about uncertainties of price responsive of DER groups as well as the accuracy of the model [1, 13, 15].Variable must be considered to optimize the operation of a VPP, drawback of using price signal control individually.

4.4 Combined Control Scheme

Combining different types of dispersed resources as a VPP, lead to reduction of maintenance and operation costs of the system and increase the efficiency. To maximize the generation of the VPP and minimize the cost of generation from renewable resources an appropriate control method is needed. Many studies have already been completed, and various control models as well as optimization algorithms have been developed to optimize the operation of a VPP [12, 18]. In doing so, controlling and managing the generation and trading portfolios in a VPP are crucial to achieve the successful outcomes that would enhance the attractiveness of the VPP concept leading to the greater uptake of this technology [7, 14, 68]. This would also make it possible to scale up the implementation of renewable energy systems giving them recognition and equal status in energy sector investment processes.

4.5 Summary and discussion

Major contributions to knowledge is made here as the developed control algorithms are a blend of those used in the marketplace and thus the various shortcomings of individual control approaches have been eliminated. As stated earlier in this chapter, using the individual schemes separately, lead to some challenges [9,13,24]. The main control challenges are:

- Uncertainties about load forecasting that cause extra balance cost

The power system balancing process, which includes the scheduling, real time dispatch (load following) and regulation processes, is traditionally based on deterministic models". Load and weather forecasts are unquestionably used in planning studies and such studies often only use their mean value statistics and do not consider the possible deviations from these mean values. Hence, to achieve a reliable system the predicted uncertainty ranges must be included into the scheduling, load following, and, in some extent, into the regulation processes network [9, 24].

- The need to consider the contractual relationship between DERs and the VPP

Indeed, the regulations and contractual relationships between different participants must be revised to enhance DER contribution to the network with a fair economic return [2,13,22].

Therefore, a good solution to handle these challenges necessitates the use of a combined control scheme to give the VPPs' participants a freedom of choice when making a decision for their operations, hence eliminating these weaknesses [13,22, 31]. As satiated previously in chapter three, in this study some elements such as WT, PV, fuel cell system and battery storage system is aggregated to form a VPP system in MATLAB-Simulink. A combined control scheme is used in this study to optimize the operation of a VPP.A hybrid control scheme is considered and modeled in chapter five by using an appropriate algorithm technique to overcome some challenges that outlined above.

Chapter.5 Optimization the operation of a VPP using ANN algorithm

This chapter outlines some theories of Artificial Neural Network (ANN) as well as the FLMVPP system modeling in MATLAB based on an appropriate algorithm technique. In this study the ANN is considered as an algorithm technique to optimize the operation of the FLMVPP system. It is essential to describe the network topology, activation functions between layers, and training algorithm to model ANN algorithm. These definitions are explained in the following subsections.

5.1 Introduction to ANN system

Optimization helps the operator to keep the network at high efficiency. It can be done by maximizing the desired factors such as power output as well as minimizing undesired one such as cost of generation under different constraints [12]. Furthermore, in power systems there are some different problems that are not possible to solve using conventional methods; as these techniques are usually based on some conditions that may not be accurate all the time. In doing so, Computational Intelligence (CI) or Artificial Intelligence (AI) methods are the only choices while these are not limited to these applications [69]. The AI is a new technique used for complex problems that are difficult to be solved by conventional approaches. As this technique is so flexible, it can be applied to different kind of constraints and objective functions. Using this method to develop solutions presents some advantages such as: shorter development time than conventional method and very robust systems [69].This method is used in this research to optimize the operation of the FLMVPP by utilizing an appropriate algorithm technique. There are various types of algorithm techniques in power system area such as Fuzzy Logic (FL), Artificial Neural Network (ANN), and Expert System (ES). Different algorithm techniques with some advantages and disadvantages of each technique are depicted in Table 5.1 [69].

FIGURE 5.1. DIFFERENT ALGORITHM TECHNIQUES COMPARISON

Technique	Advantage	Disadvantage
Fuzzy Logic (FL)	Easy modification Steady state in a shorter time Convenient user interface Easy computation Widely available tool box No need for execution method	Each parameter affects the other one More computation involved Difficult to define exact rules
Artificial Neural Network ***(ANN)***	Do not require apriority knowledge of system model, Fast and robust learning ability and adapts to the data, Easy computing very useful in solving the nonlinear Problems	Large dimensionality not scalable
Expert ***System (ES)***	Prepare plan, analyse, manage, control and operate various aspects of power generation, transmission and distributions systems Load, bid and price forecasting	Permanent and consistent. Easily transferable or reproduced. Easily documented. Natural knowledge representation. Separation of knowledge from its processing

As it stated previously in this thesis the ANN algorithm technique has been used. Furthermore, reasons to choose ANN are based on some features such as data adaptability, and high accuracy especially for uncertain data. The ANN is also available in MATLAB-Toolbox and by choosing a set of suitable data from previous layer the ANN can be modeled in MATLAB software.

5.1.1 ANN Topology

The ANN network consists of a large number of processing elements called nodes or neurons connecting together via specific network architecture while operating in parallel. The connection link between input and output is associated with weights that contain information of input signals. Furthermore, the neural network tasks can be summarized as control, classification, prediction, and approximation that can be reformulated in general as function approximation [13, 70].

The function approximation is described as a set of function to build ANN architecture in order to estimate the value of inputs. The basic model of ANN structure is illustrated in Figure 5.1.In this structure, X_1,X_2,…, X_n refer to inputs, Y represents output, and W_1 ,W_2,…,W_n show neurons' weights which are connected to other neurons via direct links [70]. In fact, weights contain information of input signals and are represented as a weight matrix which is also known as a connection matrix. In other word, all those inputs, neurons and outputs are structured in layers that consist of a number of interconnected nodes with an activation function; each neuron contains a function of inputs that neuron receives. In this structure, Patterns will be connected to network via input layer by communicating to one or more hidden layers. In this layer, the actual processing would be done via weighted connections system. Consequently, the hidden layer will be linked to final layer which is the output layer. In other word, the aim of using this method is to transform inputs into meaningful outputs by optimising the amount of available resources [70].

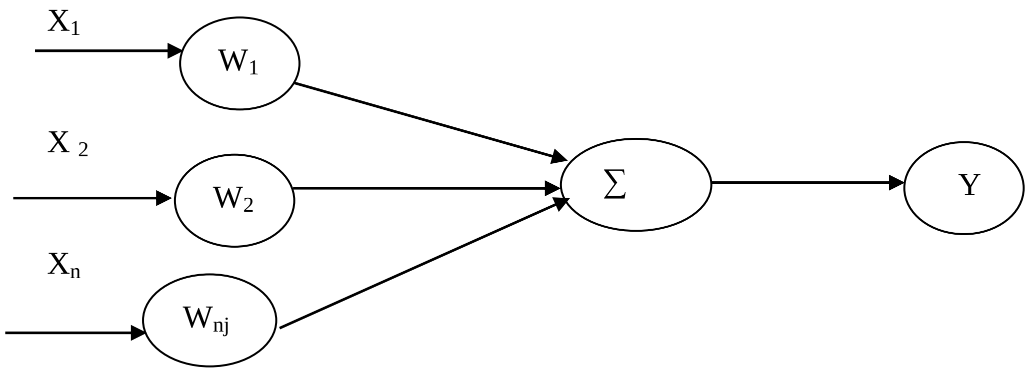


FIGURE 5.2.BASIC MODEL OF ANN

Each layer of the ANN network is explained in detail in the following subsection.

5.1.2 Input Layer

As stated previously, each layer in an ANN architecture system has its own specific function. The input layer in this method is the number of input signals from outside world by sending them to all neurons in the hidden layer [13, 70]. A number of variable values will be presented to the input layer. Subsequently, it will be standardized these values and distributes them to each neuron in the hidden layer.

In addition, to have a more flexible and accurate pattern it is important to provide as many input data as possible. The input layer does not process input patterns as it does not have computing neurons [13].

5.1.3 Hidden Layer

The middle layer in ANN network is called hidden layer. The ANN architecture could comprise of as many hidden layers as required [13, 70]. A single hidden layer is sufficient for classification problems, while the two hidden layers where the sigmoid transfer function is used for all neurons are enough to compute an arbitrary function of the inputs. It is essential to utilize an appropriate ANN network structure as it is so sensitive to number of layers and neurons. In this study a network with three-layer architecture is considered and modeled; two-hidden layer with one output layer [70].

5.1.4 Output Layer

This layer establishes the output pattern of the entire network by accepting a stimulus pattern from the middle layer. In addition, as the output layer corresponds to the number of output variables, so it is easy to find out how many neurons should be in the output layer [13, 70].In this study, the number of neuron in the output layer is one, as there is only one output variable is considered to model ANN in MATLAB software.

To determine the input-output relation in ANN network the activation function of this structure is needed to be defined.

5.1.5 Activation Function

The activation function which is also known as transfer function determines the relationship between input and the output neurons by connecting weights of neurons to the input while representing the activation of the neuron [13, 70]. It also determines the computation processed by a neuron and the output function associated to the overall activity that is transferred to the next neuron in the processing stream. There are many applications for activation function in the ANN network. Some of the most common applications are as follows [69, 70]:

- To calculate the output response of a neuron
- Sum of the weighted input signal

The transfer function which has been applied in this study is sigmoid function.

5.1.6 ANN Training Algorithms

To get more accurate and appropriate outputs with minimum errors the ANN algorithm needs to be trained. Training algorithm makes it become more experienced over each epoch. In addition, the ANN will be trained by logical methods to adjust weights of neurons [69, 70]. One of these methods is a propagation training algorithm which is also applied in this research study. This approach is a part of supervised training where the appropriate output is given to the algorithm by applying adequate iterations. In fact, after each repetition the internal error rate will be improved as each iteration loop through the training data. The Internal error rate is a difference between the desired output and the ideal output provided by the training data. Consequently, weights will be re-calculated for each array of the training set and adjusted at the end of the iteration.

Furthermore, the propagation method would be used only with derivative activation functions as a need of calculating the gradient to each neuron connection through ANN [69, 70].In the below sub-sections, two types of training algorithms comprising propagation method are described.

5.1.6.1 Supervised learning

The supervised learning algorithm which is also known as feedback algorithm provides a feedback if the computed output of the network is correct. In this type, a set of ideal output is required to calculate the desired one. The aim of applying this algorithm is to adjust weights of neuron at each epoch to minimize the error. There are some types of supervised algorithm such as Back-propagation, Manhattan update rule, and Levenberg-Marquardt technique [69, 70].

5.1.6.2 Unsupervised learning

Unsupervised learning algorithm is used as a self-organization technique by organizing data through the network while detecting them from developing similar resources. Furthermore, it is important to design an appropriate network so that an ANN network is able to learn tasks with independent criterion more accurately. In this technique, weights will be modified concerning independent criterion. There are various types of supervised algorithm such as Hebbian rule and Self-organizing rule [70].

5.1.7 Applications of ANN to Forecasting

There are many studies have been done on forecasting applications to achieve more accurate results.An accurate load forecasting has a great potential on producing energy as forecasting is widely used in the energy supply chain these days [13].Furthermore, a large number of methods have been analysed to achieve more precise data due to the economic impact of accurate electricity on load prediction. Based on studies have been reported by Bunn and Farmer, the increasing of one precent in load forecasting error in the British system caused a loss of 10 million pounds per year [13, 70].

Comparative studies have been done so far, showed that ANN algorithm successfully applied in a wide range of forecasting problems. Consequently, Moshiri and Brown proved in their study that ANN based models outperform the autoregressive models more accurate than other forecast models [70].Based on these studies, and the requirements set in section 5.1 the ANN technique is used in this study to optimize the operation of a FLMVPP. In doing so, the required data and output which are applied in ANN system in MATLAB software is described as follow:

5.2 ANN Modeling in MATLAB

To identify the combined control scheme of the FLMVPP system, **ANN** technique with three layers has been developed. The input-out data for identification are detailed in the following sub-section:

5.2.1 Preparing the training data set

The aim of applying the ANN technique to the FLMVPP system is to find the proper values for neurons and weights to minimize the error between the identification data and the output of the network. In this research study, the technique is used to train the system is Back Propagation (BP) training method. This method is used to adjust weights between neurons. As stated earlier in this chapter, this network has been claimed quite powerful to solve multifaceted problems [18]. In this study, the ANN toolbox of MATLAB-R2015b is used to run the model.To do so, the input data and target have been used to model in MATLAB software based on ANN algorithm is determined as follows:

- Target: total electricity generated from the FLMVPP system is applied as target in ANN system which is collected from simulation run in chapter 3.
- Input 1: historical price which is applied as input data in ANN collected from AEMO website.
- Input 2: historical demand profile for western suburb of Melbourne. This data is also collected from AEMO to apply as input in this network.
- Input 3: the revenue from sailing electricity generated from the FLMVPP system. The profit is assumed as a difference between sale of electricity and the

cost of energy generated by the FLMVPP system. The formula is stated as follows [13,18]:

- $Cost_{FLMVPP} = \sum_{t=1}^{T} Cost_{VPP}(t) = \sum_{i=1}^{N} e_{FLMVPP}(t).\pi_{FLMVPP}(t)$ (5.1)

Where, e_{FLMVPP} is electricity generated by the FLMVPP system, and π_{FLMVPP} is the cost of energy generated by the FLMVPP system. Then;

$$\sum_{i=0}^{n} e_{FLMVPP}(t) = (e_{WT}.\pi_{WT}) + (e_{PV}.\pi_{PV}) + (e_{FC}.\pi_{eFC}) + (\pi_{ZBB}) \quad (5.2)$$

Where, e_{WT} is energy generated by WT, π_{WT} is cost of electricity generated by WT, e_{PV} is energy generated by PV, π_{PV} is cost of electricity generated by PV, e_{FC} is energy generated by FC, π_{eFC} is cost of electricity generated by FC, and π_{ZBB} is cost of electricity stored by ZBB in case of energy exceeded.

$$profit = \max[\pi.p - cp] \quad (5.3)$$

$$\pi.p - cp > 0 \quad (5.4)$$

$$p_{\min} \leq p \leq p_{\max} \quad (5.5)$$

Where, p is the power generated by the FLMVPP system, π is the price of electricity sold, and C_P is the cost of electricity produced by the system.

Constraints: $P_{Load}(i) = P_{W.T}(i) + P_{P.V}(i) + P_{fc}(i) + P_{ZBB}(i)$ (5.6)

The constraints should be met on each hour.

The objective function of the optimization is to maximize the revenue of the FLMVPP system which stated in Equations (5.1) to (5.6). Hence, by maximizing these equations the profitable generation will be achieved. To calculate this formula, the cost of electricity generated by each component in the FLMVPP system is calculated as follows:

5.2.1.1 Cost of the generation from the FLMVPP system

As stated previously in chapter 3, the FLMVPP system in this research is consisting of four different elements which are Wind Turbine (WT), Photo Voltaic (PV), Fuel Cell (FC), and Zinc Bromine Battery (ZBB) systems. In this section, the cost of electricity generated by each element of the FLMVPP system is defined and calculated to apply in ANN network.

5.2.1.2 Cost of the electricity generated by solar farm

These days PV markets are increasing quickly worldwide including Australia. Australia's dry climate and latitude gives a potential to produce solar power. Most of the Australian's continent, in the north, receives almost 5 kWh/m^2 daily radiation even during winter [59]. As Australia is the sunniest continent on the earth planet, it receives more sun energy than European countries. According to the Bureau of Meteorology BOM website, as one of the good sources of solar data in Australia, the Northern Territory and Western Australia have the best solar exposure. Furthermore, the annual sun exposure in Melbourne is 1500kWh/m^{2}and 2200 in Brisbane, while it is 1100 kWh/m^{2}in south of Germany and 800 kWh/m^2 in north Germany [59].As stated earlier in chapter 3, one of the most important factors to produce electricity by PV system is a location of installation which determines the economics of PV power production. PV systems and solar parks could be located close to infrastructure, forests and houses since they are virtually silent with a very little risk to flora and fauna. In

Victoria, the largest solar farms are situated in Bendigo and Ballarat with the capacity of 300 kW, while each farm provides enough solar power to 150 households. These are Australia's largest ground mounted, grid-connected solar [71].

In this study, 450solar systems are modeled in Physical layer (PL) from the FLMVPP system to form a solar park. To optimize the operation of the system, the cost of the modeled solar park must be calculated.

The determined factors have been calculated from the following equations [38]:

$$\text{Electricity price} = \frac{\text{ALCC in \$}}{\text{Total electricity production in one year (kWh)}} \quad (5.7)$$

Where;

ALCC (Annualized Life Cycle Cost) = LCC/P_a (5.8)

Where; LCC (Life Cycle Cost) = Sum of all present worth (PW) and

$$P_a = \frac{(\mathbf{1}-\mathbf{X}^{\mathbf{n}})}{(\mathbf{1}-\mathbf{X})} \quad (5.9)$$

Where; n is the system's life time is assumed to be 20 years.

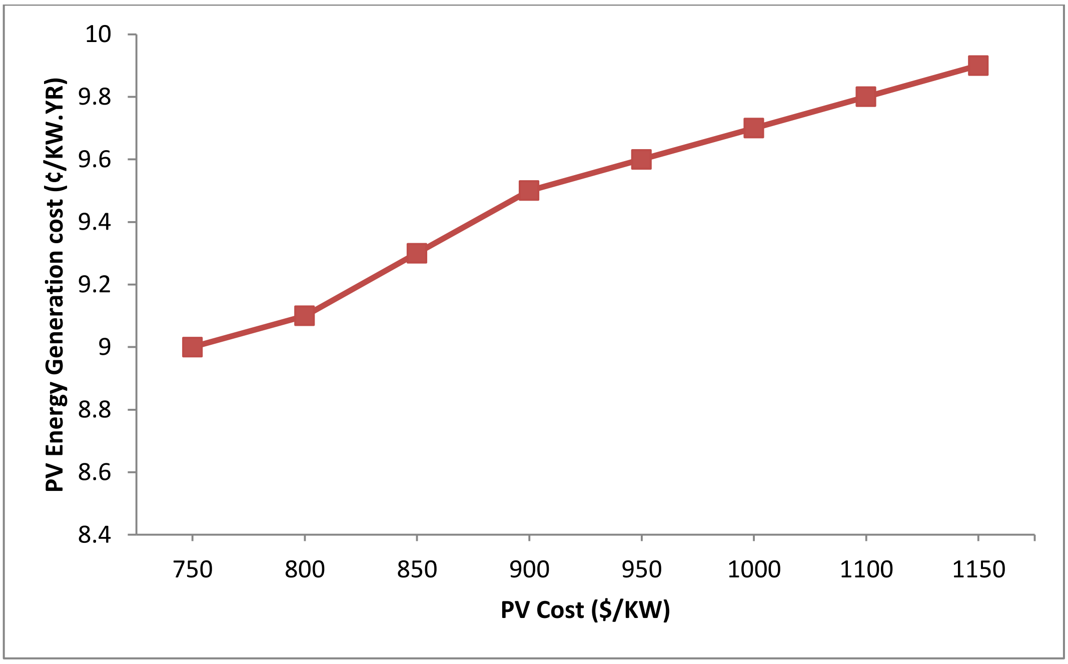
$$PW = (P_a \;) * \text{ (Cost of an item, which is needed in the beginning of each year)} \quad (5.10)$$

$$X = \frac{(1+i)}{(1+d)} \quad (5.11)$$

Where; i is an inflation rate: =3%, and d is discount rate: =4%

$P_{a1} = \mathrm{X}\ \mathrm{P_a}$ (5.12)

The capital cost of the PV system is considered in a range of 750-1250A$ per kW since the solar system cost in the market is variable. Based on Balld Hills wind farm report the price of energy generated by PV farm system is 90-100 A$ per MWh (9-10 cent per Kwh) [72]. The above parameters and equations have been calculated and imported from excel software. The cost of electricity produced by PV farm in the FLMVPP has been shown in Graph.5.1.



GRAPH 5.1.COST OF POWER GENERATED BY PV SYSTEM

As shown formerly in chapter 3, 450 PV systems with a capacity of 200kWhave been modeled in MATLAB software to form a PV Farm (PVF). As shown in the simulation in chapter 3,the power produced from the PV farm is 1.76*10^6 MWh per year. Therefore, the total cost of power generated from PVF in the FLMVPP system, is:

$$(90\sim100) * 1.7 * 10^6 = (153\sim170) * 10^6 \quad \text{A\$ per MWh per year} \quad (5.13)$$

The results indicate that the cost of PV electricity in Australia is a way too expensive from other conventional sources. However, the new subsidies program from Australian government helps to short the gap between PV and conventional electricity cost [39].

5.2.1.3 Cost of the electricity generated by wind farm

Wind power is exceptionally growth all over the world and turbine machines have been changing to more power full and efficient systems during the past decades. Australia is one of the good examples by having the wind installed capacity from 1300 MW in 2008to 4187 megawatts in 2015as there are so many good wind sites throughout the country [73, 74]. Although, the power of new machine has increased by having higher hub heights and locating in a better wind site, the corresponding capital cost dropped as the cost of the rotor is proportional to diameter while the power delivered is proportional to diameter squared [34]. The cost of electricity generated by a wind machine is calculated based on the following Equations:

$$\text{Electricity price} = \frac{\text{ALCC in \$}}{\text{Total electricity production in one year (kWh)}} \tag{5.14}$$

Where; ALCC (Annualized Life Cycle Cost) = LCC/P_a (5.15)

Where; LCC (Life Cycle Cost) = Sum of all present worth (PW) and

$$P_a = \frac{(1-X^n)}{(1-X)} \tag{5.16}$$

And,

$$PW = (P_a) * (\text{Cost of an item, which is needed in the beginning of each year}) \tag{5.17}$$

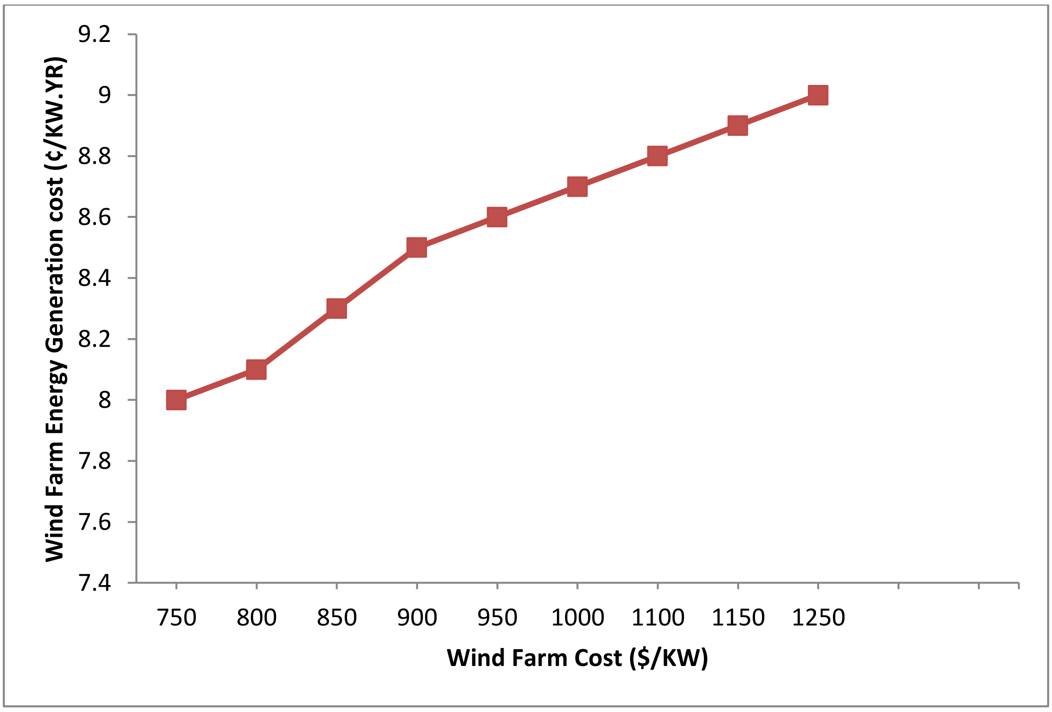
Where;

$$X = \frac{(1+i)}{(1+d)}$$ and n is considered as a system life time. (5.18)

Where; i is an inflation rate: =3%, and d is discount rate: =4%

$$P_{a1} = X\,P_a \qquad (5.19)$$

In this study, to calculate the capital cost of the wind system, the price of a system is considered in a range of 750-1250 A$ per kW since the system cost is variable in the market. Based on Balld Hills wind farm report the cost of energy generated by wind farm is 80-90 A$ per MWh (8-9 cent per Kwh) [72] which is shown in Graph 5.2.



GRAPH 5.2. COST OF THE POWER GENERATED BY WIND TURBINE

As stated previously in chapter 3, to model a FLMVPPsystem,60 wind turbine machines with a capacity of 2000kWis modeled in MATLAB environment to form a Wind Park

(WP).As the WP generation in this system is 1.6*10^6 MWh per year. Therefore, the total cost of power generated from WP in the FLMVPP system is:

$$(80 \sim 90) * 1.6 * 10^6 = (128 \sim 144) * 10^6 \quad \text{A\$ per MWh} \tag{5.20}$$

This result has been considered in the next level as a data for ANN algorithm in MATLAB software. As shown in Equation (5.20) the price of wind farm is cheaper than PV farm and will beat the price of coal generation which is a remarkable achievement for Australia. As an example, in South Australia wind farms were producing around 33% of the state's electricity in 2016 and the last coal-fired power station finally had been closed [75].

5.2.1.4 Cost of electricity generated by fuel cell

The fuel cell technology generates electricity through electrochemical processes and in principle it operates like a battery though the FC system does not require recharging. In a FC machine energy will be produced in the form of heat and electricity as long as fuel is supplied [76]. Furthermore, it requires less maintenance parts since the system is compact, lightweight and has no major moving parts therefore [53].There are more Fuel benefits of applying FC systems compared to traditional power generators which as follows [76]:

- Fuel efficiency,
- little noise operation,
- No harmful emissions at point of use,
- easy to maintain
- high-quality heat generation

As stated previously in this section, FC systems run on hydrogen which is the simplest and most available gas in the universe. Although there is a large number of hydrogen in the earth, it is combined with other elements; oxygen and carbon. It can be extracted from any hydrogen-containing compound such as renewable and non-renewable resources. Fuel cell systems utilize hydrogen with almost zero polluting emissions by making it the ultimate clean energy carrier. Afterward, the hydrogen will be condensed, stored and transported from production site to consumers point. Hence, running a FC system through hydrogen production method is carbon emission free [57, 76].

It is worth to be noted that accurate equipment and procedures must be designed for the safe use of hydrogen as hydrogen is flammable gas and has the potential to react with oxygen in the air [57, 76].

Depending on type of the system and its design, a FC machine could reach to efficiencies more than 50 percent. Hence, such a system would be able to reduce the impact of power generation on global climate change by decreasing the amount of greenhouse gases [77]. Fuel cell power plant also operates in a wide range of power outputs, from few kilowatts to mega-watts. Furthermore, there are different types of fuel cell which are commercially available today such as: alkaline fuel cell (AFC), proton exchange membrane (PEM) fuel cell, and solid oxide fuel cell (SOFC). Each FC type has its own unique chemistry operating characteristics that defines its application [57, 76, 78]. The SOFC system is applied in this research study which is detailed in the following sub section:

5.2.1.4.1 Solid Oxide Fuel Cells

SOFC system that has been considered in this study operates at very high temperature; between 700°C to 1,000°C. High temperature operation reducing the cost of SOFC system as there is no need for precious metal catalyst which enables internal reformation of fuel. This system uses a thin layer of zirconium oxide as a solid ceramic electrolyte so it is a capable option for high powered applications such as: transportation, industrial as well as central electricity generating station. This system is also applicable for distributed generation, auxiliary power, and electric utilities. Integrating SOFC machine to the FLMVPP system make the system more cost effective and almost emission free [78].To supply fuel for FC systems, hydrogen can be produced from a wide range of hydrogen-rich material in different ways such as: steam reformation process of natural gas (roughly 48% globally), and biogas resources which is being more popular these days. However, cost of hydrogen production is variable as it depends on the production scale and innovation rate.

There are two common hydrogen production methods in Australia [79]:

- Steam reformation of methane
- Electrolysis of water

Currently the most cost-effective way to produce hydrogen is steam reforming. Although steam reformation of gas or coal lead to significant greenhouse emissions**,** the CO_2 produced through this process will be captured and sequestered to manage emissions in a practical and economical way.

The cost of natural gas is about two thirds of the hydrogen production costs, hence the cost of bulk production of hydrogen from natural gas follow changes in the market price of natural gas. There is a large potential to produce hydrogen in Australia since there are various low cost resources such as: coal, natural gas and renewable are available. The Australian Coal Association's initiative is aimed to reduce greenhouse emissions by realizing the potential of technologies such as coal gasification [79,80].

There is clearly some way to go before hydrogen delivered by any of the above means can compete with the cost of natural gas on a delivered energy basis. At current exchange rates the assumed cost of natural gas is equivalent to about $5/GJ, which is significantly below the cheapest option for hydrogen, namely $10-15/GJ for advanced on-site steam methane reforming [78,79,80]. The costs of natural gas and reformer operation are comparatively low. Consequently steam reformation of methane is currently the cheapest and the most common way of hydrogen production as there is no capital cost by using this method [78,79].

At the simplest level, the process is based on heating up hydrocarbons, steam including oxygen which is combined in a reactor in next step. Throughout this process, the component will be split up to water molecule and the raw material hence, H_2, CO and CO_2 will be gained. Indeed, the hydrogen gas comes from both steam and the hydrocarbon compound. A main drawback of using this method is the potential for sequestration of the CO_2 emissions from using fossil fuel sources. This applies to the continuous use of fossil fuel as well as the production of hydrogen from fossil fuels. Using sequestration helps to manage environmental emissions [80].

Moreover, Australia's substantial renewable energy resources, such as wind, and solar energy could be used in electrolysis method to produce electricity for the production of hydrogen. However, the keenness of the energy supplied in this way remains a fundamental issue.In this study to calculate the Cost of Electricity (COE) for a fuel cell three major factors have been considered. These factors are as follows [80]:

Capital cost: 3620$/kw

Fuel cost: $10-15/GJ

Operating and maintenance cost 10c per Kwh

Life time 10 years

The cost of electricity ($/MWh) can be calculated using the following Equation:

$$COE = \frac{.125cc}{\mathrm{H}} + \frac{3.412\mathrm{FC}}{\varepsilon_s} + \frac{\mathrm{O}\&M}{\mathrm{H}} \qquad (5.21)$$

Where 0.125 is a capital recovery rate (excluding taxes and insurance), CC is the capital cost ($/kW), FC is the fuel cost ($/$10^6$ Btu), 3.412 is the theoretical heat rate,ε_s is the fractional efficiency, H is the annual operating, and O&M is the operating and maintenance cost. Based on Blue Gen current energy cost delivered by SOFC is about 33 c per Kwh.

5.2.1.5 Cost of energy generated by Zinc Bromine Battery

Energy storage system plays an important role in a smart grid by allowing utilities to manage residential, industrial and commercial peak demand in a cost-effective way.

Zinc Bromine Battery (ZBB) system, has developed modular system architecture for over the last few years by Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO). This storage system has been considered as an extensive resource to power systems as diverse power sources and different types of energy storage to meet demands in peak load. Although ZBB storage system had been a poor market performer in the past few years, it is now given the proven status of its technology and low market capitalization. Moreover, it has limited drawbacks and more attractive advantages potential. By increasing the usage of renewable energy sources the ZBB system became more popular for being clean and smooth of intermittent renewable energy generation [21, 81].

These storage technologies are applicable for large scale-grid, grid support, distributed generation and renewable integration [81]. The main reasons to use ZBB storage system in this research are as follows:

1. The ability of 100 per cent charged and discharged per cycle: which distinguishes them from other types of batteries; a function that cause damages most other batteries' life.
2. In full charge or discharge status the system would be placed on standby mode: which performs without any damage to battery performance or life.

In fact, this storage resource acts as a pre-charged power generator and can be unattended even for months without taking place any self-discharge. During this period, even if the battery saves up to 80% of its State of Charge (SOC) the terminal voltage still can reach to zero volts. Another motivation behind this storage system that makes it so attractive is the potential of restarting in case of energy needed following by selfsustaining and supplying the entire energy stored. There are more key benefits of this resource which are as follows [21, 81]:

- full DC architecture,
- easy installation,
- ability to be interfaced with a range of available inverters,
- DC voltage of between 440V and 800V.

An efficient solution to utilize storage system is combining multiple storage systems connecting in parallel or series rather using individual one. This solution increases the efficiency of storage systems more than 80% while reducing the capital cost. Furthermore, incorrect optimization lead to increase the capital cost even more than double which refers to the discharge duration of the battery [21, 60].

In particular, integrating ZBB storage system with the FLMVPP system in this research influences the whole network by adding some benefits to the system which are as follows[82]:

- Reducing losses and connection costs
- Improving the network reliability, voltage, power factor and power quality
- Supplying energy during peak price
- Minimizing customers' electricity bills
- Supporting intermittent power resources

As stated previously in modeling of Battery in chapter three, 300ZBB storage systems have been installed in the FLMVPP system. The capacity of each battery is 3MW which are connected in series. In this thesis, 300 systems have been split in six packages including 50 batteries per package. The reason to do so is to make the FLMVPP system more efficient as it is not economic to use entire storage systems if only the small portion of demand needs to be compensated. Hence, dividing storage systems to small groups of 50 dramatically reduce the service and maintenance cost while increase the life span of the battery [83].

In addition, the cost of electricity generated by ZBB system in large scales based on report collected from red-flow company and shows 52c per kwh [84].

Details of calculating the nominal levelized cost of energy (LCOE) for the delivery of electricity are as follows [21, 83]:

5.2.1.5.1 Levelized cost of energy

The cost of the electricity derived by ZBB storage system is as follow:

$$F = B * E \tag{5.22}$$

Where, F is total Kwh output per battery life time, B is cycles, and E is effective Kwh per cycle.

$$G = F/A \tag{5.23}$$

Where, G is cost per Kwh in (USD) and A is recommended retail price (USD).

$$G/J \tag{5.24}$$

Where, J is UDS: AUD and, G/J is cost per Kwh (AUD).

Market exchange rate: USD=1.32 AUD (5.25)

TABLE5.2. SPECIFICATION AND COST OF THE ZBB SYSTEM

$/kW	Efficiency	lifetime	Depth of discharge	Lifetime throughput	$/kWh
2000	75%	10 y	100%	2737 kwh	.52
2500	80%	20 y	100%	5475 kwh	.52

Based on simulation run in chapter 3, the capacity of the ZBB system considered five times more than demand which is about 900 Mwh. Hence, the total cost of the storage system in the FLMVPP is:

$$900Mw * 52Cper\ Kw = 46800\ \$\ per\ Kwh\ per\ year \quad (5.26)$$

The ZBB storage system is one of the most sustainable and cost effective batteries available in the market. This storage system is economic and cost effective since the electrode stack is changeable by only 50% of the total cost of the battery when the battery reaches to end-of-life while other elements of the storage system is conserving [83].

The maintenance-free lifetime energy throughput of a ZBB system depends on different factors in a daily cycle depth. For instance, in some areas with frequent blackouts can rely on ZBB system working in storage mode. While, there is not any maintenance charge needed. In case of outage and emergency needs, the storage system will be switched to power supply mode to compensate demand. The battery can be expected to last more than 20 years in case of weekly complete discharge without any maintenance cost for the entire period [81, 83].

In the vast regions of Australia with no connection to the grid which are relied on expensive imported fuels, the storage systems would reduce energy costs and boost reliance on renewable energy. For instance, the consumption of diesel reduced by 50% in King Island, Tasmania, after swapping from conventional power plant to renewable energy and battery storage [83].

5.3 Optimized the Operation of a VPP: Achieving the Energy Balance

Nowadays power plants are at risks and uncertainties that are coming from different sectors in a deregulated market environment. Some of these sectors are as follow [17, 85]:

- technical limitations
- unstable electricity market prices
- fuel price uncertainty

It is difficult to determine the relationship between the load and the stated factors. Researchers have used ANN systems to define the relationship between the load and selected factors since the ANN technique would be able to encode complex and nonlinear relations. Moreover, research shows that load forecasts which have been produced by ANN techniques are more accurate compared to other factors [69, 70].

This research aims to simulate a combined control scheme for the FLMVPP system with different types of DERs. The main aim of this task is to optimize the DERS' operation based on some factors such as demand and electricity price broadcast by the FLMVPP system. In doing so, the ANN algorithm is chosen to identify the scheme of this DERs group. In fact, the system needs adequate historical information of each DER to characterize a combined scheme of the DERS' to different electricity price. In this study, the historical data collected from Australian Electricity Market operator (AEMO) website for different period of time. The AEMO is defined in the following subsection.

5.3.1 Australian National Electricity Trading

A large amount of Australia's electricity is still produced from the combustion of fossil fuels such as coal, gas, and oil [85].The amount of energy produced in Australia from 1974-2015 has been shown in Figure 5.2.

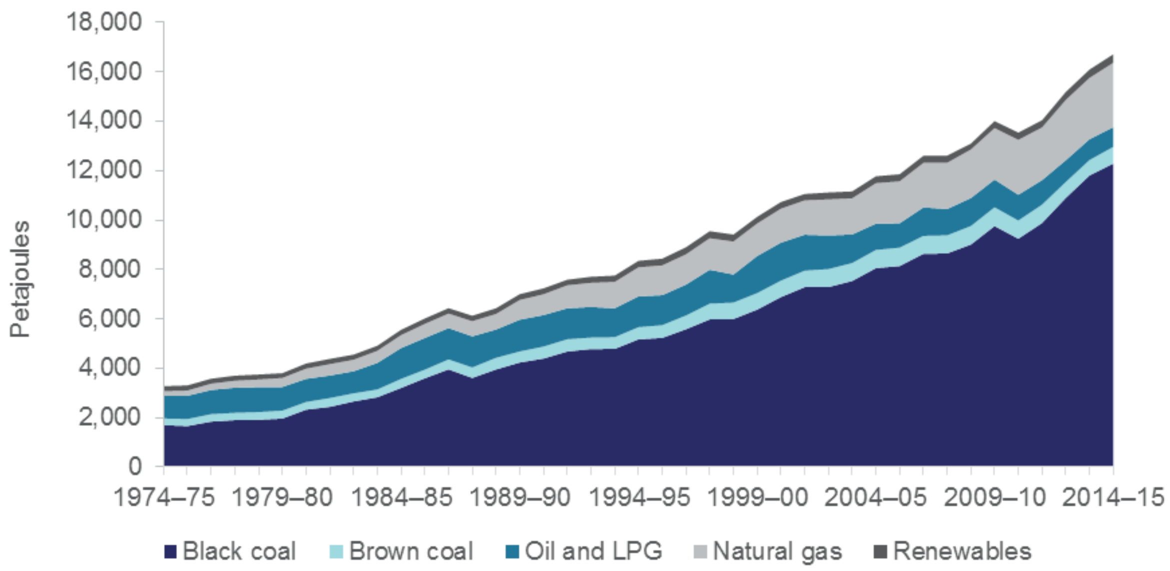


FIGURE 5.3.ENERGY GENERATION IN AUSTRALIA BY VARIOUS FUEL TYPES [85]

The National Electricity Market (NEM) in Australia is a wholesale market for the supply of electricity to retailers and end-users in the six Australian states [85, 86]. In NEM, the electricity exchange between generators and consumers is facilitated where the total generation output is combined in a pool and scheduled to meet the demand.

This electricity pool is not physical but rather a set of procedures that the Australian Energy Market Operator (AEMO) manages according to statutory provisions [86].

Efficient operation of the Australian NEM is retained by AEMO, which also develops the electricity market, improves its efficiency, and coordinates the planning of the interconnected power system. The demand and supply of electricity in Australia is balanced through AEMO's actions. Hence, sophisticated IT systems are needed to underpin the operation of the NEM including the responsibilities to balance supply with demand, select operational elements at any given time and determine the spot price. A centrally-coordinated dispatch trading process referred to as the spot market is used to match supply and demand instantaneously in real-time [86].

In this research study, to optimize the operation of the FLMVPP system, the ANN tool with three layers is used in MATLAB environment. The input-output data used in this tool are collected from the simulation run in chapter three and AEMO website as well. It is essential to find an appropriate ANN structure as the computational performance of the method is sensitive to the number of layers and neurons. The general structure of ANN technique has been shown in Figure 5.3.

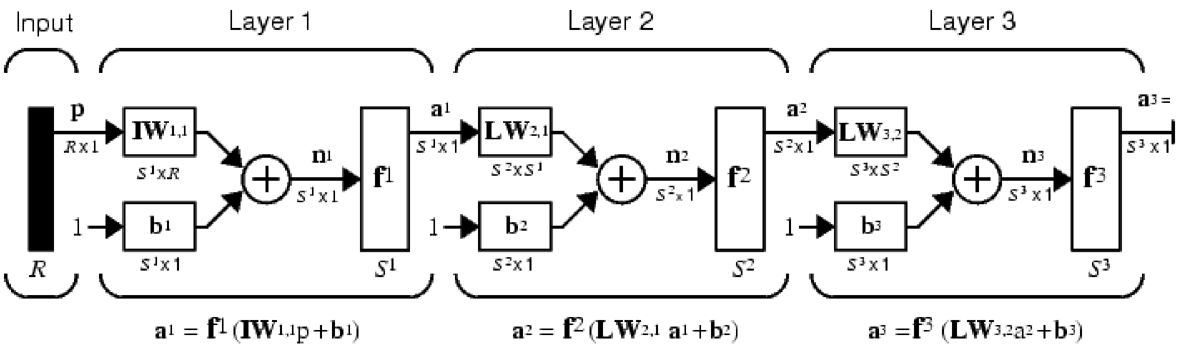


FIGURE 5.4.ARCHITECTURE OF A THREE-LAYER ANN [13]

The question of how many hidden layers and how many hidden nodes should exist in ANN layers have not been precisely solved yet. In this research, the ANN network with three-layer structure; two-hidden and one output layer is considered. To compute an arbitrary function of inputs, neurons of two hidden layers which use sigmoid transfer functions are sufficient and a single hidden layer is enough for classification problems [70]. As choosing the number of neuron in the hidden layer is difficult, the below formula is considered based on theoretical and empirical limits [13, 70].

$$\text{Number of neoruns} = 2 * \mathrm{N} + 1 \quad (5.27)$$

Where; N is the number of inputs.

The output produced by the BPNN is called estimated output. The difference between target output and the estimated one is called error. Thiserror is usedin the calculation of Least Mean Square Error **(**LMS**)** which is shown in the following Equation [13, 70]:

$$E = \frac{1}{2}(To - Do) \quad (5.28)$$

Where E is error, T_O is the ANN target and D_O is the desired output.

The BPNN operates by propagating errors backward from the output layer and would stop operation when unacceptable error is occurred.

To optimize the operation of the FLMVPP system, some factors needs to be satisfied. These factors are as follows:

- Minimizing the cost of the load
- Using the VPP resources as much as possible
- Trading on the day-ahead market by selling or purchasing energy

As the storage system is installed in the FLMVPP system, the required numbers of price scenarios become larger since responding to the price signal is not only depending on current demand and prices but also relies on system's former actions.

5.3.2 Constructing and training the BPNN

To develop ANN model in MATLAB environment a three layer ANN with a set of data and target have been defined.To choose more accurate number of neurons for each hidden layer, the number of neuron is iteratively changed in first and second hidden layer. With each combination, the NN is trained more than one time to find the minimum error for entire data [13, 70]. Details of information of training system in ANN network have been shown in Figure 5.4.

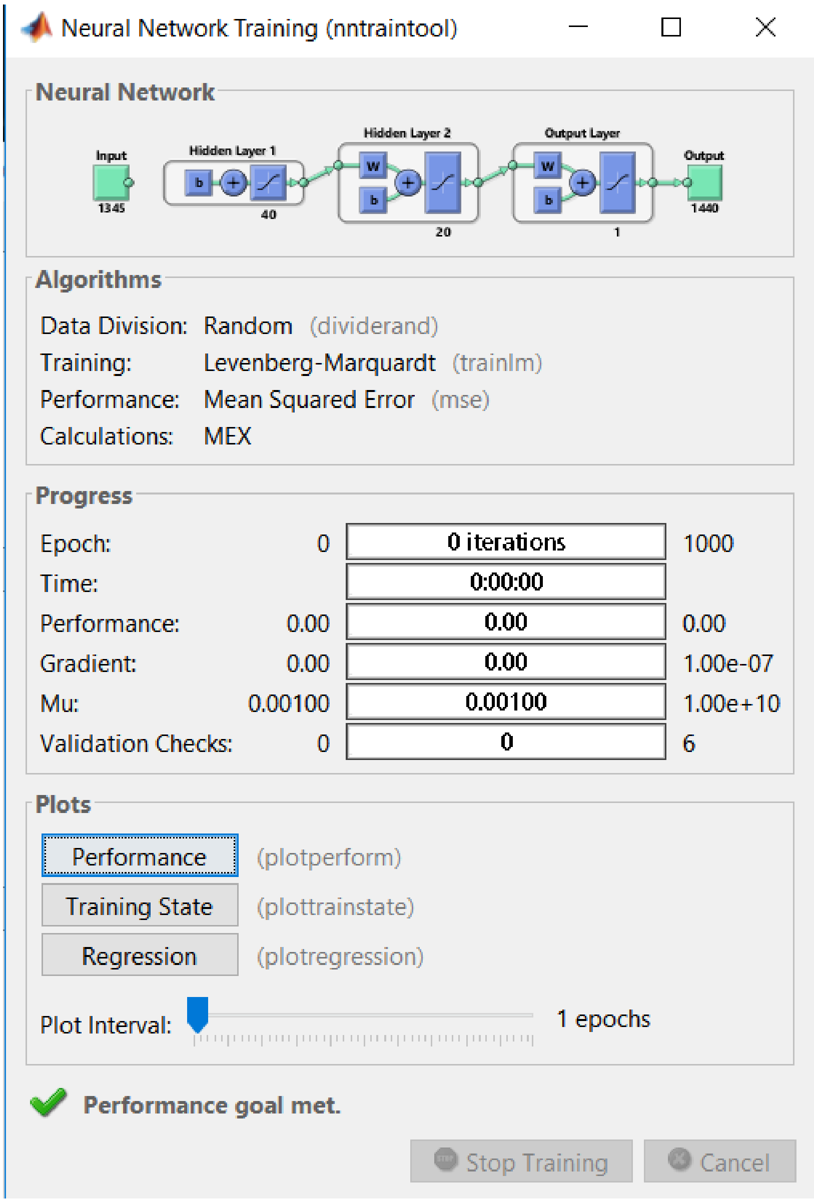


FIGURE 5.5.TRAINING SYSTEM IN ANN NETWORK

This figure illustrates the information of training system; the training process will stop when the validation failure reached to its maximum number.

5.4 Testing the trained BPNN

There is always an error in systems integrated with renewable resources as these sources are intermittent and their generation is not 100 percent accurate. Indeed, the power generated by renewable energy resources is predictable which causes some errors as well as costs [13, 18]. However, the error could be minimized by applying ANN algorithm to the modeled system with appropriate training system. Furthermore, errors in the network are the difference between target output and ANN output which would be minimized by reducing this gap. Consequently, cost would be minimized and system will be optimized [1].To capture more accurate scheme for DERs under a certain circumstances, sufficient and accurate data must be simulated.

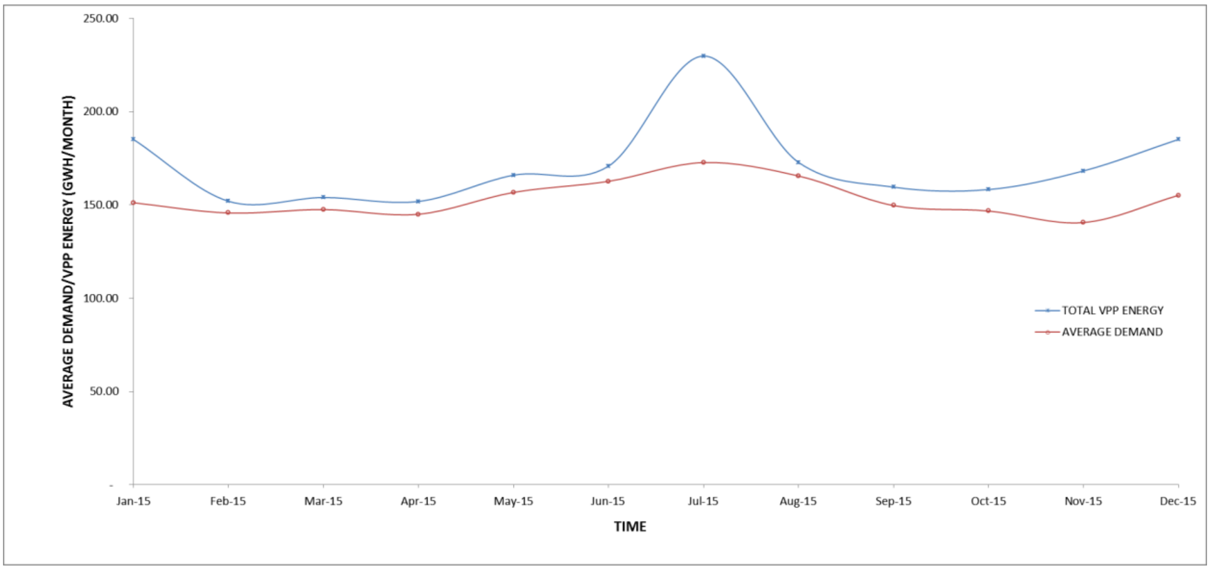
According to the proposed scheme, the output of the FLMVPP system would be applied as target to the ANN network. In this study three different period of time have been developed and tested in ANN network in MATLAB software, which are as follows:

- The average monthly data for the whole 2015
- Data for the first Saturday and Monday of each month in 2015
- The period of 5 consecutive days from 10^{th} to 15^{th} Jan 2015

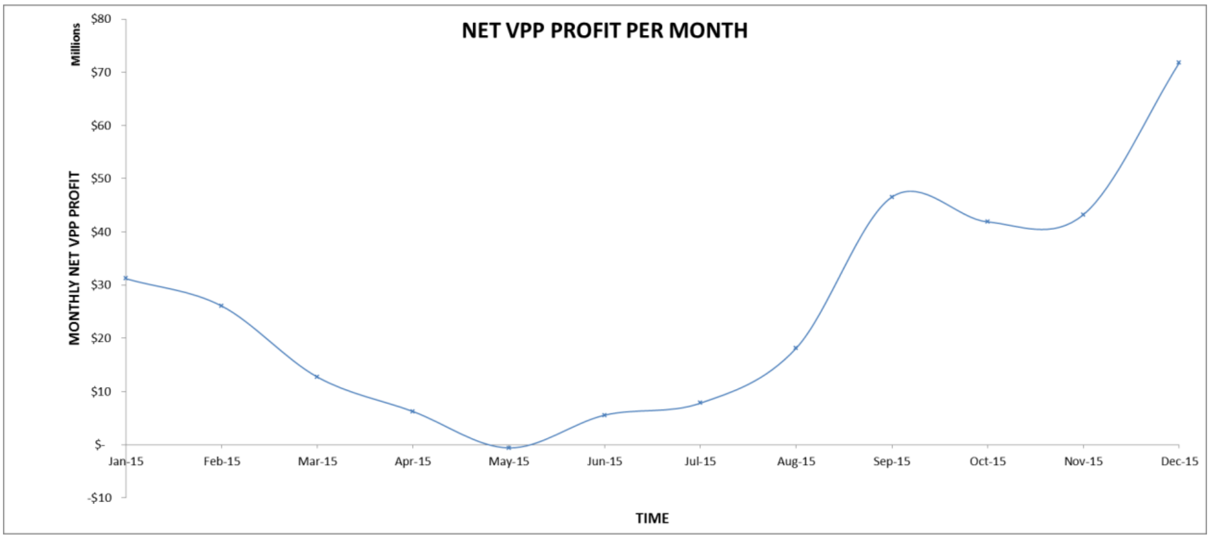
Each scenario has been modelled and detailed as follows:

Scenario 1: in this scenario, all inputs and target in ANN network have been modelled based on average monthly data. In ANN system demand, price, and the profit from selling power to the grid have been considered as input data and the power generated from the FLMVPP system has been taken as a target. All data is available in Appendix and also has been shown in Graph 5.3 and Graph 5.4.

Moreover, in this scheme in a situation that demand is greater than power generation, the fuel cell or battery will connect to the system to compensate the load. To apply generation data in ANN system the backup of the network also has been added to compensate demand at some points which has been shown in the Graph 5.3.



GRAPH 5.3. AVERAGE MONTHLY DEMAND AND GENERATION FOR THE WHOLE 2015



GRAPH 5.4. AVERAGE MONTHLY PROFITS FROM SELLING OF POWER

In this scenario, by applying input data and target to the ANN system the system needs to be trained 30 times to find the minimum error for the whole data. In this case, when the number of neurons in hidden layers set to 29 and 12 respectively the desired output is achieved. Figure 5.5, illustrates the information of training system for this scheme;

the training process stopped when the validation failure reached to 6 which is its maximum number in here.

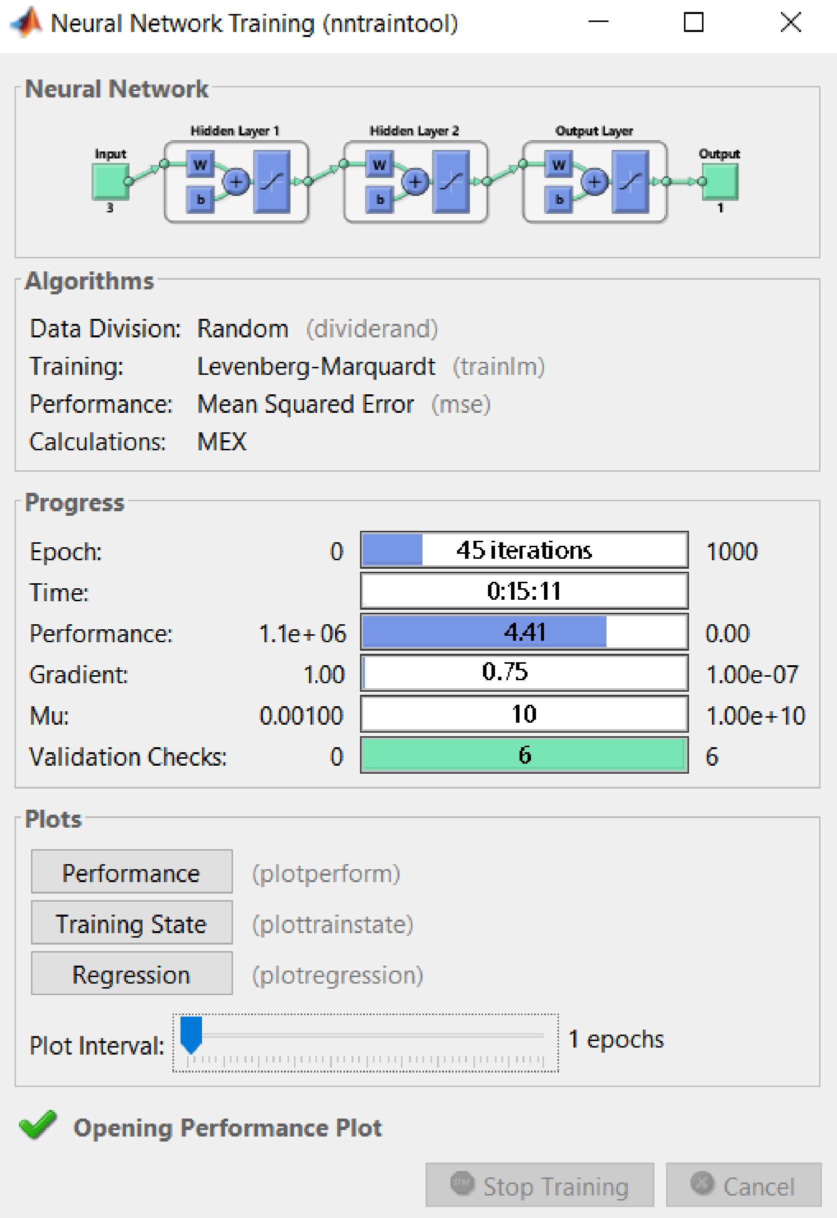
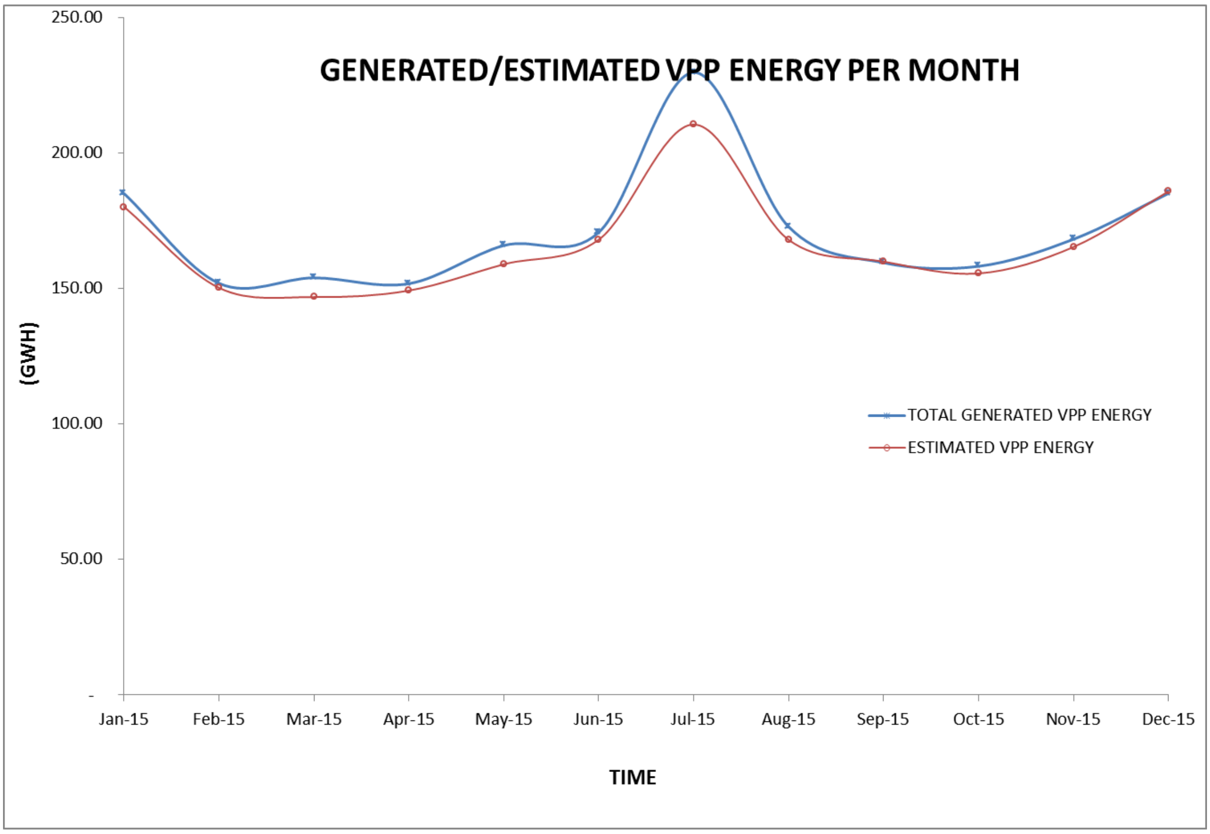


FIGURE 5.6.TRAINING SYSTEM OF SCENARIO 1

Based on the developed model, the generation of the FLMVPP system and the estimated production are closely overlapped that is determined the minimum error of forecasting in the system. The comparisons of these two outputs have been shown in Graph 5.5.

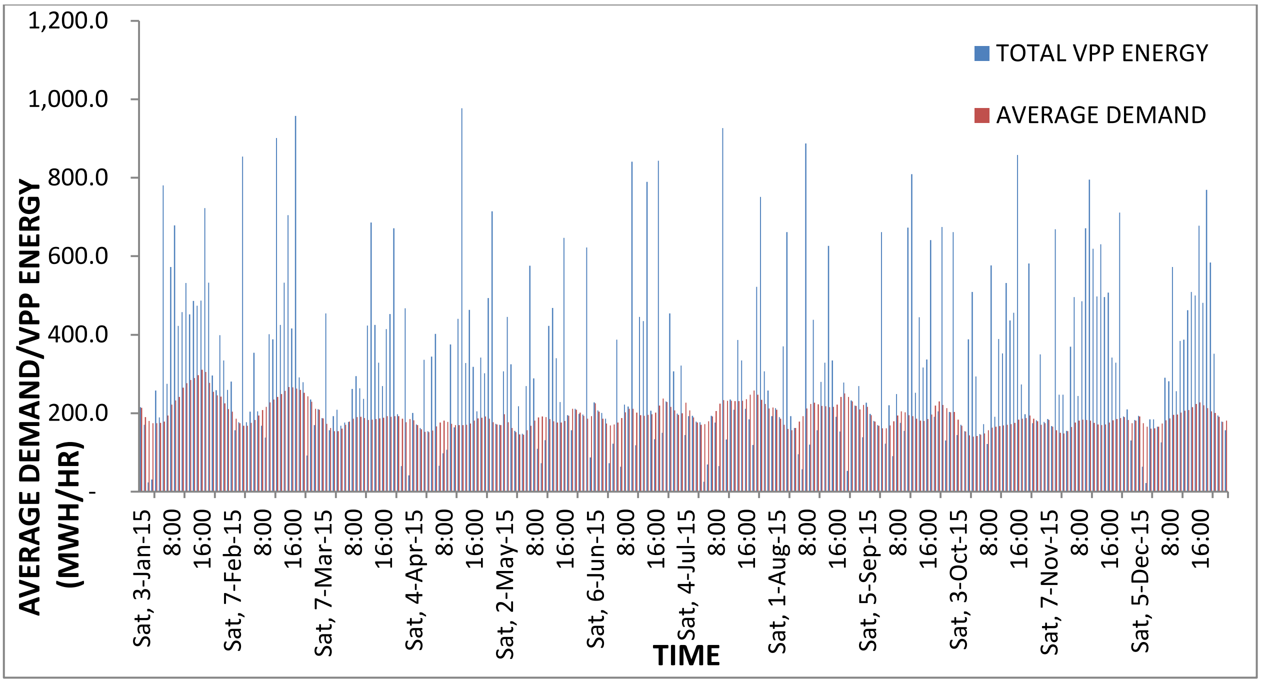


GRAPH 5.5. GENERATION OF THE FLMVPP SYSTEM AND THE ESTIMATED ONE

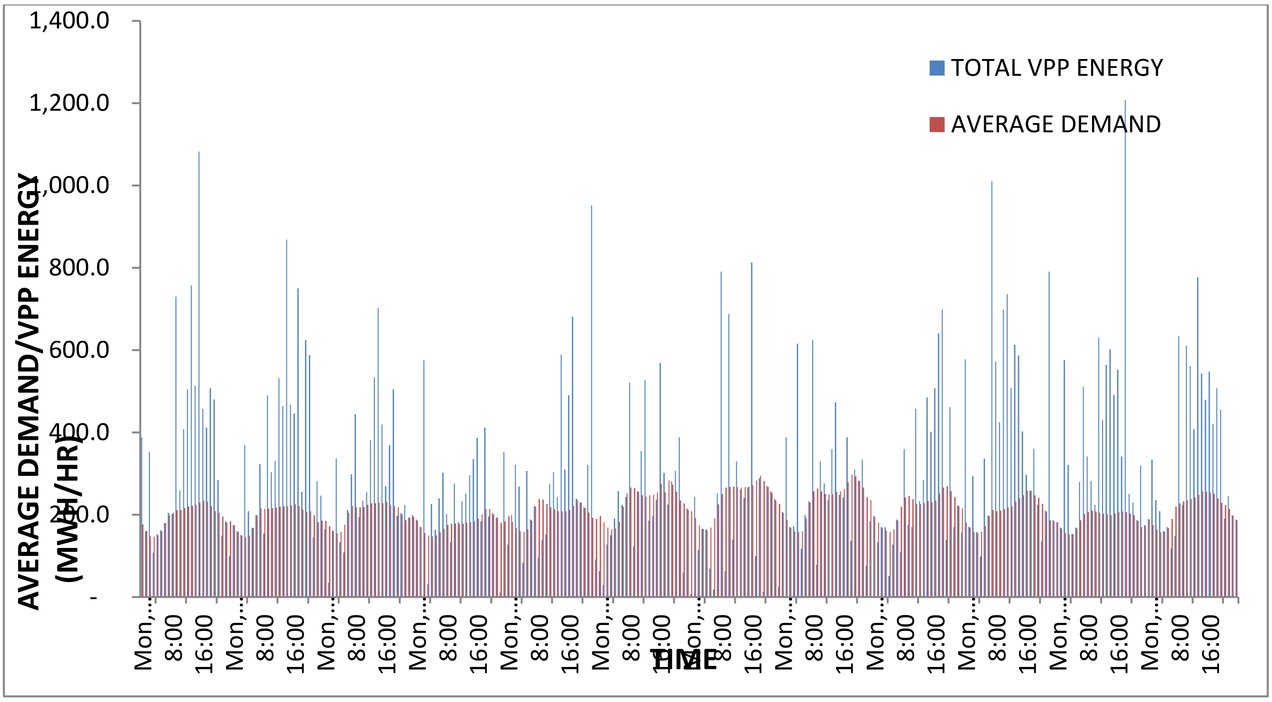
The error which occurs by estimation considerably challenges the prosumers to choose the appropriate price scheme. In fact, the extra balancing cost, as an undesirable effect of forecasting error, will be the primary factor for DER owners [13, 18].In this respect, having a combined control scheme would be a viable method to solve this issue. The advantage of applying this technique on a VPP system is to assist DER owners to make a stress-free and easy decision to choose the best scheme based on their historical portfolio. Although this scenario is based on average data, the developed model shows the minimum prediction error for the system which concluded the optimization generation of the system.

The next step to test the model is applying more information on the basis of hourly data which defined as follow:

Scenario 2: in this scenario all data is based on first Saturday and Monday of each month in 2015. For a day with 24 consecutive hours, it is assumed that each hour has one price scenario, so a given load profile for that day would be 24 price data that lead to different values of generation as well. The demand and generation data for the first Saturday and Monday of each month have been illustrated in Graphs 5.6.and 5.7 respectively. Based on these graphs, where the generation from the FLMVPP system is much bigger than demand, the exceed production will go to batteries to store and will apply as a backup in peak times. Furthermore, in case batteries are full the surpass amount of electricity will sell to the grid based on an appropriate scheme on a real time.

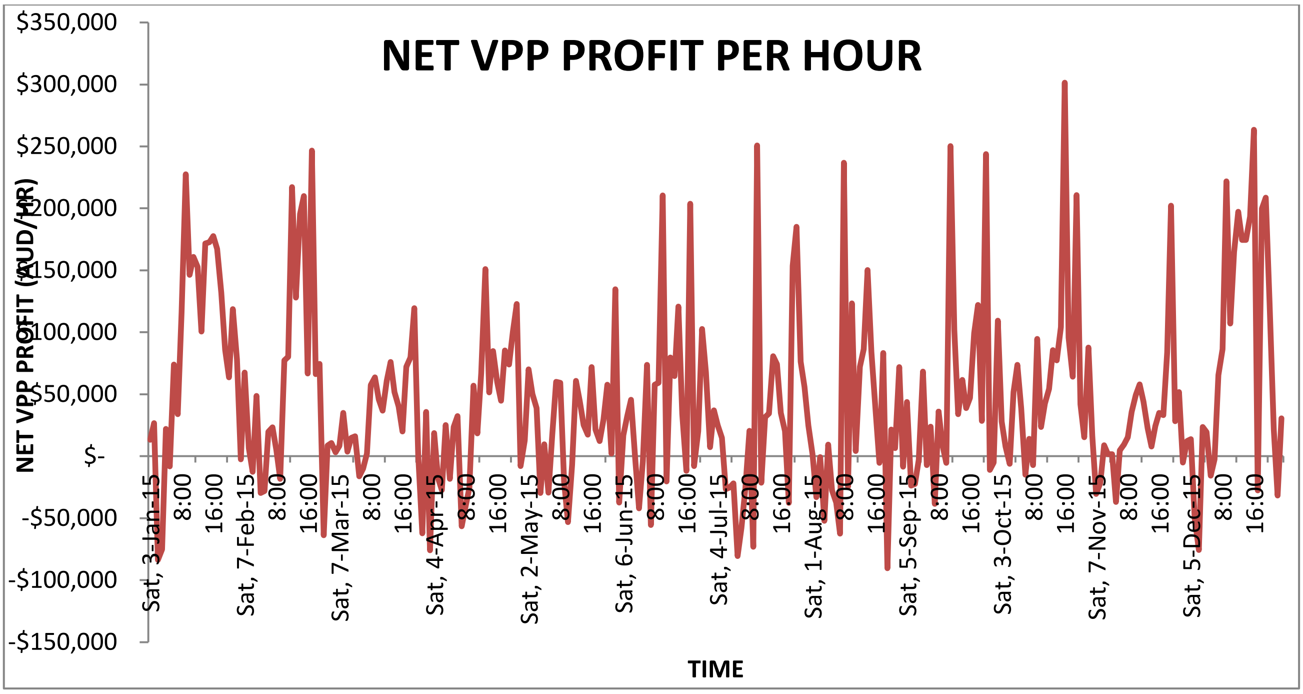


GRAPH 5.6. HOURLY DEMAND AND THE FLMVPP GENERATION F THE FIRST SATAURDAY OF EACH MONTH

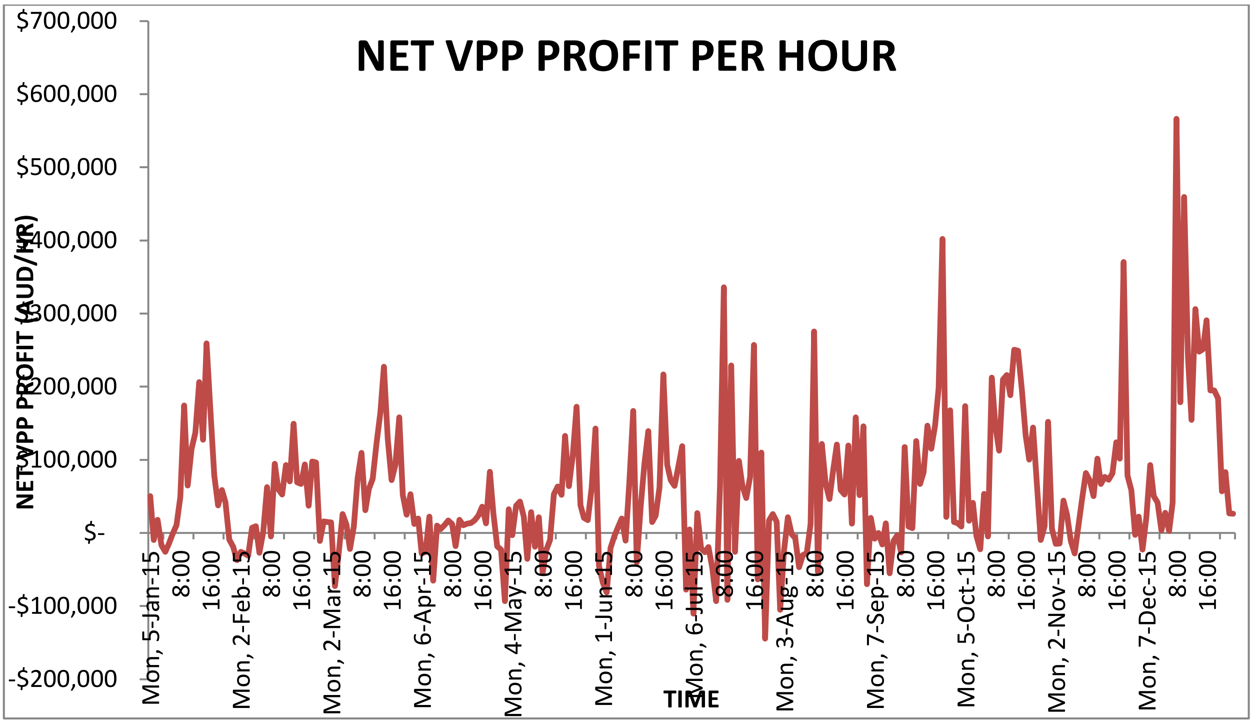


GRAPH 5.7. HOURLY DEMAND AND THE FLMVPP GENERATION FOR THE FIRST MONDAY OF EACH MONTH

The next input data in ANN network is the profit from selling the power to the grid. From the Graphs 5.8 and 5.9, it is obvious that the higher profit of the system is interpreted as greater amount of generation compare to demand and that the backup is full so , the exceed power will be sold to the grid on peak periods with a higher price.



GRAPH 5.8.THE PROFIT OF SELLING POWER GENERATION TO THE GRID ON SATURDAY



GRAPH 5.9. THE PROFIT OF SELLING POWER GENERATION TO THE GRID ON MONDAY

In this model, to choose the proper number of neurons for each hidden layer, the number of neuron is iteratively changed from 60 to 90 for the first hidden layer and from 40 to 60 for the second one. In this case, the ANN system is trained 90 times to find the minimum error between target and the output which is achieved by setting to 85 and 56 respectively in hidden layers. Moreover, information of training system has been presented in Figure 5.6by showing the training process stopped at 6 and the iteration epoch at 715.

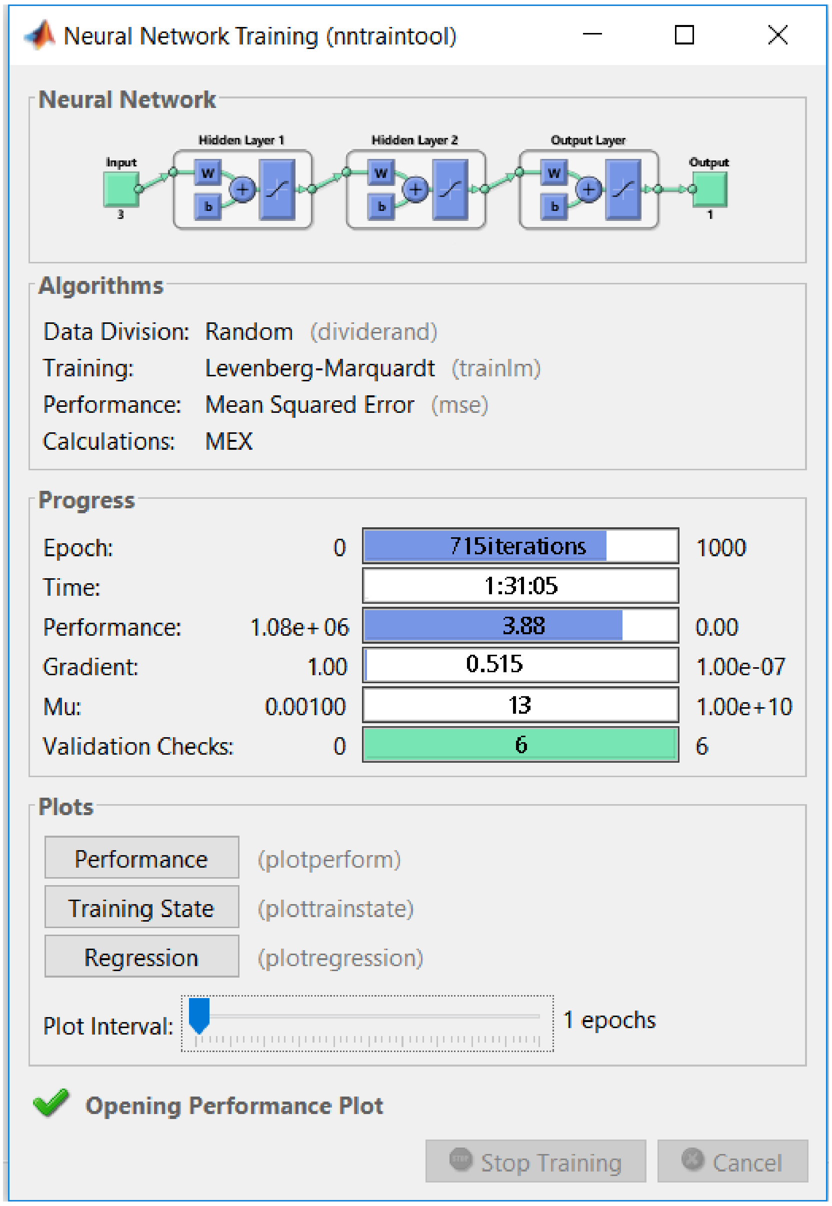
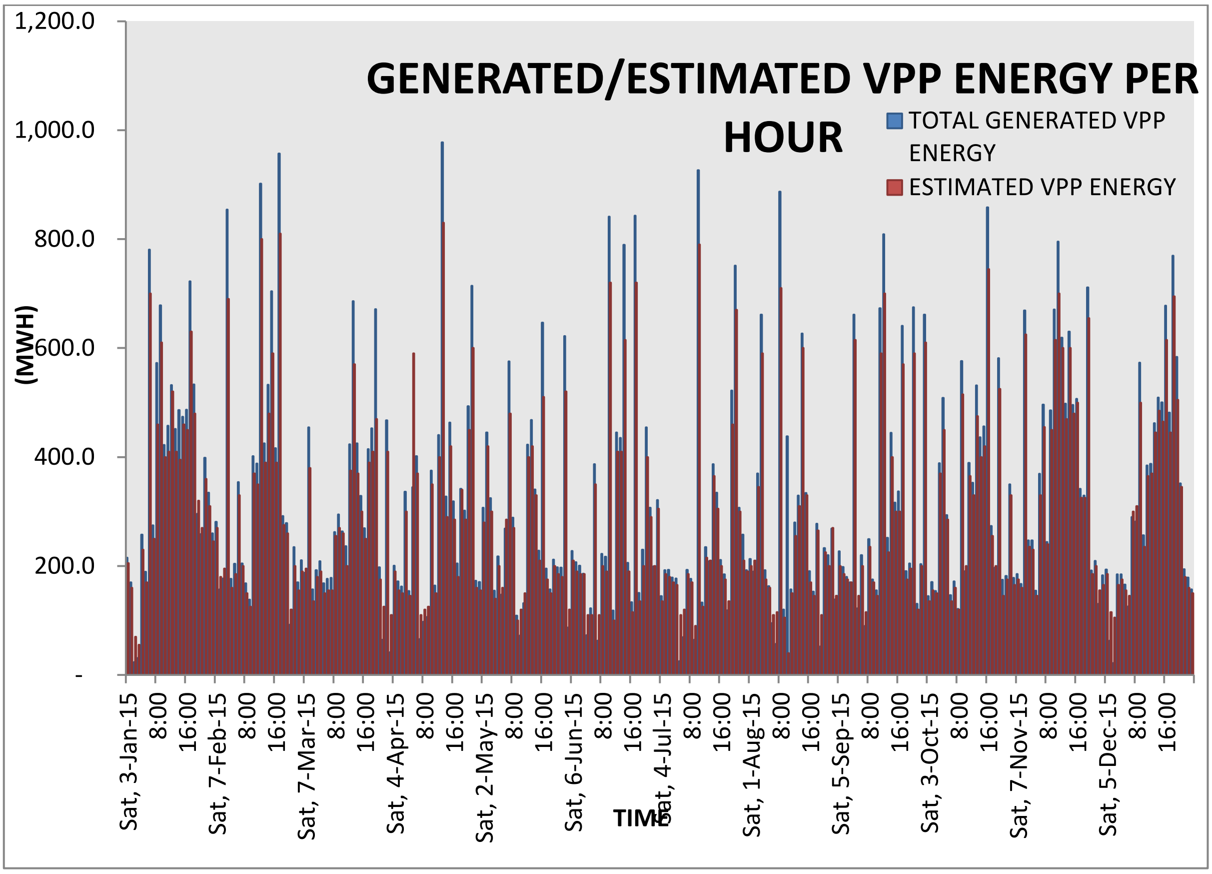
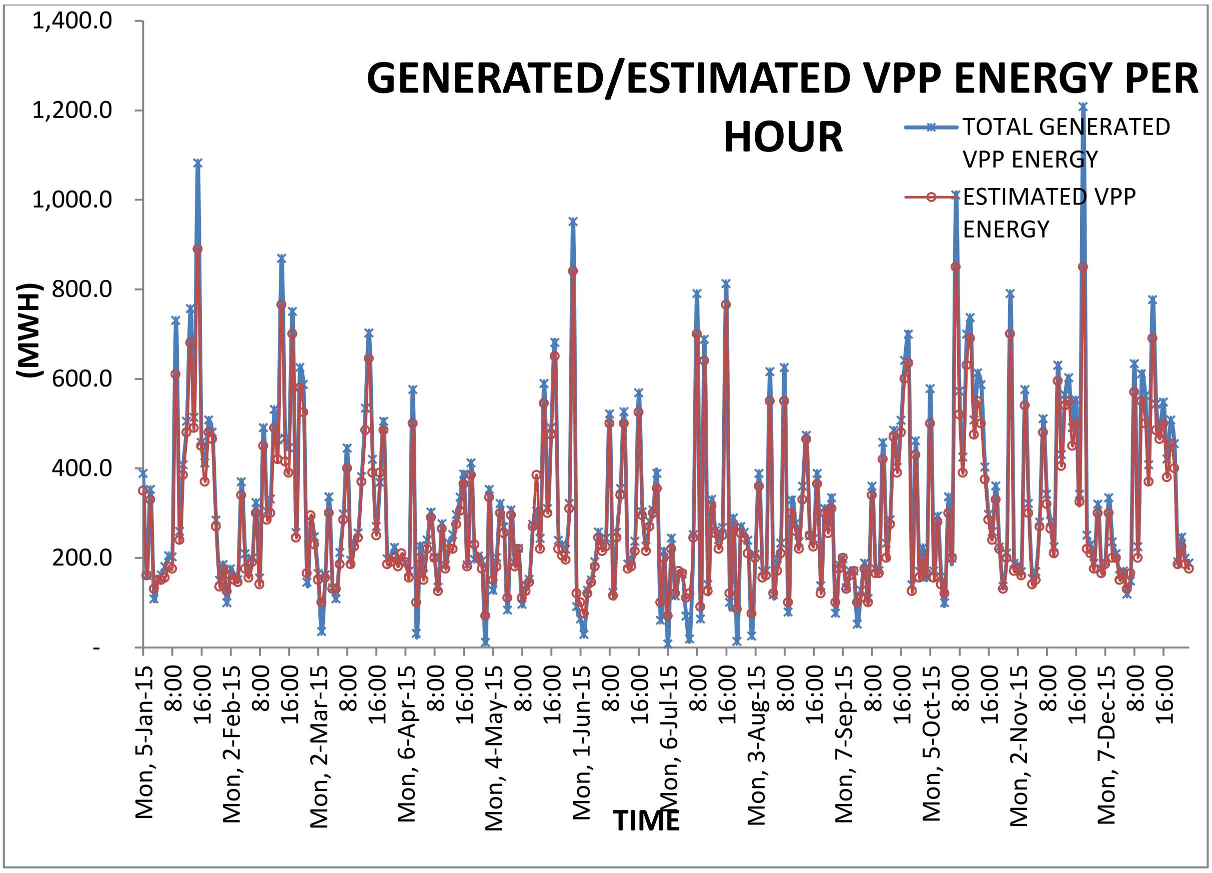


FIGURE 5.7. TRAINING SYSTEM OF SCENARIO 2

The designed model in this case shows that the FLMVPP system generation and the estimated power are closely matched which also describe the error of forecasting reach to the minimum point. The results for first Saturday and Monday of each month have been presented in Graph 5.10 and Graph 5.11 respectively.



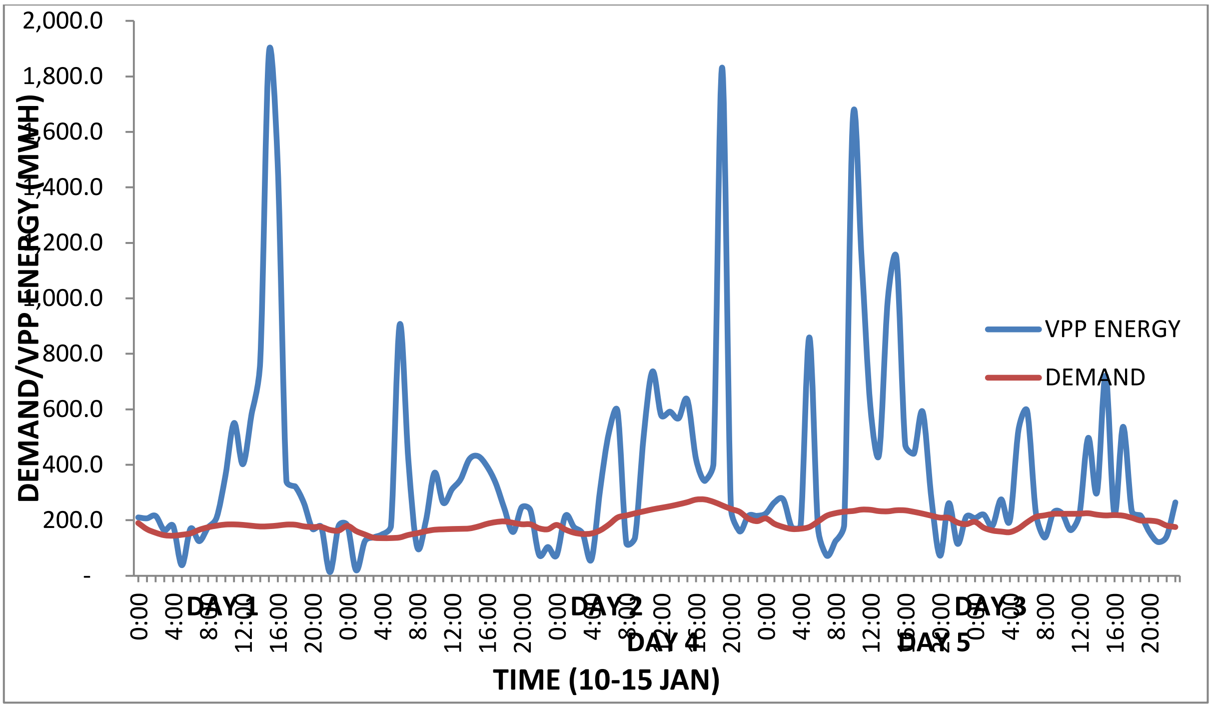
GRAPH 5.10. GENERATION OF THE FLMVPP SYSTEM AND THE ESTIMATED ONE FOR FIRST SATURDAY OF EACH MONTH



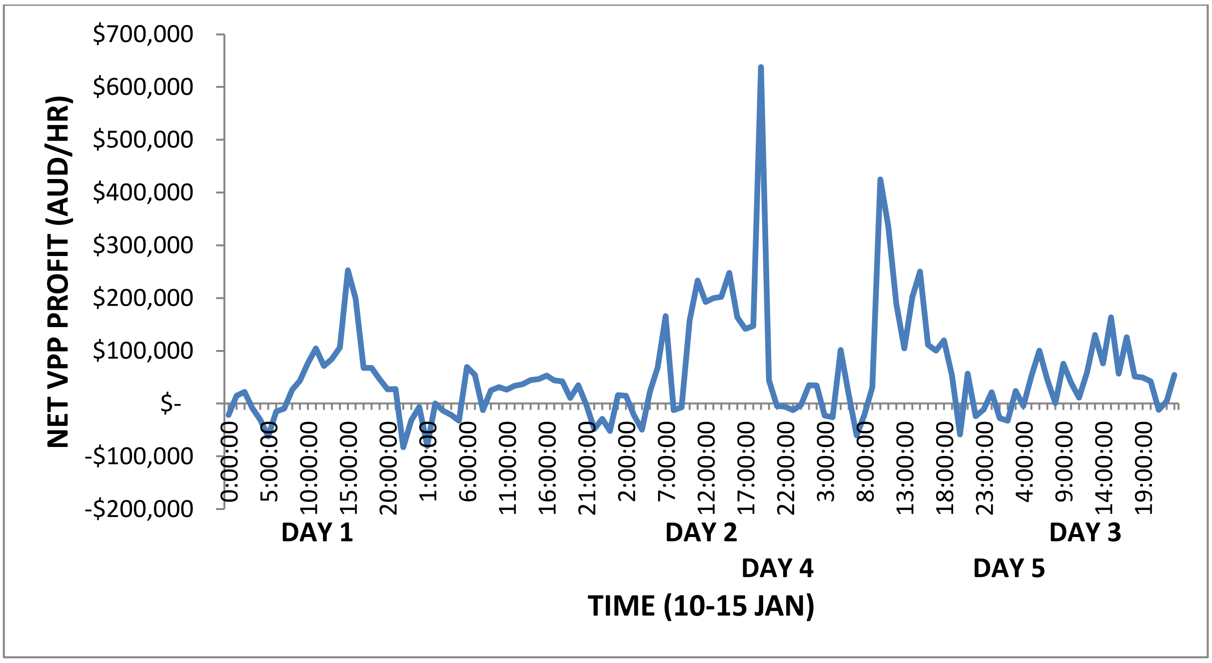
GRAPH 5.11. GENERATION OF THE FLMVPP SYSTEM AND THE ESTIMATED ONE FOR FIRST MONDAY OF EACH MONTH

In each graph, data has been tested and the model also developed to identify the best applicable scheme for the system. Consequently, in this scenario being nearly matched values between power generated from the FLMVPP system and the estimated generation define reliability of the system which is remarkably reduce costs and maximize operation of the system. The next step is to test data for consecutive days which is described in section 3.

Scenario 3: In this scheme, all data and target have been considered for five consecutive days from 10th to15thJan 2015. Furthermore, demand, generation of the FLMVPP system and the profit of selling power to the grid have been shown in Graphs5.12 and5.13 respectively. The entire data is available in Appendix and also has been shown in the following graphs for visualisation purpose.



GRAPH 5.12. DEMAND AND GENERATION FOR FIVE CONSECUTIVE DAYS FROM 10TH TO 15TH JAN 2015



GRAPH 5.13. PROFIT OF SELLING POWER TO THE GRID FROM 10TH TO 15TH JAN 2015

In order to develop the model in ANN system, two hidden and one output layer have been selected. In this scheme, the number of neuron is iteratively changed from 40 to 70 for the first and 20 to 30 for the second layer. In this case, the ANN system is trained 60 times to find the minimum error between target and the output which is achieved by setting to 59 and 26 respectively. The information of training system in this scenario has been shown in Figure 5.7. The training process stopped at 6 with the iteration epoch at 414.

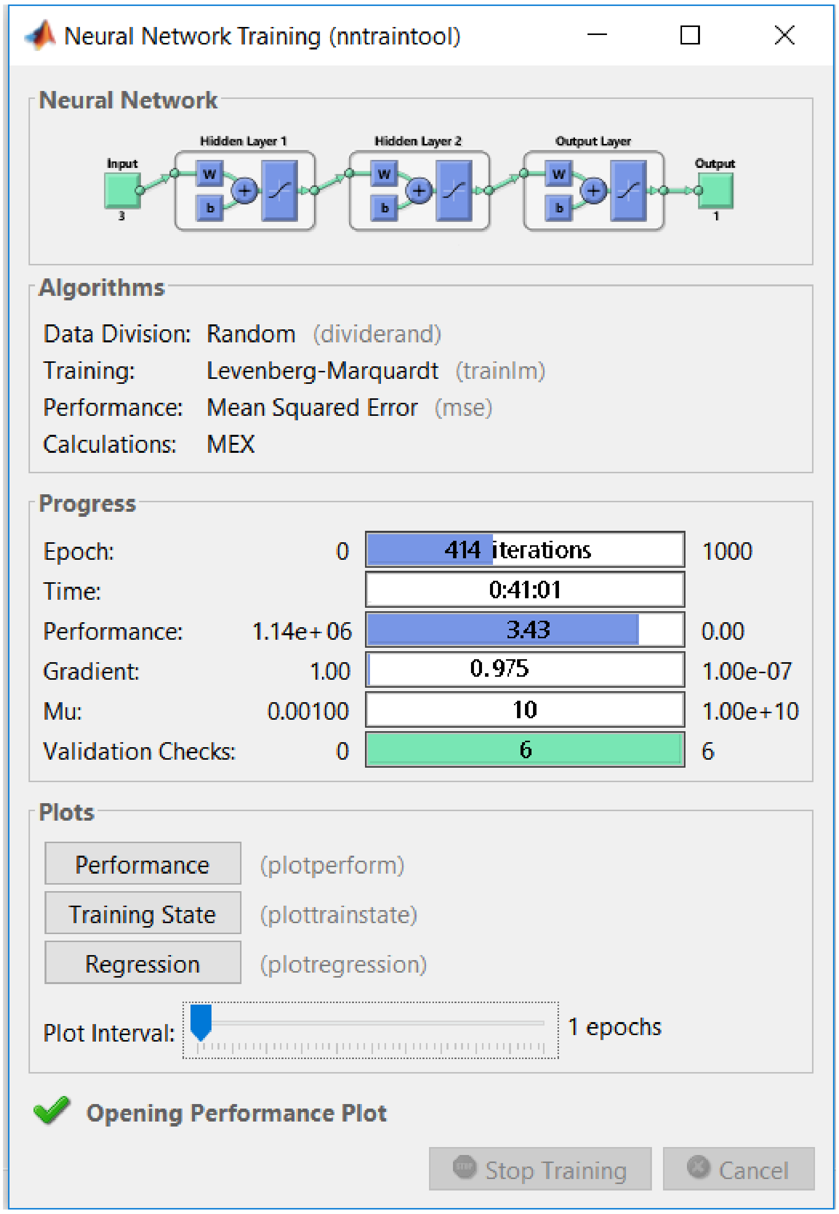
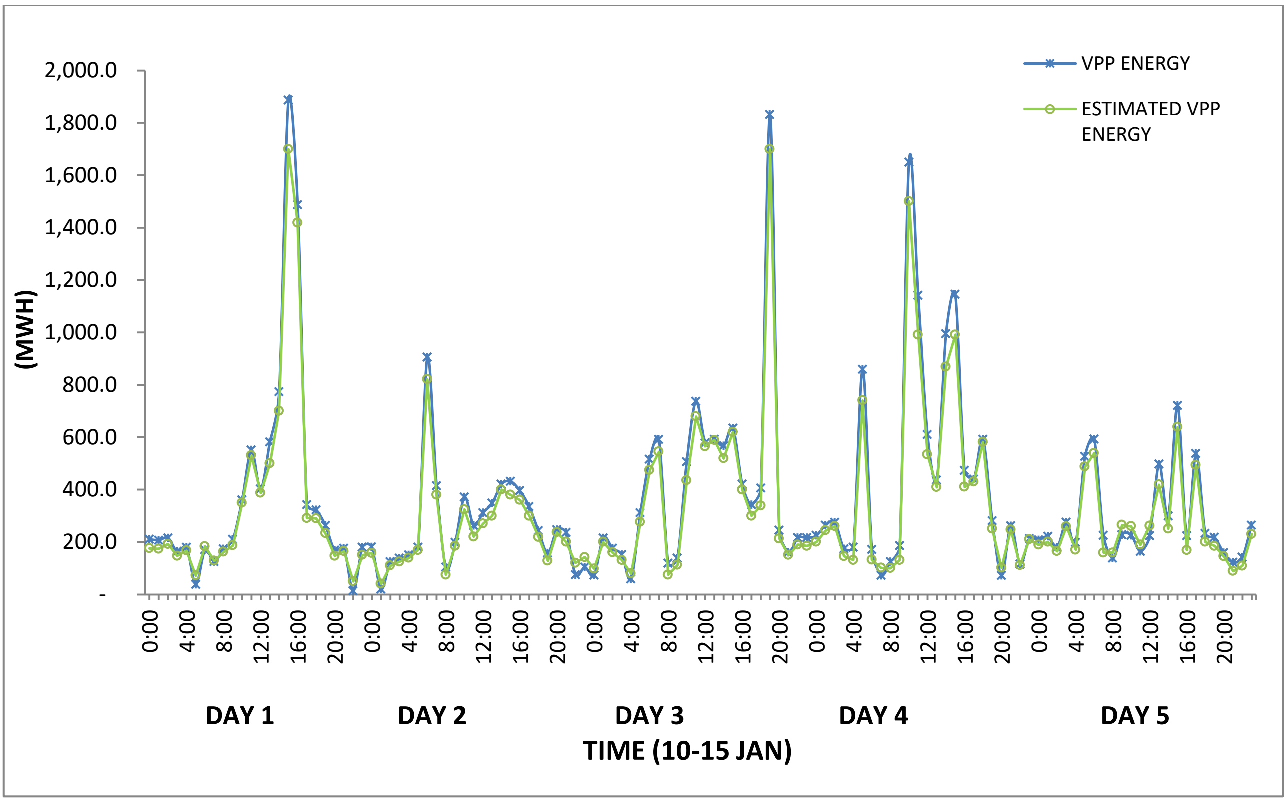


FIGURE 5.8. TRAINING SYSTEM OF SCENARIO 3

Consequently, the model run based on data collected from AEMO and on the basis of the generation from the simulation run in chapter 3;the power generated by the FLMVPP system. Furthermore, generation from the FLMVPP system and the estimated production have been presented in Graph 5.14 to test the model. As shown in this graph, the estimated production from the ANN model is so close to generation of the FLMVPP system.



GRAPH 5.14. GENERATION OF THE FLMVPP SYSTEM AND THE ESTIMATED ONE FROM 10TH TO 15TH JAN 2015

Based on the developed ANN model, participants of the VPP system would be able to forecast the generation of DERs for defined price. Furthermore, in case of increasing the number of aggregated DERs to thousands, using combined control scheme in a system would help it to achieve much smoother regulation with the minimum cost

5.4.1 Improving Results

If the network is not sufficiently accurate, there are different approaches that can be applied to improve results. Some of these approaches are as follow [63, 70]:

- Initializing the network and the system will be training again. By initializing the network, the parameters are different each time and might produce different solutions.
- Increasing the number of hidden neurons as increasing the numbers of neurons in the lead to more flexibility in the network. The reason is that the network has more parameters that it can optimize.
- Using additional training data. By providing additional data for the network, it could be able to produce a network that simplifies well to new data.

Moreover, training system at each time lead to get the result in a different solution due to some different factors which are as follow:

- different initial weight
- bias values
- different divisions of data into training
- validation
- test sets

Consequently, it is important to retrain network several times to ensure the accuracy of an ANN technique. Since, on the same problem there are different outputs for the same input on different neural networks that has been trained [63, 70].

5.5 Result validation and discussion

In this chapter, a combined controlled scheme for the FLMVPP system has been proposed and designed in MATLAB software using ANN algorithm as a proper technique to optimize the operation of the system. In this regard, selection of input parameters for ANN network is crucial to perform forecast as having errors in a system with ANN based technique is inevitable. In this research study, the aggregated historical real data have been applied to predict the DERs' generation in the FLMVPP system, so that prediction leads to some errors. However, errors have been reduced to a very small level by properly trained the modelled system to identify DERs generation. Since the generation of the FLMVPP participants keep changing, so estimation must be done to different classes of prosumers rather than one.

Secondly, the proposed system has been modeled in the MATLAB environment and simulation works were carried out with predetermined scenarios which highlight the accuracy and reliability of the proposed scheme. The utilized models are very versatile and can be used in different smart grids with various renewable resources. Obtained results verify the reliability and viability of the developed system.

To develop model in the system, different scenarios of various period of time have been compared and applied to the system for testing and identification purposes. The aim of applying different time intervals is to test and show the accuracy and validation of the developed model.

As stated previously in chapter three, the FLMVPP system has been simulated based on mathematical model and the output of the system has been tested in ANN network based on real data to find the proper control scheme as well as verify and validate the result. Even though various time intervals of real data have been applied in each scheme, results approve the same concept by achieving the minimum forecasting error. This could be easily found by comparing values and graphs of each generation; estimated production and generation from the FLMVPP system.

Comparing graphs of these values illustrate that developing a combined control scheme instead of using individual one minimize costs of generation by minimizing the error of forecasting as well as optimizing the operation of the system. By applying combined control scheme to the system, prosumers would be able to quickly update their knowledge to choose which scheme is more suitable for DERs' generation; whether direct controlled or price signal response. Applying an individual control scheme such as price signal to the system lead to some challenges which are as follows [63]:

- The price signal control scheme can be used to roughly control a large number of participants,
- Using new tariff, with naive participants and naive VPP, a double-complex set of adaption to the new scheme will take place,
- It is risky for the early operation of price controlled VPP by posting price signals directly to the participants without receiving any confirmation from them since the unbalance is associated with the penalty cost,
- Having a negotiation procedure before posting the final negatively impact the participants' keenness.

As stated above, the individual controlled scheme of a VPP system is not a flawless solution since it is difficult to handle uncertainties [63]. By applying the combined control scheme in the system, participants can freely decide which scheme is better for their patterns. Moreover, it is a feasible solution for large utilities to smooth the integration of DER and propose more efficient solutions to use DERs

Chapter.6 Conclusion

Smart Grid technology aims to achieve reductions in energy consumption and generation, as well as CO_2 emissions by establishing a synergy between energy generation, consumption, and distribution. It can be achieved by linking these three elements via an advanced metering, communication, and decision making process.

The application of different renewable resources in a Virtual Power Plant (VPP) system might seem as a drawback at first sight. However, the motivation behind the concept of the system implies that the VPP system would be able to coordinate the various types of energy resources. This organization helps to minimise the cost of power generation and maximise the profits from selling the generation of these resources. Since the VPP system is an emerging area in power grids, the VPP concept is in the high attention of researchers work. There are many research studies and applications have been done in this field from different aspects and lead to develop power engineering indelibly.

However, not much work has been made towards control systems as the researchers mainly focused on some issues such as: renewable based DGs, load sharing, and stability and only individual control scheme issues and considerations have been considered. Therefore, still a huge knowledge gap exists in this area. Nevertheless, there are some publications focusing on VPP controlling where some combined control methods are proposed. These proposed schemes are not as comprehensive as the scenario proposed in this study from several aspects. These aspects are as follows:

Firstly, uncertainties about load forecasting cause extra balance cost. The power system balancing process, which includes the scheduling, load following, and regulation processes is conventionally based on deterministic models. Moreover, load and weather forecasts used in these studies focused on achieving an energy balance between conventional generation and energy storage on one side as well as system load, intermittent resources, and scheduled interchange on the other side. Such studies often use their mean value statistics and do not consider the possible deviations from these mean values. Thus, it is not easy to predict to meet the demand as well as additional costs which incurred by those needs. Hence, to achieve a reliable system the predicted uncertainty ranges must be included into the scheduling, load following, and, in some extent, into the regulation processes.

The second one is the need to consider the contractual relationship between DERs and VPP system in broad detail to solve problems such as imbalance settlement. Moreover, regulation and contractual relationships between different participants must be revised to enhance DER contribution to the network with a fair economic return. Consequently, the major concern about these schemes is cost.

This thesis explored the innovative concept of a Virtual Power Plant system by applying an appropriate control scheme to optimize the operation of a system. The key contribution in this research study was to develop a combined control scheme to mitigate various shortcomings of individual control approaches. Considering the growth of DGs and optimization issues to minimize the cost of system's generation a combined control system is a relevant contribution to the literature. Beneficially, a VPP system has been developed to be versatile, so as to be applicable to several grids with different set of components. In this study, a combination of intermittent and base-load generation capacity is modeled in MATLAB. Then, the interaction of these DERs is achieved by modeling the Five Layered Modeled VPP (FLMVPP) system. In this scenario, the

FLMVPP system is simulated in MATLAB-Simulink software. To model the system, four different types of DGs such as: Photo Voltaic (PV) system, Wind Turbine (WT), Fuel Cell (FC), and Zinc Bromine Battery (ZBB) as a storage system have been considered.

One of the main features of this modeling is to capture a better understanding of the system operation by separating the function of each layer while adding flexibility to the system. As the function of each layer is separated from others, it is easy to modify each part of the model without modifying the whole system.

As the FLMVPP system is designed to achieve more cost effective and reliable electrical energy, a suitable control method is also needed to tackle this target. One necessary control strategy is the generation schedule which optimizes the operation of a Virtual Power Plant for DG units. As the next step, the combined control scheme is developed to achieve a better control method as a novelty of this research. This method has been applied as a feasible solution to mitigate the weaknesses of individual schemes thus far outlined. The FLMVPP system then has been developed in MATLAB software using Artificial Neural Network (ANN) algorithm as an appropriate technique to optimize the operation of the system outlined.

Furthermore, the ANN method is not only limited to these applications as this method widely utilized through engineering and mathematical fields. This technique, as an optimization algorithm is quiet flexible and can be applied to many types of objective functions and constraints. Developing solutions with this tool have two major benefits which are as follows:

- shorter time development
- robust and accurate system

Consequently, the novel FLMVPP and its controlling system have been developed and investigated for its appropriate and reliable operation. This has been done by considering data in three different period of time to test and identify the developed model. By applying appropriate data and target the desired results achieved. The results show that the cost of the system is minimized by minimizing the error of prediction which also leads to maximize the operation of the system.

The system has been modeled in this research study is quiet flexible so that it can be applied in different smart grid topologies with various set of grid components. This scheme is aimed to give a choice to the VPP's participants to easily make a decision for their operations. VPP research and the publications in this area date only to a few years back, and therefore, this field requires much more attention.

By considering these features and the associated challenges, this research study highlights a number of key points and some recommendations for future work.

6.1 Future work

The idea of VPP is an interesting topic that lots of research needs to be done in this field. Some issues are proposed for future works which are as follows:

- Using reversible fuel cell machines help to reduce overall system costs particularly by integrating with renewable energy resources such as wind and solar. In this case, in the presence of renewable energy the system would be able to generate hydrogen and consume it to produce power in the absence of the renewable energy. To operate in reverse mode special requirement such as catalytic electrodes should be developed which is not available for current fuel cells.

- Utilizing hydrogen will improve the viability of using more renewable energy to generate electricity. By storing electricity as hydrogen the problem associated with the intermittent nature of some renewable energy sources will be resolved. Furthermore, producing hydrogen from fossil fuels has the potential to increase CO_2 emissions significantly. So, there is a future of the hydrogen economy that is linked to renewable energy.
- Australia is well located into the large scale worldwide renewable resources by having so many resources such as wind and solar.so the having off-grid power systems by connecting battery storage would be very cost-competitive. Since the price of storage system falls and grid electricity remains expensive**.**

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