Design and Development of Protection, Control and SCADA of Model Zone Substation Laboratory Based on The IEC61850 Communication Standard

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ABSTRACT

Introduction of IEC61850 standard for substation automation has envisaged higher efficiencies and reliability in operation of energy management systems (EMS). However, despite its benefits, utility companies are hesitant to adopt and integrate IEC61850 standard because of lack of knowledge and skills among engineers in power supply industry. Under this circumstance Victoria University has been a pioneer to model Victoria University Zone Substation Automation System based on IEC61850 standard which can be a test bench and training facility for people from industry and students in academic. Basically, the focus of this research project is concerned with the design and implementation of a model zone substation automation laboratory based on IEC61850. To simulate a real-world scenario, the model zone substation primary system is designed to match the exact requirements and arrangements as exists in Melbourne-Victoria grid terminal zone substations. Therefore, the Victoria University model Substation Automations Systems (SAS) also included two sub-transmission lines, two distribution transformers, bus couplers and feeders and their protection, control, measuring ang monitoring systems. For this SAS arrangements there are eight protection and control panels have been included to match the real-world scenario. Therefore, protection and control segregation have been designed for Main Protection (X - Protection) using ABB relays and Backup Protection (Y-Protection) using GE relays, and Communication switches, RTU and SCADA also from different venders like ABB, SIEMENS and other, and all of them compatible with the IEC61850 standard. For the designing purpose two stages have been defined; station bus level which includes configuration and communication between Protective

Relays from ABB & GE, and stage two is process bus level including IEDs, CBs and Merging Units for sample values (SVs) Measurements. Through this project, interoperability facilities are inherent in IEC61850 communication standard are utilized to communicate and share substation events and reports among protection relays from different manufacturers such as ABB and GE and other. To implement this fundamental aspect of IEC61850 the overall communication system is connected to Ruggedcom switches and configured according to IEC61850 standards, using proprietary software packages and a system configuration (SCL).

In fact, the main idea for development of Victoria zone substation laboratory is to provide power engineering students, and industries like utilities for hands on experience such as how to perform tests in IEC61850 functions using various software tools from different manufacturers.

The main work for this research project was to identify the current industry requirements for SAS and design and develop a simulation system for the use of academic back ground. Therefore, to fulfil this task successfully my background as SAS design engineer work experiences contributed to a greater extent to design and implementation process of this research project.

Moreover, with the extension of the IEC61850 from substation automation level to cover distribution & transmission automation for IEC61850- 9-2 LE. In short, Victoria University's model zone substation laboratory can be utilized for R&D purposes customizing for any research studies based on IEC61850 communication standard, and given the capabilities offered by IEC61850 standard and limited implementation at substation level, development of a test bench for further utilization of IEC61850 in Power System Automation level is appreciable.

Student Declaration

“I, Srilal Gunasekera, declare that the Master by Research thesis entitled “Design and Development of Protection, Control and SCADA of Model Zone Substation Laboratory Based on the IEC61850 Communication Standard” is closer to but no more 60,000 words in length including statements and quotes and exclusive of tables, figures, appendices, book reference, references and footnotes. This thesis contains no material that has been submitted already, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work”.

[redacted]

Signature: Date: 18/11/2017

ACKNOWLEDGMENTS

The Master of Engineering by Research project presented in this thesis has been carried out with my overwhelming joy. Because I could expand greatly my electrical power system protection knowledge toward this research project and development as discussed in this thesis.

I take this opportunity tender my heartiest thanks for the people who help me, directly or indirectly, to make this thesis success. Therefore, it is indeed my pleasure to thank first the Head of the Engineering, Department of Electrical and Electronic Engineering, Victoria University, Professor Akhtar Kalam for his invaluable and expert guidance tendered that encouraged me to complete this project. Especially his attitude towards the professionalism was great and his extraordinary patience and experiences were helpful to provide advices as per the exact requirements in many aspects. His encouragement, inspiration, and liaising with his personal connects from the industry that I received from time to time were great to fulfill this project real. I would happy to give my regards also to Professor Aladin Zayegh for his valuable advice and positive feedback provided during my conference paper writing and this thesis work.

I must thank my wife, two sons and daughter for their moral support for pursuing this work. If my wife's constant assurances and assistance has not been there, completion of this project would have not been possible. I also would like to thank my mother who gave me blessings and moral support for my higher studies.

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Finally, the understanding and co-operation given throughout the project by my wife Samadara and children Randy, Deli and Yoshina who had to bear the constraints of my long hours of stay away from home and not contributing to their day to day needs, are greatly appreciated.

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LIST OF ABBRIVIATIONS

ABB	Asea Brown Boveri
AC	Alternative Current
ARS	Auto Re-Closer
AS/NZS	Australia -New Zealand Standards
BI	Binary Input
BO	Binary Output
BUEF	Back Up Earth Fault
CB	Circuit Breaker
CBF	Circuit Breaker Failure
CID	Configured IED Description
CT	Current Transformer
DC	Direct Current
DEF	Directional Earth Fault
DSP	Digital Signal Processing
EF	Earth Fault
GA	General Arrangement
GE	General Electric
GSE	Generic Substation Events
GSSE	Generic Substation State Events
GOOSE	General Object-Oriented Substation Event
GUI	Graphical User Interface

HV	High Voltage
ICD	IED Capability Description
ICT	Information and Communication Technology
I & C	Instrumentation and Control
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
LE	Limited Edition
LED	Light Emitting Diode
LN	Logical Nodes
LV	Low Voltage
MEF	Master Earth Fault
MMS	Manufacturing Message Specification
MU	Merging Unit
NOC	Network Operation Centre
OHS	Occupational Health and Safety
OLTS	ON Load Tap Changer
OS	Operating System
PACS	Power Automation Control system
PC	Personal Computer
POTT	Permissive Overreach Transfer Tripping
PPS	Pulse per Second
R & D	Research and Development
RTDS	Real Time Digital Simulation
RTU	Remote Terminal Unit

SAS	Substation Automation Systems
SC	Short Circuit
SCADA	Supervisory (or Substation) Control And Data Acquisition
SMV	Sample Measured Value
SCL	Substation Configuration Language
SCD	Substation Configuration Description
SLD	Single Line Drawing
SV	Sampled Value
TC	Technical Committee
VESI	Victoria Electricity Supply Industry
VT	Voltage Transformer
VU	Victoria University
VUZS	Vic Uni Zone Substation
VUZSA	Vic Uni Zone Substation Automation
WAP	Wide Area Protection

LIST OF PUBLICATION

1. Gunasekera S., Kalam A, Pejman P., “Design and Development of Model Zone Substation Automation Laboratory for Research, Study & Testing IEC61850 Standard”.

   CIGRE -2017, Study committee B5 colloquium September 2017, Auckland New Zealand

2. Gunasekera S., Kalam A, Zayegh A., Design of Zone Substation Automation System Modeling Laboratory for IEC61850 Standard.

   AMSC Conference and Publication November 2017, Kolkata India (payment for The publications did not go on time)

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1 CHAPTER 1: INTRODUCTION

1.1 Background

Substation Automation Systems are defined as all protection, control, monitoring, metering, SCADA, communications and other associated equipment including connections of Voltage transformers (VTs) and current transformers (CTs) and their circuits, also AC/DC power distribution for the protection and control panel equipment. SAS are designed to protect, control, monitor primary and secondary plant and equipment within the electrical network providing seamless interoperability facilities using many communication protocols.

Most of in supervision of substation conventions are yet dependent on MODBUS and DNP3 protocols and still accept costly hard wire signals are more solid than correspondence signals. To fight with these issues, fibre optic advancements and interoperability between various vender explicit IEDs by means of the utilization of Generic Object-Oriented Substation Event (GOOSE) or more absolutely IEC61850 standard has turned out to be increasingly mainstream interest in the substation automation industry. The IEC61850 standard is the sole standard to consider all standardization correspondence needs inside Substation Automation Systems.

The flow pattern for savvy substation of the energy system has brought about numerous service organizations expanding the venture of executing IEC61850 standard for their Substation Automation Systems (SAS). Be that as it may, Engineering process for realizing of substation automation utilizing IEC61850 standard requires both the learning of applying different programming tools and energy about ideas related to Information and Communication Technology (ICT). Essentially, these have been the primary purposes behind numerous utilities to defer the usage of IEC61850 standard as there is yet an absence of learned clients inside the power designing industry who are represented considerable authority in these product instruments.

Having considered the above facts, it was proposed that the University of Victoria and the industry associates to establish a facility for a zone substation simulation testing facility and to be known as the Victoria University Zone Substation Automation Simulation laboratory. The main purpose of this research project is to design and implement the proposed substation automation simulation laboratory using IEC61850 standard. Therefore, this future lab facility can be used as a testing and training facility for both power engineers and power engineering students in Victoria and Australia wide.

Research, design and developing the model zone substation automation simulation laboratory, or the model power system protection and control lab using IEC61850 standard at Vic Uni. has been proposed as industry and government funded and supported project. Therefore, this research project thesis is aimed to complete the design and implementation parts of proposed real time power system protection and communication laboratory, especially identifying all causes of negative aspects that had to put on hold of this project for about two years.

The proposed new methodology is to design and implement a model zone substation automation system (SAS) according to the arrangements of a real terminal zone substation as exists in Victoria State's terminal zone substations. The SAS simulation lab at VU is expected to technically support the changes occurring in the electricity supply industry in Victoria State and expect to expand for other states as well once the lab is set up with full functions. The Victorian Zone Substation Simulator Lab will also provide training, technical expertise, education, research and development activities as the number of suppliers and consumers increases in the market.

The significance of the project can be highlighted in its contribution for providing real-world simulation of SAS for education and training purposes. Moreover, as the extension on IEC61850 standard continues to cover different domains in power systems automation, there is always a need for laboratory facilities for verification of the results related to research on IEC61850 standard. In any case, the intrinsic issue suffered by the before endeavours was the way that the span of the undertaking and time associations to actualize it. Having recognized these troubles, the spotlight is apparently in the way of growing new philosophy to plan and built up the proposed model zone substation automation framework (SAS) which portrayed by this proposition.

1.2 Significance and Research Motivation

The objectives and motivations of this research project are summarised as follows:

- Conceptual design of model zone terminal substation automation system and review the power system protection design according to IEC61850.
- Select protective gadgets that are test conformant, interoperable and coordinate execution necessities according to the protection and control functions included in the design. The first stage it has been selected IEC61850-8-1 standard only. Therefore, expansion to Bay level or IEC61850-9-2 is the next step of the research project.
- Design Panel schematics, Protection SLD drawing with clear hard wire and GOOSE messages, assemble panels and wire the protection panels according to the compatibility with the AS/NZS standards and regulations. For e.g. substation secondary designs should comply with Victorian Electricity Supply Industry (VESI) specifications, and panel wiring arrangements should be comply with Wiring Regulations AS/NZS 3000-2008.
- Protective relays (14 different types from ABB & GE Individually) configuration using relay specific manufacture's given software tools to obtain SCL files. This includes reading ICD and make it as CID and export it as SD format. This gives an opportunity to master a System Engineering Tool (e.g. ABB IET600) to configure SAS for IEC61850 engineering for complete SCL file. Having done system configuration, it will be tested using OMICRON's CMC356 test Universe test set.

- SCADA and HMI engineering, RTU design and configuration, IED Engineering expertise. Export the CID files to get generally speaking framework arrangements and interoperability between the transfers;
- Review different types of protection logics that can replace traditional hard wire signals with GOOSE and may be RGOOSE.
- Challenge of EF and BUEF & MEF design done with only GOOSE messaging. Protection SLD are done based on GOOSE only design.
- Power system study and protection setting calculations for the model zone substation and preparing Relay setting report for 14 different types of IEDs.
- Simulate faults through Real Time Power System Simulators. This provide ability to test and qualify IED, including interoperability tests (this may be include as future needs based on current budgets for the project)
- Access to world class practical and laboratory infrastructure to support learning and the link to industry
- Practically test the validity of protection and control functions in different IEDs the algorithm using both the IEC61850 testing unit real time simulations.

1.3 Aims / Objectives of the Research

The structure of this model zone substation security and control is finished by coordinating the accurate prerequisites and courses of action of terminal zone substation mechanization in Victoria. Therefore, utilities such as Jemena, AusNet Services, and United Energy substation design principles have been studied and followed.

The model (Victoria University Zone Substation Automation System) is considered as 66/22 kV terminal zone substation with two bays, including two sub-transmission lines, two distribution transformers, bus couplers and feeders and associated equipment, protection and control systems. Figure (1) illustrates the single line diagram (SLD) of the Zone Substation considered which describes the primary structure and secondary equipment allocations for the substation.

The design plan, correspondence, deduction and testing parts of certain venture expectations is executed through both equipment and programming usage. The utilization of abnormal state computerization instruments for IRD building, for example, IET600, PCM600, EnerVista Launch Pad. For the framework testing IEDScout will be utilized by virtue of their capacity to help the IEC61850 convention and cook for all assurance IEDs and sound control units OMICRON's Test Universe programming will explicitly be utilized towards the reenactment and testing of the structured insurance and control calculation and check of blame properties.

Real Time Digital Simulation System software will be used for power system simulation and fault creation and subsequent analysis for IEC61850 standard. To obtain this simulation facility later of the project there are few proposals being discussed with the industry supporters to test and install a real-time simulator once the lab is setup. To extent this research facility type is concerned this lab with constant recreation, because this will be the first of its sort in Australia and will assume a creator of jobs for VU and the business in Victoria and countrywide.

The details of the methodology and techniques to achieve the requirements of this thesis research are as follows:

- Design and Drafting: Autodesk 2014 is used for panels, SLD and Schematics design and drafting. Having satisfactorily completed the protection SLD, protection equipment such as IEDs have been allocated for in the panel design drawing. AC/DC power wiring distribution schematics drafted prior to schematics.

  Substation Hardware Assembly: The insurance and control boards are collected as the accurate prerequisite to coordinate the Victorian Utility security board gatherings. In any case, there is a critical structure reverence that is not normal for regular hard-wired methodologies, the recently created IEC61850 convention replaces many parallel copper wires with only a couple of sequential connections by utilizing the utilization of Ethernet and fiber optic advancements. By presenting IEC61850-9-2 in future will additionally decrease the copper wire sum that right now considered. Along these lines, the back boards will look many less wires and, in this manner, will be neater and clean than customary substation security and control boards. This IEC61850 correspondence likewise plans to decrease the general support costs related with activities by means of usage of benefit the board capacities in utilities.

The panel design arrangements are done as per normal substation protection panel design practice, i.e. one panel per one protection system or one bay, also considering the bay arrangements in the primary system designs. There are two bays considered for this model zone substation automation system. For e.g. Pane No1 is allocated for the bay one sub-transmission line one protection and control system, and panel two is for the bay one transformer one protection and control system and so on. The IEDs and peripherals used in the panels are arranged as the top layer is for Ethernet Switches, and the second layer is for Main protection (or 'X' Protection) IEDs, the third layer is for Backup protection (or 'Y' Protection) IEDs and then CB management IEDs layer. Notwithstanding this errand, the production and mounting of MCBs and Links 19-inch rack mounting framework are collected withstanding present day Occupational, Health and Safety (OHS) rules.

- IEC61850 engineering: Having tastefully finished the reasonable wiring, transfer collecting of the merchant explicit IEDs, the undertaking will concentrate on achieving interoperability between transfers utilizing the IEC61850 element of Generic Object-Oriented Substation Event (GOOSE) informing. The primary worry with this specific errand is that IEDs from various producers are 14 unique models for the whole substation and are hard to design, every maker utilizes their own exclusive apparatuses for various models.

- The primary objective of the research proposal of the project is to carry out feasibility and then complete the design, then construct and commission the proposed model zone substation automation test system or in other words protection and control test laboratory, because as described above, this research study project proposal of IEC61850 standard laboratory for VU has been there for a few years due to lack of expertise to complete some areas of the project.
- The other objective is to plan, design, and arrange to implement the substation real-time simulation system using a software tool and secondary injection equipment. This will facilitate the teaching of substation automation systems just like in live condition, because the system is simulated, and faults can be simulated as in real time. Other than these, there are some other important objectives also, such as to identify and analyses the existing issues to fulfill the research project. For this, it is important to take stock of current implementations, what materials and support that has been received till date, what needs to be done in order to continue the design toward the cost and time effective design proposal to complete the laboratory be ready by the end of 2016. Also holding discussion with external parties to get their support to get assistance in some areas of the project. If these targets can be achieved, this IEC61850 standard laboratory of VU will be ready to provide training facilities for external and internal interested parties in the near future.

1.4 Outcome of the Research

As it was proposed by the Victoria University and industry associates to establish a facility for a zone substation simulation testing laboratory for IEC61850 standard, the facility was known as Victoria University Zone Substation Automation Laboratory. The School of Engineering Science and the Smart Energy Research Unit at Victoria University is always active in similar various projects such as for power generation, transmission, control, protection and utilisation of electricity industry. Therefore, the Victoria University Zone Substation Automation Laboratory project is envisaged as a skilled provider of knowledge focusing on aspects of understanding the concept and application of IEC61850 standard on a real-world system.

The industry research done on implemented the IEC61850 protocol in some projects contribute to knowledge that the current concern of the industry is attaching to challenges of design and maintenance of IEC 61850 based systems. Therefore, the awareness that IEC 61850 conformance alone is not enough to obtain interoperability, interchangeability or maintainability within or of PACS is growing. The requirement for such research and test lab for IEC61850 protocol as university level was highly regarded by the industry and venders.

It was proposed that a number of intelligent electronic devices (IEDs) for system and equipment protection (such as transmission line, transformer, feeders, bus zone, CBF protection), software (SCADA packages, RTU programming, relay logic programming, system configurator, Real time simulator), ARC, etc. be installed at VU computers (desktop and laptops) to demonstrate features of zone substation for the benefit of students, professionals and technical personnel. The facility is intended to become a centre for the zone substation studies in Victoria.

To meet the prerequisites of interoperability between merchant explicit IEDs, it needs to utilize the IED and PACS arrangement instruments. Preceding the standardisation of the IEC61850, distinctive merchant IEDs were for all intents and purposes difficult to speak with each other. Having tackled this issue by presenting IEC61850 standard the present pattern is for "we need easy to use and seller free design apparatuses". This came as makers still intentionally structured their product items utilizing their very own restrictive devices, which means clients needed to support one seller more than another. Therefore, such a lab can be utilized to discover a few answers for location the business concerns.

1.5 Research and Design Methodology

The chapters of the thesis are organised as follows:

Chapter 1: This chapter covers a brief summary of the Research Objectives and Inspirations, Research Design Procedures of the research project and the originality of the thesis.

Chapter 2: This chapter presents a complete literature review discovering core features of Substation Automation Systems (SAS) of the Victoria University and how it has become as a research project.

Chapter 3: Provides all hardware design and constructions of the protection and control model panels at VU. All SLDs based on each protection and control design and panel arrangements, AC and DC wiring diagrams technologically advanced for the practical assembly of the SAS of IEC61850 testing panels of VUZAS. A comprehensive explanation of all IEDs and their allocations according to the protection design arrangements, Panel Ethernet switches and station Ethernet switches design topology and GPS clock are discussed.

Chapter 4: Presents the separate and complete SAS functional description for “Protection and Controls” used for the VUZSAS project. Also, about arrangements of GOOSE messages with relay specific configuration software and SAS Configurator tool. The configuration procedures of the publisher and subscriber to generate, test and set IEDs is strained through CID, ICD, SCD and SCL files.

Chapter 5: Testing, panels wiring testing, AC/DC system testing, demonstrates the procedure by means of Real Time Simulation and applied tests integrating the moveable IEC61850 testing unit with Dobler, RTDS. The Dobler test set is arranged together with the RTDS for CT and VT settings of the relays to generate system fault and distance protection recordings. These sections function as the zones of protection obligatory to plot the R-X planes of the IEDs. The trip time, reach, CB status, distance to fault accurateness and harmonics are all can be analysed.

Chapter 6: This chapter covers the ‘Conclusion’ for major benefits of the project, future proposals of the exploration and suggestions for continues improvement for the proposed lab project.

2 CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

Terminal and Zone Substations are generally considered to be those that have an operating voltage below 100 kV. The role of terminal and zone substation is to convert incoming transmission voltages to voltages suitable for distribution networks. Therefore, zone substations generally consist of two or three distribution transformers and two to four sub transmission feeders and individual MV/LV feeders, voltage drop compensators and switching equipment. This primary current carrying system in any substation is called 'primary system', there is also a secondary system, and the role of the secondary system is to replicate the primary system for the purpose of proper monitoring and protection of the substation.

Remote control and indications of zone substations and field equipment are vital in ensuring safe, efficient and effective operation of an electrical distribution network. This is normally done with the development of SCADA (Supervisory Control and Data Acquisition) systems. SCADA systems main functions are to provide remote control of remote devices and to return the status, alarm and system operating data from remote devices. Remote control is generally required from one or more strategically located control centers. The main control point is often known as the Network Control Centre [1].

Terminal stations and Zone substations are drawn schematically and represented as Single Line Diagram

Figure 1 – Shows typical representation of a 66/22kV terminal zone substation which has 4 sub transmission lines, 3 distribution transformers, 3 bus bars with 2 bus couplers and 6 feeders with reactive power compensators connected to each distribution bus. The colours are represented different voltage levels.

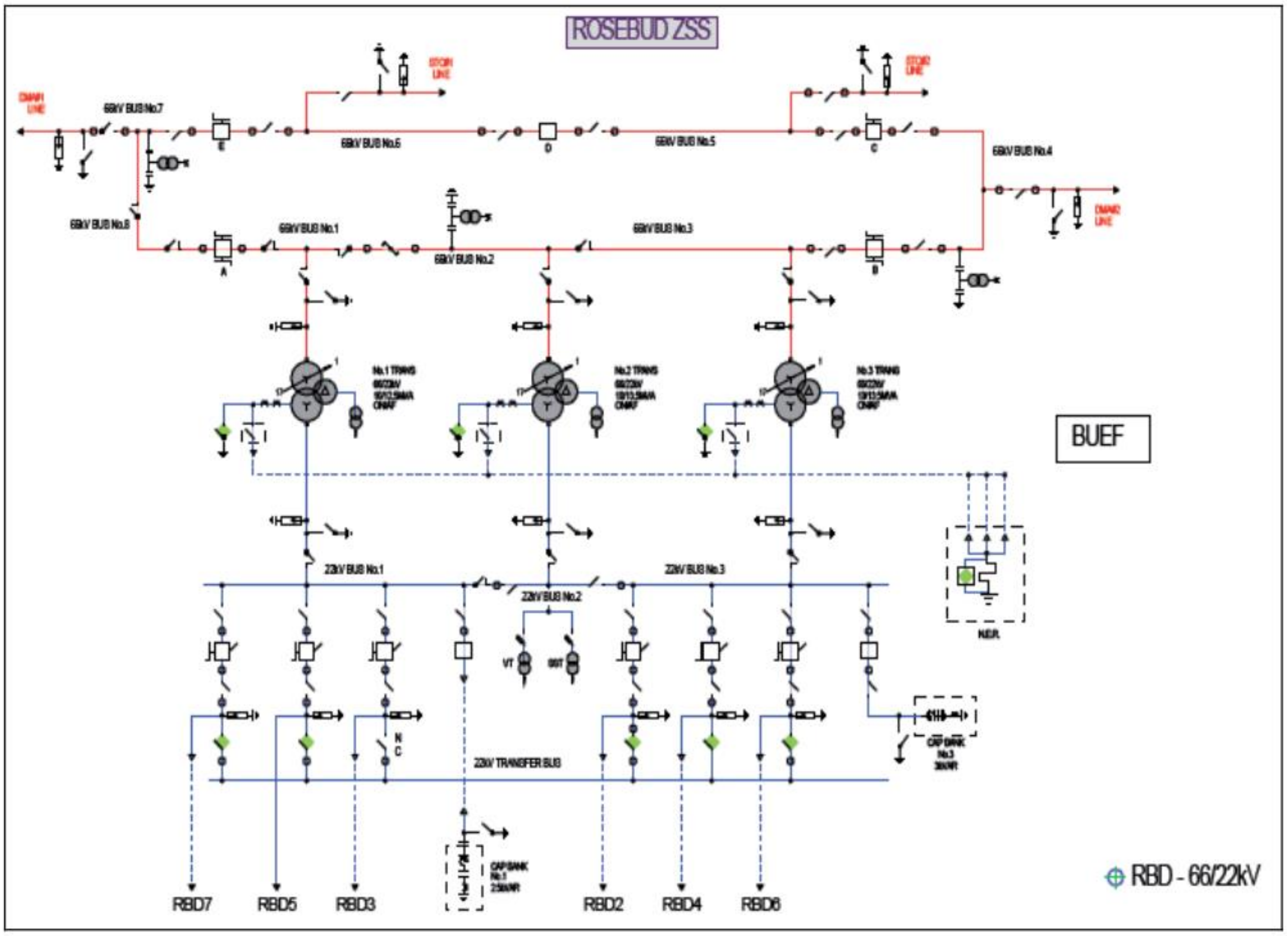


Figure 1: Single Line Diagram of Terminal Stations and Zone Substations

The proposed research venture will execute another plan and build up a model zone substation insurance and control lab at VU utilizing IEC61850 correspondence standard on station transport level. IEC 61850 is a standard for the structure of electrical substation protection and control. The IEC61850 protocol for the most part depicts the security transfers interoperability offices among various assurance hand-off fabricates, which is the correspondence among defensive transfers. These standards will encourage to share the substation events and reports between various protection methods of various insurance frameworks with no trouble of sharing the information successfully with no time delay. These conventions are Ethernet based utilizing rapid switching devices to get the vital reaction times beneath two to four milliseconds for defensive handing-off. This is done so as to get the insurance and control of the substation adequately and productively than existing system plans in zone substation in Victoria. Current mappings for this standard are to MMS (Manufacturing Message Specification), GOOSE (Generic Object-Oriented Substation Events), SV (Sampled Values), and soon to include Web Services.

IEC61850 standard have been used in high voltage transmission installation for the last 5 years in Australia. However, in Victoria this standard is still new and a hesitant technology due to lack of knowledge by staff working in this area of standard in the utility companies. In Victoria the first utility zone substation with IEC61850 standard was commissioned in 2015 (as a partial compatible one) at Broadmeadows substation of Jemena. The contractor, ABB Ltd; had given their proposal to Jemena to upgrade this substation with several design proposals of full station bus IEC61850 standard compatible upgrade solutions. However, having done series of meeting discussions, Jemena decided to upgrade only a part of the substation as a trial substation for IEC61850 standard in protection and control. The main reason was the company did not have enough skilled staff to maintain the substation automation of this kind. However, this new protocol is getting more popularity in Europe, Middle East, America and other parts of the world.

Therefore, requirement of such laboratory for the industry had been discussed in 2006 AUPEC publication which was presented by a research team led by Prof. Akhtar Kalam of VU (2). Also there had been some more publication in this research topic, viz. “Laboratory Upgrades for the Next Generation Power Utility”, and “IEC61850 Portable Testing Unit Capable of Multi-Vendor Interoperability”.Etc.. published by the same team in 2010 and 2011 respectively. As a result, in 2011, IEC61850 standard portable test unit for Multi-Vendor Interoperability had been designed and built by VU as a doctoral research project outcome (3). This unit had been developed as a convenient IEC61850 testing unit equipped for accomplishing interoperability among three different vendors of IEDs including ABB, Areva and SEL. Also, this IEC61850 testing unit was used to serve as a replica of a real-life in-service substation. The apparatus is furnished with copper, fiber and Ethernet abilities to send and receive GOOSE messages as ICD, CID, SCL and SCD files utilizing consistent hubs.

As a result, many concerned parties in the industry, academic researchers, and students have used this transportable test unit (See Figure 2).

Figure 2: Portable IEC61850 Testing Unit developed by VU

Electrical and Electronic engineering discipline within VU has not given up its initial research project proposal, i.e. the requirement of Laboratory Upgrades for the Next Generation Power Utility. Therefore, a model zone substation protection and control lab with IEC61850 standard has been proposed. As a result, during the last two to three years, the project has been progressed by finding external industry funds, a location for the zone substation laboratory at VU, collecting equipment, etc., and holding discussion with the utilities and industries to get their supports, searching design proposal as an academic novel design

As identified, presently the research and design expertise and the skill for developing the proposed model substation automation (or power system protection and control) lab at VU is not fully established. Therefore, this Master's Research project proposal has been introduced towards the completion of the design and manufacturing of this model zone substation.

On reviewing literatures the following has been noticed: The Department of Electrical and Computer Engineering, Texas A&M University had discussed about Modelling and Simulation Tools for Teaching Protective Relaying Design and Application for the Smart Grid using MATLAB/Simulink in their conference paper of Oct 2010, but no usage of the IEC61850 standards or as real time testing facility of protection relays has been developed (4). Another interesting publication by Queensland University of Technology had discussed about precision timing and real-time data networks for digital substation automation, however the proposed a new technology which is for both the measurement of primary currents and voltage and transfer of these measurements to substation control systems enabling significant improvements to the

design and operation of substations using IEC61850 communication protocol, but lacks research on the zone substation modelling and real time testing facilities (5).
There are several successful laboratory simulation implementations done in the past such as on generator protection simulation system, but this has been limited to demonstrate the concept and complicacies of generator protection in the laboratory environment [6].

OPAL-RT TECHNOLOGIES of Montreal, Quebec, Canada is a leading company for power system real-time digital simulation systems. Their HYPERSIM simulation is the only real-time digital simulator with the power to simulate and analyses very large-scale power systems with three-phase buses. It is used for factory acceptance and system integration testing, as well as for R&D works and commissioning tests. This solution relies on open architecture, high-speed parallel processing and modular scalability to deliver standard real-time simulators designed to meet the evolving needs of the most demanding utilities and manufacturers (7).
Figure 3 shows the OPAL-RT simulated power system for full IEC61850 standard substation automation system, it also how does the substation primary and secondary systems simulation and how does it connect to a protective relay as simulated Sample values or GOOSE.

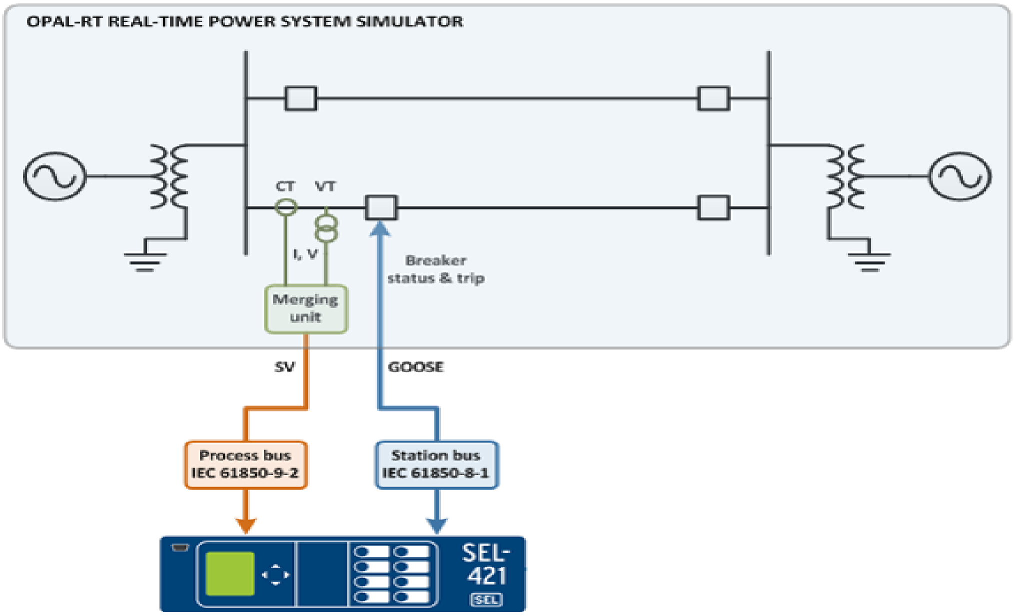


Figure 3: OPAL-RT simulated power system

Figure 4 shows schematic representation for VU lab as discussed with OPAL-RT simulation solutions. This diagram shows how all equipment are integrated to form and simulate a real substation. This system proposes to simulate both the process bus and station bus at the same time.

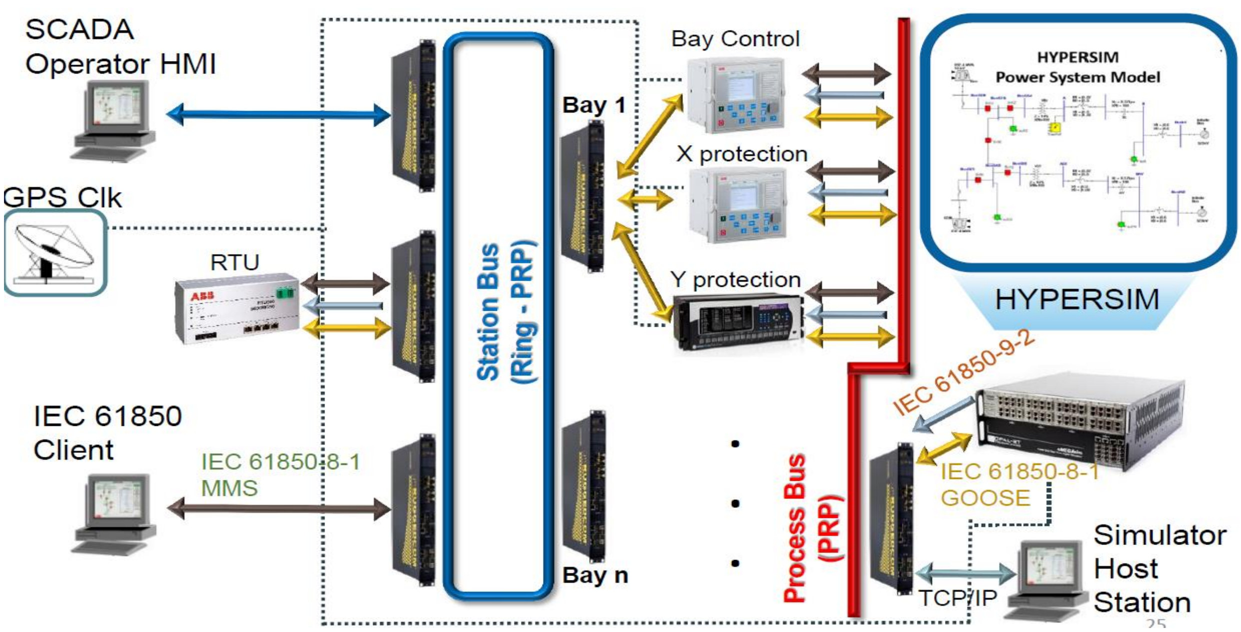
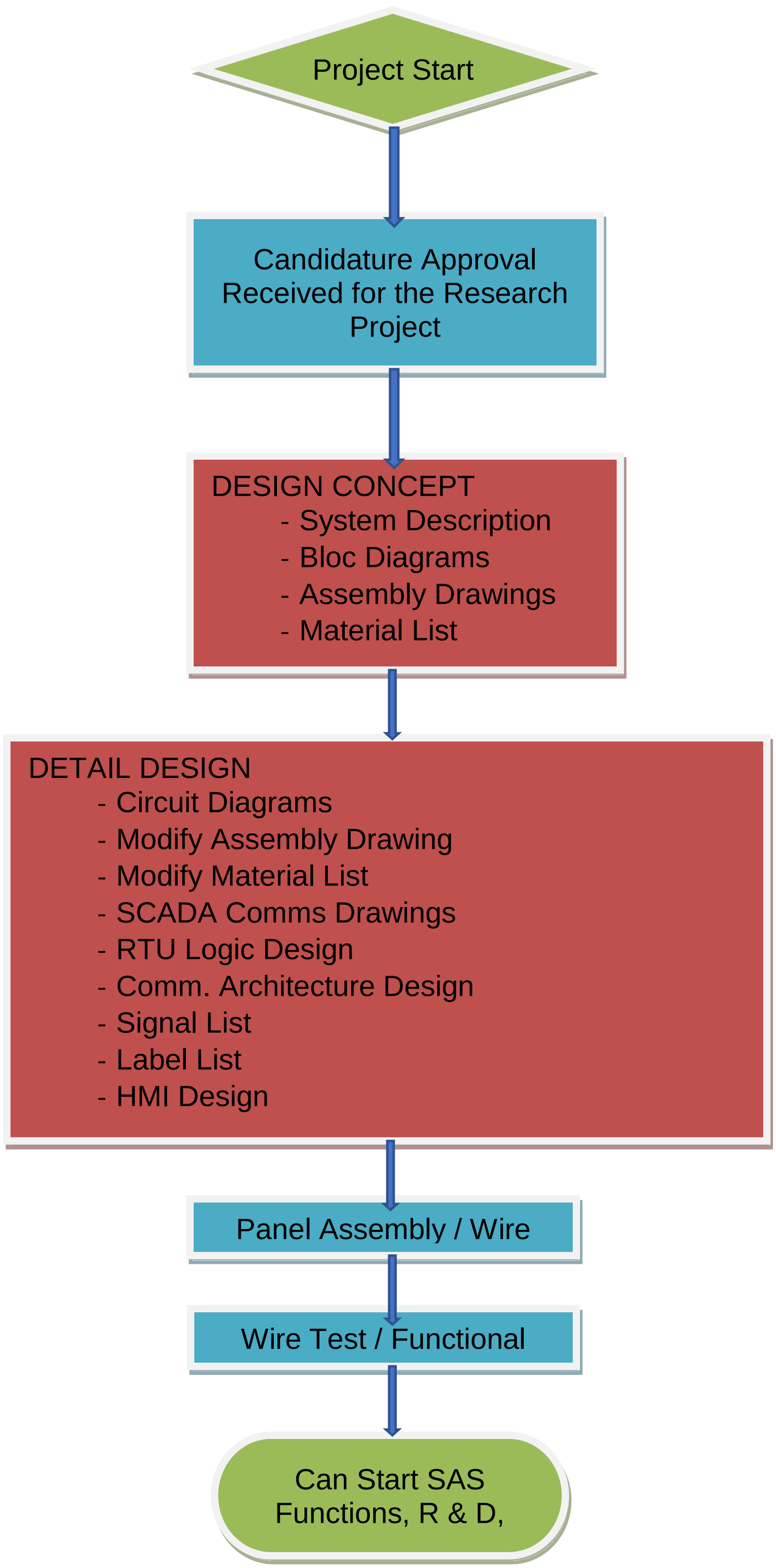


Figure 4: Schematic representation for VU lab with OPAL-RT simulation solution

3 CHAPTER 3: DESIGN METHODOLOGY

Following flowchart described the model SAS design methodology :



According to the above flowchart, some documents related with some design steps are not documented and not attached to the research report., however the mandatory design documents have been included in.

The model zone substation automation system is designed based on the conceptual protection single line diagram (SLD) as illustrates in Figure 5. According to this SLD design criteria for the model VUZSA System, it has been 66/22 kV terminal zone substation with two bays, including two sub-transmission lines, two distribution transformers, bus couplers and feeders and associated equipment, protection and control systems. The SLD in Figure 5 also describes clearly the primary structure and secondary equipment allocations for the substation.

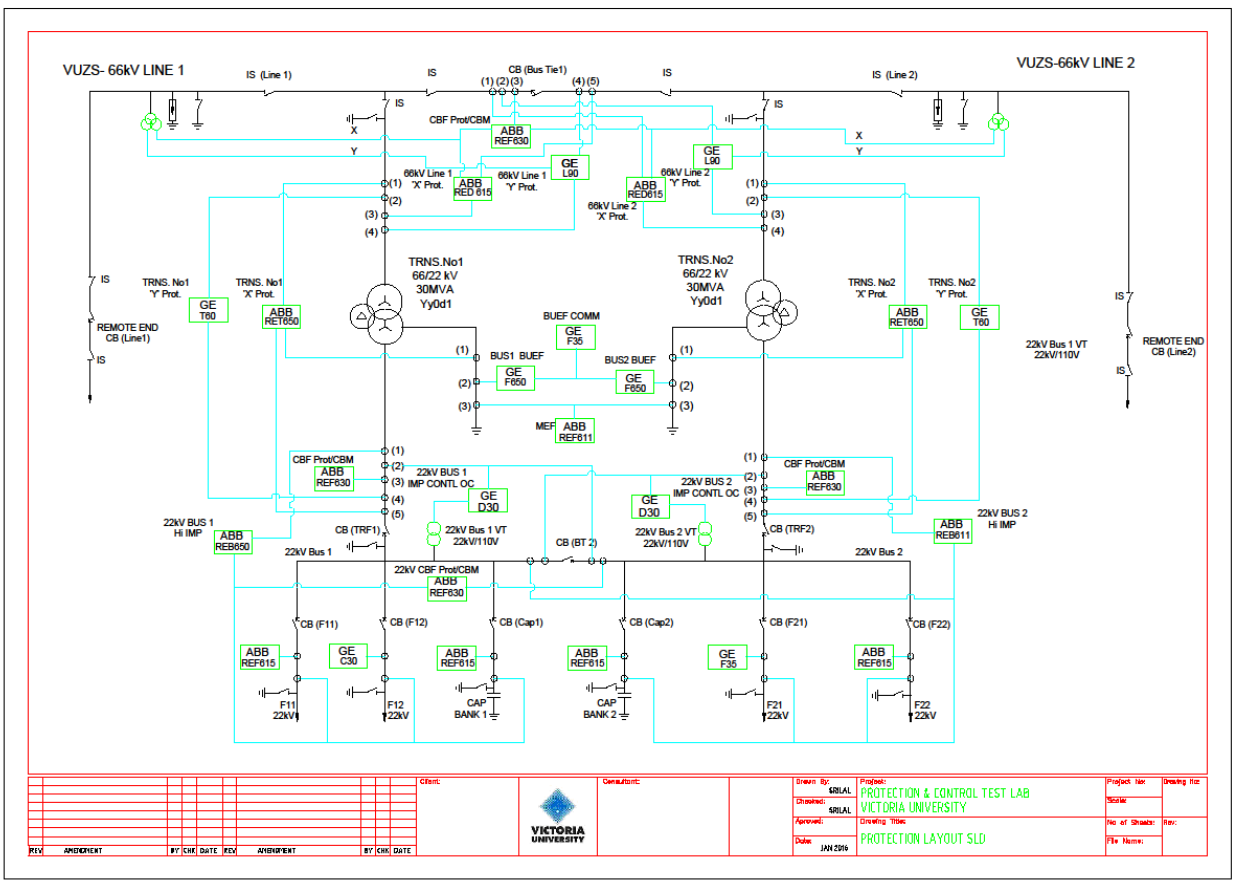


Figure 5: SLD of the VU Zone Substation

The Protection and Control system is designed as for 66/22 kV Victoria University Model Zone Substation, and the equipment selected for the substation design arrangement is as follows:

66/22 kV Zone Substation included with: -

- 66kV Sub Transmission Line Bays
- 66kV Bus Tie Circuit Breaker
- 66kV Local and Remote End CBs per Transmission Line bay
- 66/22 kV Transformers, one per Bay
- 22kV Bus Couplers
- 22kV Circuit Breakers including 22KV Bus Tie CB
- 22kV Feeders including CBs

Refer to the single line drawing described above, and considering the standards generally applied in the industry for protection panel designs arrangements an overview of the 66/22kV main protection and control equipment.is shown in Figure 6.

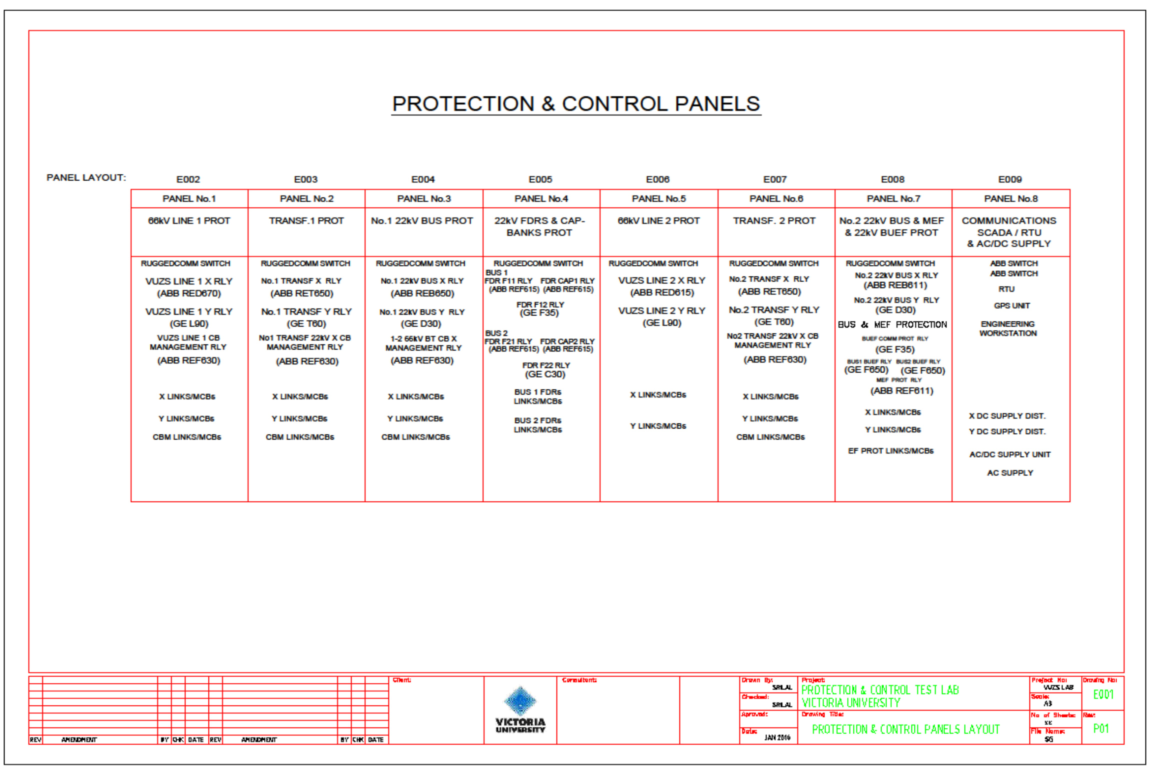


Figure 6: Panel Lay out Design of the VU Zone Substation

Panels with design incorporating 66/22kV plant are provided as follows (Table 1):

66/22kV Substation	**Item Designation**	**Panel**
66kV VUZS No1 Line & CB	ABB RED615, GE L90, ABB REF630	No 1
66/22 kV Transformer 1 & CB	ABB RET650, GE T60,ABB REF630	No 2
22kV Bus 1 & CB	ABB REB650, GE D30, ABB REF630	No 3
22kV Feeders	ABB REF615 (4), GE F35 (2)	No 4
66kV VUZS No2 Line	ABB RED615, GE L90	No 5
66/22 kV Transformer 2	ABB RET650, GE T60,ABB REF630	No 6
22kV Bus 1 & MEF, BUEF	ABB REB611, GED30, GE F650	No 7
SCADA & AC/DC Supply	ABB RTU560/ MicroSCADA	No 8

Table 1: IEDs and Communication Hardware in VUZS Automation Laboratory

3.1 Protection and Control Cubicles

The protection, control, RTU communication equipment and Substation Monitoring Equipment (SMS) are mounted in cubicles from ERNTEC Pty. Limited. The protection cubicles, which include a vertical strip of marshalling terminals on both sides of the back panel. Panels have dimensions 900 x 700 x 2100 (W x D x H) mm and are of protection Class IP 54. The cubicles have a 19-inch fixed frame for mounting the protection, control, RTU560 communication equipment and SMS equipment. Cubicles do not have a front door with a Perspex insert. The cubicles are painted with the same color on the interior as the exterior. The cubicle color is RAL 7035 (light grey texture). Indoor lighting is provided in each cubicle. All wiring within the cubicles is done using 1.5 sq. mm wire except those for CT and earth circuits that use 2.5 sq mm wires. The exception to this is 1.0 sq. mm wire used where equipment can only accommodate this size of wire the wires, with the exception of some equipment which are unsuitable for lugs, will be terminated with the use of lugs. Terminals used are M6/8.STI for isolatable, M4/6.SNBT for analog, and M4/6 for non-isolatable terminations and all are from Phoenix. Horizontally mounted isolatable (or linked) terminals drop open and vertically mounted terminals open towards the right.

The wire system and numbers, internal to the cubicle, are to our standard practice as per this project. Wires within the same module (i.e., a rack or relay) do not have wire numbers. Wires from module to module or module to terminals (where “terminal” means terminal block e.g. M4/6 or M6/8.STI) have three-digit wire numbers. CT and VT wires are numbered as RI, WI, BI and RU, WU, BU followed by a numbed to be three digits. All wires, except, those for CT and VT circuits and earth wires are grey stranded flexible wire. CT and VT and AC supply wiring is of the phase colours red, white, blue and black and earth wires are green/yellow.

Terminals for AC type circuit wiring (e.g. CT, VT, 240Vac) and DC type wiring (e.g. trip, control, auxiliary supplies) are separated into separate groups. This reduces the extent to which AC and DC wiring covers common routes.

Panel Labels are black lettering on white gravoply fixed with double sided adhesive tape to the panels sizes are per Victorian Utility standards.

4 CHAPTER 4 – PROTECTION, CONTROL & COMMUNICATION FUNCTION DESIGNS DESCRIPTION

4.1 Protection Function Designs Description

The primary function of the protection scheme is to provide

- safety of personnel
- safety of equipment
- Minimize possible disturbance to the system in the event of faults.

Tripping of a faulty part of the system shall take place before adjacent parts of the system are affected. The design of the protection scheme is such that high tripping reliability will be achieved for e.g. GOOSE Tripping.

4.2 Protection Basic Principles

4.2.1 Protective Relaying- Introduction

Power System Protection and Protective Relaying are the terms that define some of the major components of electric power system protection and control engineering. This is concerned with the identification or detection and furthermore separation or disconnection and controlling for system faults or short circuits and any other abnormal states and conditions of the energy framework. When consider the role of protective relaying following three criteria of the power system design and power system operation are important:

- Typical or normal operation
- counteractive action from claiming (prevention) of electrical failure
- Minimizing the consequences of faults.

The above highlighted terms include those base necessities for providing the existing client demand and a certain measure for foreseen future demand of the load. Configuration of the energy framework to ordinary operation includes real overhead for supplies What's more incorporates attention of:

- Selections between thermal, hydro, nuclear or renewable and sustainable power sources.
- Location of power stations
- Power transmission to the client
- System analysis of the load behavior and forecasting for the future demand
- Power metering and monitoring
- Regulation of Voltage and frequency
- Power system procedure
- System upgrades and upkeep necessities
- The issues of plant or component failure.

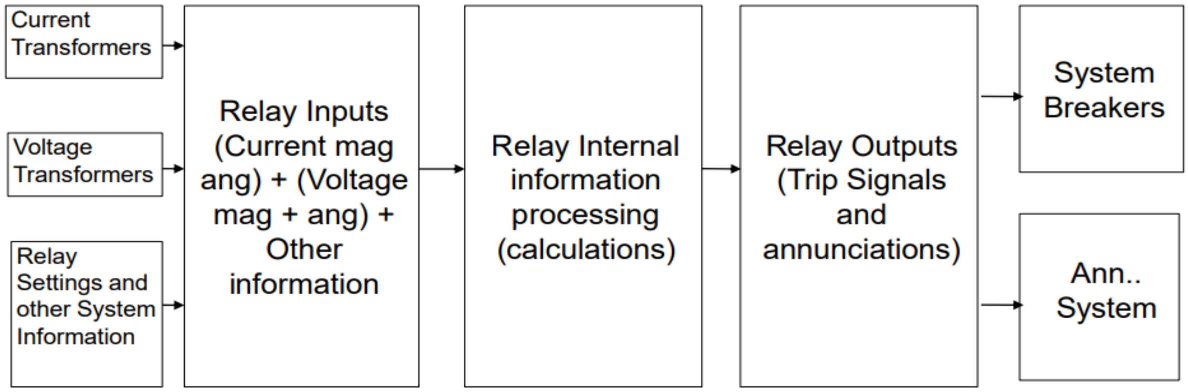
Protection assurance structures need to not intercede with or confinement the ordinary task of the machine anyway should reliably screen the machine to end up mindful of electrical faults or surprising electrical conditions.

Other vital factors in the layout of the energy device are:

- integration of structures designed at preventing failures, and
- requirements for alleviating the results of fault when happens.

Considering the new methods of analysis of power system, it engages both recourses', as said through the cost of somewhat precise condition. Significant developments proceed to be done towards increased consistency. But also, an increasing number of higher dependences is being positioned on power systems. Subsequently, even although the likelihood of faults is diminished, the acceptance of the likely damage to the facility is also reduced.

Following Diagram Describe Simplified Protective Relays Basic Components



4.2.2 Power System, Plant and Layout of Substations

The resulting notes offer a summary of power networks and in this manner the power framework's types of gear that are relevant to style of the power protection structure. They likewise describe a bit of the different CB operation plans which possible to be changed over from one power system arrangement to another active system. This would assure to spot few of main issues which require to be well-considered inside the plan of power system protection.

Power System

Power network for power generation, transmission and distribution is arranged from generators, transmission systems, power transformers, static compensators, i.e. and so forth related in an exceedingly framework to supply solid transportation of voltage from the generator point to the client without and disturbance or distortions. The points of confinement of the plant (scope and electrical stipulations) and its related disconnected switchgear, alongside the technique of the framework, majorly affect the arranging of the protection framework.

System impedances and system grounding measures can verify the greatness and pathway of fault currents, range and place of CTs and VTs that can verify the planning zones of protection that, successively effects the reliability, dependability and availability of the full power structure. Subsequently, the protection expertise should have a thorough experience and familiarity of the design of each power system and therefore the facility so as to influence the design. [21]

The following paragraphs in short define several plant and system design concerns.

Power Generators

Power generators seem in an exceedingly range of sizes starting from 1 MW (classically in a co-generation power station) to 800 MW or additional in a massive oil fueled plant. The voltages produced are usually strained within the vary of 11kV to 22kV because of type limitations within electrical insulation of the generator systems. This suggests that increase transformers of voltages are usually required to attach at the generator to the power transmission, also vital limitations within the type of unit protection and system, so the generators are considered as the source impedances for the protection viewpoint.

A difference is created for two circumstances, specifically the direct and quadrature axis that cowl the locations once the rotor poles axis is in part with poles of the generator, or not in phase and ninety electrical degrees out. Short circuit current (of one brief fault from the electrical power network) have reactive behavior principally and can cause drips within the voltage of direct axis, so it tends to use the impedances of the direct axis for any short circuit simulation and calculations.

When consider the key design parameter of a generator, it can be known as generator impedance. This impedance behaves differently with time subsequent nature of faults, because of the circulation current in the generator electrical circuit due inductive behavior of generator winging. The value of these currents or the source impedance is generally subjected to change with the time factor that will pass through the origin of the generator circuit, and therefore three time zones are defined for three Impedances values for the determination of three different values of fault currents. They are basically name as:

- The sub-transient reactance (X_d”) - this fixes the peak fault currents during the first one to three cycles from a fault occurrence.

- The transient reactance (X_d’) - this fixes the level of current three to twenty cycles, which is specific to the generator, and can contribute to a fault throughout that transient time.

- The steady state reactance (X_d) - this fixes the solid-state stabilizing short circuit current value after the above transient reactance time.

The factor of the time which regulates the length of sub-transient period, and transient stages and connected is called time constant of the short current is set by the impedance of the generator, basically known as Q-factor as ratio of inductance and resistance, also referred as X/R quantitative of the generator winding. It's typically mentioned because the X/R quantitative relation of the electrical machine (i.e. generator). For the complex generator arrangement, the Q-factor relation can be the maximum value which is close to the generation supply, and decreases since the transformers, transmission lines are interpolated amongst the load and the generation and therefore, the X/R quantitative relation is vital factor that need to resolve issues with power system performance evaluations.

In protection computations strategies, we will in general think about the apparent voltage at the terminal of every electrical machine that is acting as sluggish for the electrical machines impedance, for example at the point when all machines are viewed as no-load, and their voltages are all in a same phase, a few designers utilize the sub-transient impedance Xd'' for their calculation of fault current and put on a decrement to curtail current with the factor of time, figuring some action and operational time of relay contacts and CBs of the protection systems. That is worthy for right rapid measure is if required, however, numerous creators just utilize the transient ohmic resistance Xd' and acknowledge this is not changed all through the operational time of the protection relays. For some applications this is a worthy to consider the fault current calculations therefore these thesis notes are upheld the usage of the transient impedance Xd'

Another aspect for the design consideration position is that the technique of neutral grounding of power systems. In protection systems system earthing methides regulates for earth fault currents within the required level of the network. The neutral point of the generators is usually grounded via a high resistive impedance to control the magnitude of ground currents of each phase to earth fault within the electrical system of generator circuits, and that may mitigate the major damages cam cause do to the generator insulations. The trail for phase to ground currents on the outdoor grid is predictable over neutral earthing of transformer star windings. [21]

<u>Power Transformers</u>

The electric power transformers of varied sizes are placed throughout the utility and other electrical distribution system. The transformers that convert the generator voltage, also called as ‘step-up’, to levels appropriate for the power transmission voltage arrangement which transmits high voltage for the load centers. Considering on the magnitude of the arrangement, power transmission high voltages can vary from 132kV to 500kV. The transformers use to reduce the voltages at the bulk load centers, also called as ‘step-down’, to usually cut down to distribution voltage levels of 66kV or 33kV which transmits bulk power over a ‘subtransmission network’. This also provides the medium HV distribution system. The voltage system in distributions is often found to be 33kV, 22kV or 11kV levels and provides distribution load centers that transform or further step-down the voltage to the client level.

The bulky load transformers or called as large transformers within the power generating plants or power transmission substations could also be created of 3 single phase elements or just with one three phase system. Due to the difficulties of transport issues, the size of the transformers needs to be considered, so this limitation will often verify the selection that should be created beforehand. Three single phase elements arrangement additionally absorbing an extra space, have a lot of complicated arrangements for their connections expressively through the connection of Delta and other types of transformer windings, despite their technical advantages. The exterior Delta winding connections have lot of unprotected areas to faults and therefore severe damages may result due to large circulating fault currents, that may be inevitably dangerous for the insulation of transformer windings, especially for Delta connections.

The impedances of transformer, inert-connections of transformer winding (e.g. star delta, interstar) and arrangements of earthing system are also vital when do the protection designs. These features confirm the greatness and path of short circuit currents and therefore the flexibility for protection arrangements design is also very important to plan for detection and isolation of faulty elements in the power system.

In design viewpoint in protection design calculations it sometimes adequate to consider the transformer impedance inductive element only, and this may generally note as a percent (%) form, or per unit (p.u.) system, i.e. percentage value of that the proportion of volt drops across the transformer terminals at nominal design parameters (voltage and current). The fault current at the transformer terminals can be calculated using the below formula. [21]

$$\frac{I_{Rated} \times 100}{\%Z}$$

Power Transmission Lines

Calculation of fault currents, Impedances and fault locations are the most important parameter of power transmission line for protection purposes. These parameters are usually calculated as impedance. i.e. in resistive and reactive ohms or impedance of power frequency and they are symbolized as R+jX or $Z\angle\theta$, where R factor is resistance and the jX factor is reactance per phase, reactance is calculated from the following basic formula:

$$jX = k \log_{10} \frac{\text{Separation of conductors}}{\text{k1 (radius of conductor)}}$$

The mutual coupling with parallel lines with the presence of overhead earth conductors are the factors that influence the impedance in a system. [21]

Substation Circuit Breaker Arrangements

Power switching, or CB arrangements utilized in a power structure or in substations within the proposed scheme are prejudiced by some factors and there is no significant correct or incorrect arrangement that can be argued, but some of the factors important that need to be considered for switching arrangements are -

- Cost benefit and savings criteria,
- History of expansion of the individual installations that is sections created within the past is wasteful to alter due to wide unfold changes which will be needed,
- Operation and maintenance concerned factors,
- Reliability, Dependability, Security, and uninterrupted and contestant power supply to the customer (Power quality issues),
- Flexibility for future extensions, upgrading and expansion.

There are several kinds of CB arrangements used on switching of the power system, but these armaments are influenced the protection system design.
The protection design engineer's major concern is that the ability to determine acceptable protection zones that may by selection to separate faulty things of the substation. During this esteem the amount and placement of current and voltage transformers could be a major thought as well. The favorite idea can be to find as CTs are placed on both side on CBs, in and out of transformers, and in and out of generators so in this manner` self-governing protection overlapped zones can be made for every equipment in the substation. This arrangement may get outcome in important prices drops as well, either within the price of the substation equipment (i.e. CB structure with the CT's mounted on it ..etc.) or within the price of extra area may be

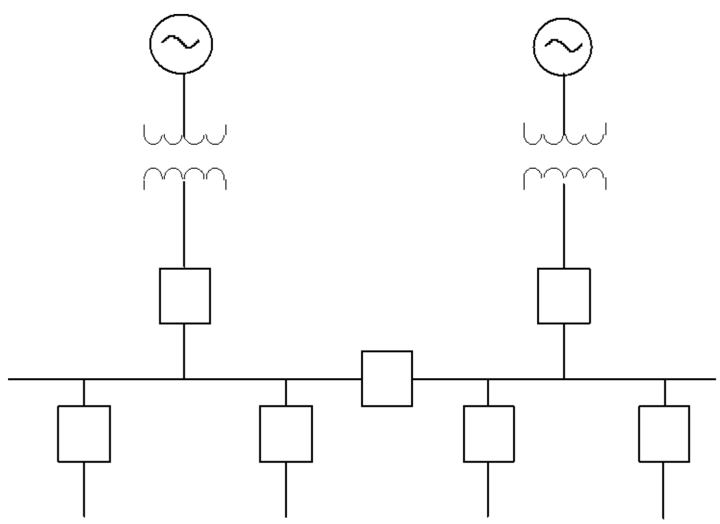
required for mounting constructions to mount CT's of free standing in the substation. In this prearrangement it's achievable to realize about the protection zones overlapping, however it may result in 'blind spots' or 'dead zones' that the need different procedures to address these second issues. For instance, the CT's set as the sideways of a CB, a fault on the insulation between the CT and the CB (Blind Spot) is now sensed by protection zones allocated for the Bus, however it is not in the way of given protection zone. The protection of the bus can function to operate the CBs of its own protections [21]

Substation Single CB Switching Arrangement

In this CB arrangement, every item that is needing to be protected in a substation has its own CB. Therefore, this arrangement has -

- Cost effective in relations of plant design necessities,
- Conventional and easy for operation and maintenance, and do them safely,
- There are some difficulties arise for selection of the location for CT's and VT's

In this substation switching arrangement, inflexibility is the major disadvantage in programming maintenance and outage plans. E.g., a supply loss for the connected plant item can have due to an outage of a. [21]



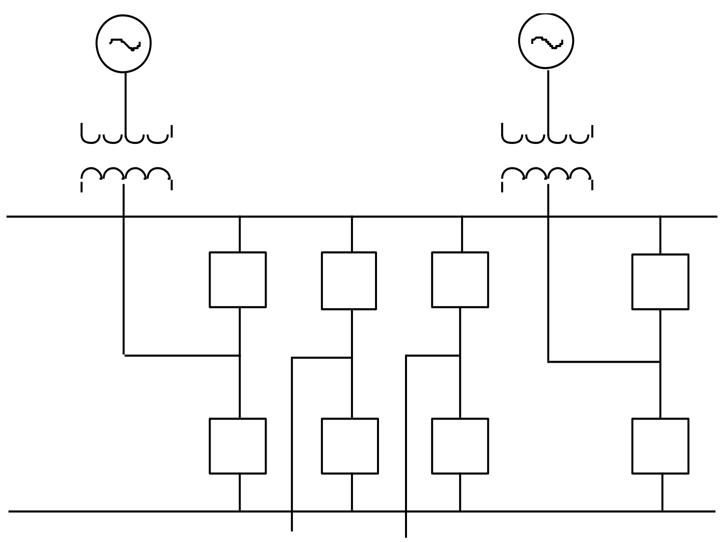
Substation Single Switching

Substation Double CB Switching Arrangement

In this arrangement, individually two circuit breakers are arranged for each plant item to provide access to either of two busbars, i.e. main or transfer bus, via this CB arrangement.

This is a versatile procedure and has the main benefit that any element of the substation may be switched over from one bus-bar to another bus-bar while not disturbing the feeders that already connected to the loads. In this substation arrangement there is not any explicit protection design issues noted that may prevent to implement. It is comparatively simple to choose protection zones for covering of every equipment in the substation, such as busbars and incoming and outgoing feeders. etc.

The main shortcoming is that the big number of circuit breaker mounting, and related auxiliary items and area needs for these things. etc. This extra spending needs to be evaluated compared to the profit from income or opportuneness of possession power stations for generation from different plants while in commission throughout the outages of panned or breakdown. etc. of circuit breakers or busbars. This can be for routine or planned maintenance and also due to a result of plant failure.



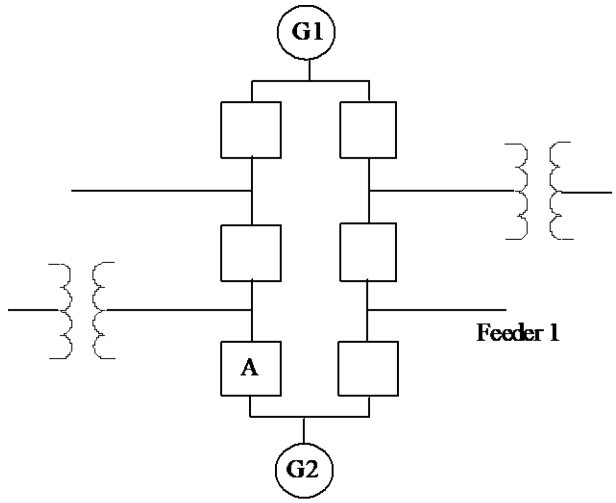
Substation Double Switching

There are a few standby resources can frequently accomplish by utilizing the both of single and double switching arrangements, which is a mixed combination. For e.g. this arrangement can be consistently kept up a generator, which can be single exchanged and help necessities on the other CB of the other bus, and this would encourage any plans for the maintenance of generator ..etc. For this situation the generators as appeared of the above CB switching diagram chart inside the doubled switched course of action, it can be eliminated two circuit breaks arrangement by single shift the generators to alternate busbars. [21]

Substation Mesh Layout

Mesh station scheme has greatest benefits compared to two layouts arrangement as above explained, because all station equipment may be set aside continuous in operation when there is an outage of anyone of the CB. Nonetheless, every item of plant needs just one CB and its simplest kind of procedure has many advantages compared with the two CB's for the double switched arrangement.

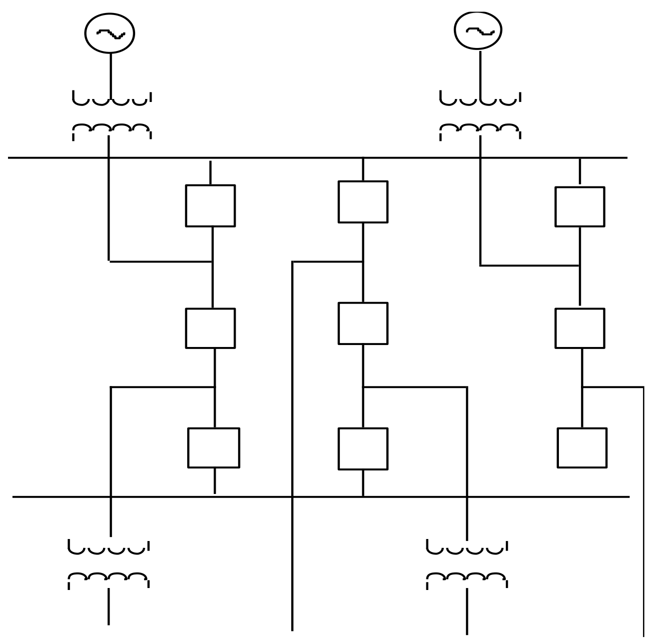
In mesh station layout, the limitation on the substation equipment quantity of things is typically about six CBs (in order), as not prejudgment the system within any occurrence of breakdowns, failures, outage etc. For e.g., referee to the below diagram of six CB mesh, for the maintenance assumed 'A' CB is opened, and there is a fault on Feeder 1, then the power system is left with one generator separated only from the faulty feeder. This layout is versatile and install a smaller number of CBs compared to the previously discussed duple CB switching procedure. In this arrangement no specific design issues from a protection point of view. It's comparatively simple to ascertain zones selected for cover of every item of the plant and therefore the in and out feeders provided CTs are supplied separately with electrical circuit breakers and substation element and looking on the scheme of the protection selected VTs are given within the feeders of outgoing. [21]



Six Circuit Breaker Mesh

Substation 1½ CB Switching

This substation arrangement has more flexibility and more descriptive system than the mesh substation described above, so this substation is known the 1½ CB substation.



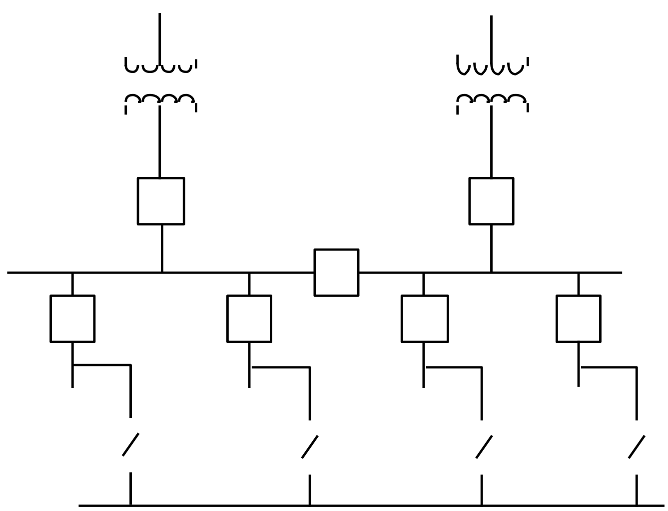
1½ Circuit Breaker

For the 1½ CB substation more CB's are there than the mesh substation procedure, so though the cost is higher but has better dependability for faults in the power transmission systems or power generation systems. In this arrangement protection arrangements is simple, but provided with CTs and VTs are carefully designed and allocated. [21]

Substation Transfer Bus Arrangement

The substations which has got many feeders, this arrangement is applicable to those substations. Because, it gives more flexibility than the single switched arrangement. This is done such a way to be kept in service if any feeder while its circuit breaker is not in service, for e.g. maintenance, breakdowns ...etc., The transfer bus is used for the connecting of the feeder with an alternative feeder in parallel or to a standby CB.
From the operation viewpoint this CB arrangement is more complicated, because it will involve transferring through auxiliary switches for the circuits of CTs, VTs and protection via a transfer isolator switch, and this done mainly to sustain enough safety on the feeder's protection.

Some difficulties also can stand up with the procedure of ground fault protection with the operation of parallel feeder lines because of the load currents can be unbalance and this residual current can pick up as false 'ground fault current' within the protection system. Superior in operation procedures could also be needed to beat this drawback. [21]



Transfer Bus

4.2.3 The Protective Relay - Function

The role of protective relaying is vital for the detection, selection and speedy isolation from supplying of any feeder, unit, or plant. etc. of a power system when it occurs a short circuit or an earth fault, or when the system behaves under irregular and abnormal way that may impact or need to restrict the actual operation of the healthy part of the power system. This can be achieved using protective relays properly selected and implemented ina substation automation system. This is included the proper protection, control, measuring and monitoring systems. If this is correctly done the protective relaying would sense any failure and irregular conditions and operate correct CBs to open and isolate the effected part from the system.

Each generator, transformer, bus, transmission line, etc. of a power system, have their own circuit breakers which are generally located closer to the unit so that faulty portion can be entirely separated from the connected power network. The allocated CBs in this manner should have adequate capability, to bear the utmost transitorily short circuit current which will travel through the faulty system, therefore to interrupt this large current they must additionally bear extra inbuilt arrangements to cutoff and extinguish a large fault currents, and then it is designed in line with definite prescribed specifications for the protection view point. Where circuit breakers and protection relays are not cost effectively justified, high rupturing fuse can be employed for this protection purpose, but it should be calculated carefully to select the ratings.

The other role of relays of distance protection is to give some suggestion for the distance to the fault or an approximate fault location. Such information will assist maintenance crew, also system operators in planning prior arrangements to the repair work by obtaining uninterrupted power supply or minimum downtime to the customers. However additionally, by using programmed event recording equipment records, the design and develop engineers can observe and can do the data fault analysis, to provide suggestion for future fault-prevention and mitigation options. [21]

4.2.4 The Protective Relaying - Principles

The power system protective relays are commonly isolated into two primary groups: -

- "primary" protection design system
- "back-up" protection design system

<u>Primary Protection Design System</u>

Primary protection relaying design is the first line of protection in the system, whereas back-up relaying provides, as the name suggests ‘back up’ for the primary protection in case of failure of the first lien one to remove the fault or anomaly, either can be due to failure of primary protection equipment or system component of the plant such as CTs, VTs and CBs.

Observation:
The equipment protective circuit breakers are situated in shut proximity to every grid component. This facility makes it potential to trip or separate solely a faulty component. Sometimes, a CB between two in line components could also be omitted, during which event each component should be isolated for a failure in either one.

Protected areas are separately recognized as protection zones for all system component. The importance of this is, if any short circuit or earth fault happening inside a protection it would trip all CBs inside that protection zone.

It is proved that, for faults inside the zone wherever two next to protecting zones overlap, additional breakers are tripped than the minimum required to disconnect the faulty component. But, if there has been no overlap, a failure in a very area between zones wouldn't dwell either zone, and so no breakers would be tripped. The overlap is that the lesser of the two evils. The extent of the overlap is comparatively tiny, and therefore the likelihood of failure during this region is low; consequently, the tripping of too several breakers are quite occasional.

When consider the protecting zones are overlapped near a CB or CT, this can be the preferred solution, because of for faults at anyplace apart from within the overlapped area, the lowest amount of CBs must be tripped. [21]

<u>Back-up Protection Design System</u>

If the system or equipment faults are not removed in the given fault clearance time due to failure or incapability of primary protection system or the failure of connected primary protection equipment, such as CBs, CTs, VTs to operate, then the ‘Back-up’ or ‘secondary’ protection system is planned to activate to clear these failures after a set time delay.

About the possible causes of failures of primary-relaying and a clear understanding of them is very important for a high-level design obligation of the practices concerned in secondary protection. Once main protection or the primary protection fails to operate it could stop primary relaying from inflicting the tripping for power system faults. Hence, primary protection system can malfunction due any of the following reasons:

- CT or VT connection to relays
- Relay supply fail - DC supply fail
- Faulty protective relays or relay functional failure
- Tripping circuit failure or broken wire in the tripping and CB mechanism
- Faulty CB and tripping mechanism.

If the primary and back-up protection systems are not segregated and organized correctly to be functioned independently, then, something failure of primary protection relaying system can additionally cause failure of back-up protection system. For e.g. if use common DC supply, common cables etc. To mitigate this issue two additional steps in protection can be considered as follows: -

- Protection ‘Remote’ backup
- Protection ‘Local’ backup

Protection 'remote' backup and protection 'local' back-up designs and protection relays are placed and set up with time coordination, and current coordination or any other logic combinations. This is mainly arranged to provide back up if the local protection fails totally to clear any fault locally by local protective relays. To this point as likely, the exercise may be to find a back-up protection equipment in diverse substation systems. For e.g., Transmission line back-up protection for a line section. The back-up relays for this line section is normally arranged to trip breakers from every section. ought to one breaker fail to trip for a fault on a line section, then as a backup different breaker are to trip; breakers and their associated back-up relaying equipment, being physically other than the equipment that has failed, are not possible to be simultaneously affected as could be the case if breakers were chosen instead. [21]

The back-up protection relays allocated at locations offer protection back-up for faults on the bus at anyplace in the substation. The back-up relays assigned as remote or local in the system can give secondary protection as back-up for the faults anywhere in the system if those relays sense the faults. Though, this repetition of back is simply and has some secondary advantage there may be some protection mal functions if the protection coordination is not calculated correctly.

The other role of this back-up protection is repeatedly to deliver assurance when the local protection apparatus is not in the capability of upkeeping its functions, also during repairs, testing and outages in the primary relaying system.

When back-up protection relaying functions, it can be evident that a greater portion of the network is separated than when main protection relaying activates properly to clear any local faults. This is an unwanted action which is also inevitable if back-up relaying is to be assigned independent of those factors that may cause primary protection relaying to fail. However, back-up protection relaying system emphasizes the importance of the second requirement of system protection, that it must operate with enough time delay so that primary protection relaying will be set up with enough time to operate if it is capable to do that. This can be further explained, when a fault happens, both main and back-up protection will usually sense it and pick up it as abnormal condition which start to operate the relays as programmed, but primary relaying is the first one anticipated to open the correct circuit breakers to eliminate the fault or faulty portion or element from the system, when the fault is cleared by the primary protection relaying then the secondary protection system relays will reset itself without taking time to operate its purpose.

The beginning of the essential accomplishment at the same place for Local Backup provides for the main protection is situated as designed by the protection engineer. Local backup generally comprises the establishment of two totally autonomous protection duplicate systems, also called separated secondary system which together with relays, CTs, VTs, cables, CBs, Tripping coils etc.

In the practical design viewpoint for numerous requirements need be met before hand, it is sometimes very difficult to follow the principle of whole separation of main and back-up protection relays. Then the design engineers try to source the system equipment in request and decide which one to trip from CBs in the circuit. Normally arranged by sending the same signal for tripping in common. [21]

4.2.5 Equipment and System Protection Schemes

The main expectation of any high voltage network of power transmission and distribution is to transmit and distribute electrical power to variety of centers for numerous purposes without having any disturbances or faults. Therefore, any power network system must be planned and accomplished to transport this electrical energy to the utilization zone subs, distribution grid subs, and load centers with high reliability and economic concerns. Between these two concerns necessities, there is an expected struggle between them. For some negotiation it is critical in liableness in the system potential to realize very high consistency for power delivering. To balance these necessities, many ways that of up security of offer while not adding an excessive amount of to the prices and can be by: -

- refining plant project
- growing the extra size
- placing different circuits to loads.

This separation of the scheme into zones, individually measured by its own CB together with protection system, delivers flexibility during typical procedure and confirms a lowest of disruption subsequent an interruption.

In any failure disorder practically in a power system, particularly a short circuit scenario, is a possible danger to a assure source as such a disorder can not only interrupt power to customers but also can reason irreversible harm to very expensive apparatus. The importance of eliminating such irregular circumstances as quickly as possible is therefore apparent. This is the role of protection and protective gear of that part of the substation.

The purpose of protective system is to sense and initiate act to eradicate instabilities as soon as it is feasible. Therefore, the protection system must be functional in overlapping zones to cover the scheme totally, that is not allowing any part unprotected. One of the most important requirements of protection is that individual plant segment which with the problems must be separated from the rest of the system, therefore protection plans, and designs must be flexible, that means if a fault happens in the system the protection is required to detect and trip only from individual bordering CBs of the item. This characteristic of CB operating selection, so-called protection judgement is accomplished by two standards procedures as described by following next two sections. [21]

<u>Systems Protection (Non-Unit):</u>

Non-unit or system protection are always time-graded schemes which apply through the signals and measurements from VTs and CTs as replicating the entire power scheme. The System Protection schemes in sequential zones are organized to function in times that are arranged through the categorization of devices to that upon existence of a failure in the system. When a fault inception, even though several protective device reply, only those applicable to the failed zone assure the CB trip action, while the rest do the unfinished actions and will reset to the original state as no fault conditions. The time discriminated Line protection can be Impedance or Distance schemes, or line overcurrent relays are the main illustrations for system protection schemes. [21]

<u>Unit Protection:</u>

Unit schemes respond to fault situations lying inside an obviously definite zone. They employ info from two or rarely extra points in a system. Also, unit protection system contains sizes of the measurement to each reach of the protective zone, also the communication of data amongst the relays from borders. Some best illustrations for the unit protection are; Differential protection relays, Restricted earth fault protection, where the incoming current to the protected unit is compared with outgoing current from the protected unit. Also, there are many examples for this unit protection schemes. [21]

4.2.6 Protection “Zones”

The protected “zone” is that part of a power system guarded by a certain protection and usually contains one or at the most two elements of the power system. For a non-unit scheme, the zone lies between the current transformers and the point or points on the protected circuit beyond which the system is unable to detect the presence of a fault.

4.2.7 Protection Requirements

There is some recommended terminology is being used in the protection design operation, maintenance for enhancing, upgrading improvement of the power system protection industry. Following are the some of the terms that are impotent to consider as the basic philosophies of protection requirements:

<u>Stability</u>

Stability denotes the capability of the protection to retain on in operational to all faults and under any energize conditions even exterior of the protective zone which is applicable. The unit protection system capability value is to be kept dead under all circumstances with failures outside their own zone. The non-unit schemes will response for the failures at anyplace of the network. [21]

Discrimination

Provide high levels of discrimination with other protection schemes to trip out the least amount of primary plant to isolate the fault. Protection is organized such a way in unit or non-unit schemes to guarantee that all parts are well protected foe all the scenarios and there is no unprotected equipment or system left behind. The protection is required to pick up fault conditions and to send trip signals to the closest CBs solely, additionally, far-famed wide as "Discrimination". Within the non-unit systems, the judgement isn't complete, however it's hooked in to responses of many similar systems, all that answer a specified abnormally. Nevertheless, for the unit systems, the judgement is complete, and it will discover and answer abnormally occurring among the zone of protection. [21]

Sensitivity

Enable detection of all plausible types of faults, ranging from high resistance phase to ground faults to solid three phase faults, in accordance with industry standards and relevant safety regulations. This term is usually used once regarding the lowest in operation current of an entire protecting system. The protecting relays are sensitive, even for very low first fault current, the requirements of all relays must to be for consistent operation and quite sensitive for all scenarios. [15] [16]

Reliability

The ability of the protection to operate correctly. It has two elements dependability, which is the certainty of a correct operation on the occurrence of a fault, and security, which is the ability to avoid incorrect operation during a fault. Power system represents an outsized capital investment and to induce most come back it should be loaded to its maximum. the aim of grid isn’t solely to produce energy however additionally to stay the system fully operation, to grant the simplest facility to the consumers and receive income for the availability expert. If fault isn't restricted to the protecting CB it may additionally can ensue of the failure to the electrical fuse. Thus, each element concerned in fault clearance is thought to be a supply of failure. [21]

Availability

Availability ensure that no part of the network is left unprotected even when a probable failure of a protective device or circuit breaker happens, plus DC supply failure

Failures should be minimized by:

- unfailing protection designs
- consistent routine maintenance
- site acceptance protection test

Speed

The idea of speed is to safety measure continuity of supply toward fast clearing any fault conditions. Therefore, if any failures cleared or disconnected in the fastest time, the superior the power scheme can be returned to normal condition. This means power may be conducted as a part of failure eliminating plans for numerous categories of responsibilities. The fault concerning phases has noticeable result on constancy specially related to ground faults of single-phase which is occurring frequency as 95% of all fault categories. The next benefit of obtaining fast fault clearance is that pointless changes that can occur in the system can be avoided, and which can happen due to:

- large arc currents
- damaged wires or conductors
- electrical machines lamination damage issues.

Fault currents can reason permanent harm if permitted to stay long for more than tripping time (seconds). Therefore, a fast failure disconnections system is imperative in power system protections. [15] ,[16]

4.2.8 Wide Area Protection and Adaptive Relaying System

Since the modern power systems are complex interconnected networks, conventional protection systems may not be able to meet the requirements for system reliability and selectivity of power supply. So Wide Area Protection (WAP) can solve problems associated with conventional relaying and WAP can provide reliable security prediction and optimized coordinated actions and can mitigate or prevent large area disturbances

<u>Drawbacks of Conventional Protection Systems</u>

Local protection devices do not consider system wide view and therefore, unable to take optimized and coordinated actions. Energy Management Systems (EMS) and SCADA systems are not able to directly catch dynamics of system and are therefore, focused only on steady state operational requirements. Drawbacks of conventional localized protection systems include lack of:

- Dynamic measurement and representation of events
- Wide area system view
- Coordinated and optimized stabilizing actions
- Adaptive relaying in coordination with local protection devices
- Handling of cascaded outages

The Need for WAP

Transmission lines and busbars are most critical elements of power system, so protection of these elements can be ensured by reliability of protection systems. Stability of protection system under all possible non-fault operating conditions a can be corrected by operation of protection during faults. WAP can increase the reliability of protection system

Data collected from each end of the line and busbars are transferred to main control center and performance of overall system is monitored. WAP trips appropriate circuit breakers under fault conditions, or when power system is close to instability. WAP can lead to increased transmission capability and improved system reliability

Major requirements for Wide Area Protection Systems

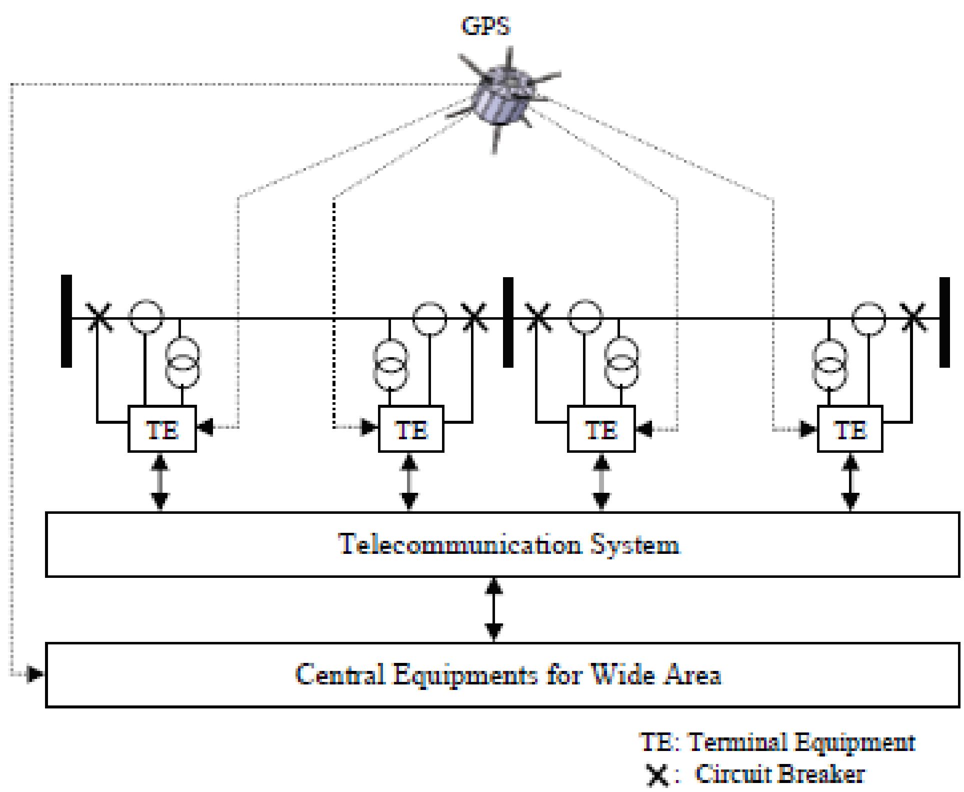
The system should be adequately designed to take care of CT saturation and/or data mismatch distortions, so coordination is required with existing local protection system to enhance system reliability and security by appending protection system with system wide information. For this Conventional protection systems based on local independent measurements and decisions may not be able to consider overall power grid disturbances and therefore may not be able to avoid blackout. WAP can be considered as a most reliable method to protect all system components at a higher level and WAP can also improve stability of network, by using extra switching, if needed

Wide Area Protection

In WAP synchronized measurement of power system quantities use from Global Positioning System (GPS) to eliminate data communication delays.

Accurate measurements can be obtained by use of Phasor Measurement Units (PMUs) that convert CT measurements to obtain fundamental current phasors PMUs can provide magnitude and phase angle of current phasor and can be used in different applications such power system monitoring, protection, fault location, etc. Communication systems of the network transfer data acceptable for protection, using fiber optic high speed networks redundancy protocol. After collecting and synchronizing necessary electrical network data, effects of bad data caused by CT saturation and data loss in communication system are attenuated. Based on acquired synchronized data, WAP algorithms isolate faulted regions, enhance transient stability of system and prevent cascading outages and large blackouts. [22], [23]

Following diagram representing Schematic Diagram of WAP :-

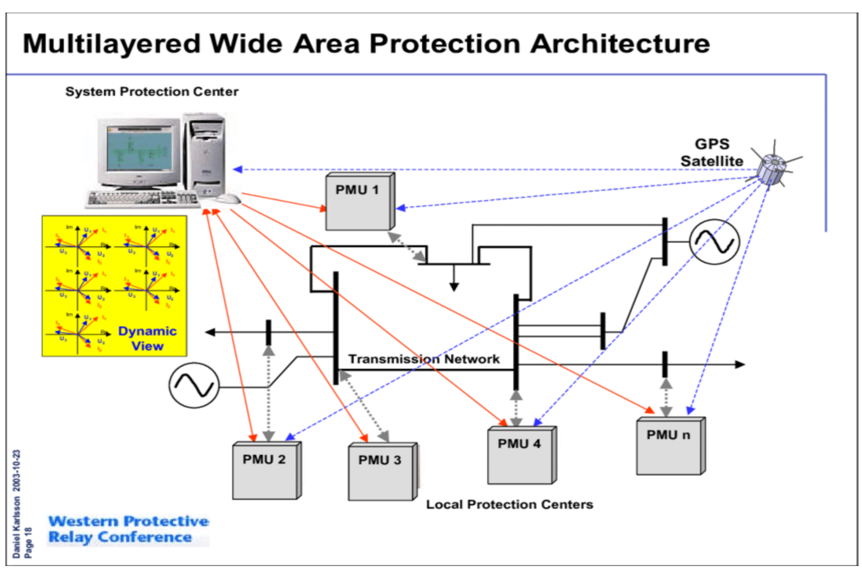


<u>Adaptive Relaying based on WAP System</u>

Many protective relay settings are often compromise settings, nearly suited for many alternative power system conditions, and may not be the best setting for any one condition.

Adaptive protection - Protection philosophy that permits and seeks to adjust in various protection functions/settings automatically in order to make them more attuned to prevailing power system conditions. Adaptive relaying may include schemes for various protection functions such as fault location, fault classification and adaptive adjustments of relay settings. Wide area adaptive protection should progress in two forms – i.e. Anticipatory scheme - Protection system characteristics are altered at the time of system stress in anticipation that a fault may occur. Responsive scheme - Protection system reacts to emergency state by taking additional switching actions to restrict impact of unnecessary operation of a protective device.

Following diagram about WAP was repressed by Western Protective Relay Conference gives the WAP architecture :



4.2.9 66 kV Line and 66 kV Breaker Protection (Panels No1, No5)

Reference drawing: single line drawing Figure 7 & Figure 15

Distance protection terminal ABB RED 670 is used for the protection 1 terminal; 2nd relay manufacturer GE-L 90 is used as the protection 2 terminal for the line feeders. For zone 1 faults the tripping is single phase. Line Differential protection is also available with Line protection relays but will be used as they need for test and study functions. Directional earth fault (DEF) function is included in both relays. Trip for DEF is three-phase.

Both distance relays will be configured in either the permissive under reach or overreach scheme, whichever is more suitable, in conjunction with the Real Time simulation system test availability.

Operation of the distance protection trips the feeder breaker. CBs are simulated with ABB High Speed Trip relays which has the 0.4 ms tripping time.

The 66-kV breaker is provided with a CB management relay type ABB REC630. This terminal includes besides CB control, circuit breaker fails, instantaneous overcurrent and earth fault and send all hard wire trip signal to trip relay (or dummy CB). This is also included to be used for stub bus protection, auto reclose control and phase discrepancy monitoring functions. The feeder protection uses this auto reclose to perform the reclose. Single-phase reclose does not require synchro-check.

The circuit breaker fail function in the REC 630 supervises the circuit breaker and is started by primary protection functions that trip this circuit breaker. Operation of the breaker fail function sends a trip signal to the busbar protection as well as to the LV breaker using only GOOSE Messaging.

In all protection panels there are no hard wire signals go across for signal. etc. but Goose only.

4.2.10 66/22 kV Transformer Protection & CB (Panels No2 and No6)

Reference drawing: single line drawing Figure 9 & Figure 17

Transformer protection terminal type ABB RET650 provides protection 1 and another manufacture GE- T60 provides protection 2 for the transformer. Overall differential and restricted earth fault protection for both HV and LV windings is included in both protection 1 and 2. Overexcitation protection is also included in protection 1 and 2.

Four digital inputs of the protection 1 RET650 and seven of the protection 2 GE-T60 are allocated for the Transformer Guards. The proposal is follows. Signals to protection 1 are

- Main Tank Buchholz Trip,
- Transformer Pressure Relief Trip,
- OLTC Pressure Relay Trip,
- Winding Temperature Trip.

and to protection 2 are

- Main Tank Buchholz Alarm,
- OLTC Oil Level Alarm,
- Winding Temperature Alarm,
- Oil Temperature Alarm,
- Oil Temperature Trip,
- Transformer Oil Level Low and High Alarms,
- Rubber Bag Alarm.

Overcurrent protection for the 66kV side is also provided in both protection 1 and 2. This will also cover for phase-phase fault on the secondary windings. Overcurrent and earth fault protection for the 22kV incomers is available from relays mounted in the 22kV switchgear.

Operation of the protective function's trips both 66 kV breakers, the 22kV breakers via high speed trip relays type ABB RXMS1 and RXMB1, also used as Dummy CBs. All trips are three phase trips. A circuit breaker fail start signal is also issued to the respective circuit breaker fail protection function in the CB management relay type ABB REC630 and other relays for each of the breakers that are tripped. CB Management and trip functions are exactly like above described line protections.

4.2.11 66/22 kV VU Zone Substation Protection BUS & CB, BUEF & MEF (Panels No3 and No7)

Reference drawing: single line drawing Figure 11, Figure 19 & 20

Bus bar Differential, EF and OC, Bus Tie CB Fail, Stub Bus protection functions are included in the substation protection schemes. Back Up Earth Fault and Master Earth Faults Protection functions are included to be similar with Utility EF protection designs. The only difference is, all signals and status are shared as GOOSE messaging.

4.2.12 Design Standards Considered

Following Australian and International standards have been considered for the VU ZSAS design:

- AS61850 – 2005 Communication networks and systems in substations - Introduction and overview
- IEC 61850 Communication networks and systems in substations

- AS1100 Technical Drawings
- AS1029.2 Low Voltage Contactors
- AS1042 Direct Acting Indicating Electrical Measuring Instruments and Accessories
- AS1044 Limits of Electromagnetic Interference for Electrical Appliances and Equipment
- AS1384 Transducers for Electrical Measurements
- AS1521 Grid Systems for Printed Circuit Boards AS1603, AS1670, AS4428 Intruder security systems
- AS1795.2 Dimensions of Switchboard Panels
- AS1939 Degrees of Protection Provided by Enclosures for Electrical Equipment
- AS2053 Non-Metallic Conduits & Fittings
- AS2373-1 Electrical Cables for Control & Protection Circuits
- AS2546 Printed Boards
- AS2676 Guide to Installation, Maintenance, Testing of Sealed Batteries in Building
- AS3000 SAA Wiring Rules
- AS3008.1 Electrical Installations - Selection of Cables
- AS3011.2 Ventilation and Cladding of Industrial Sites
- AS3191 Secondary Cables
- AS3439.1 Switchgear and Control Systems Assemblies
- AS60269 Low Voltage Fuses

- AS61010.031 Safety Requirements for Electrical Equipment for Measurement, Control & Laboratory Use
- IEC 60068 Environmental Testing
- IEC 60255 Measuring Relays and Protection Equipment
- IEC 60297.1 Panels and Racks
- IEC 60297.2 Cabinets and Pitches of Rack Structures
- IEC 60297.3 Sub-racks and Associated Plug-in Units

4.2.13 Design Considerations

The model Zone substation protection schemes are designed to protect primary and secondary plant and equipment from potentially damaging fault currents, over voltages, to maintain system stability, to minimize risk to personnel within and external to the station, and to minimize the loss of supply to customers. For achieving these design targets, following Protection Requirements have been considered:

Therefore, positioning of VTs and CTs in the SLD are arranged to ensure appropriate protection coverage of the primary plant and equipment for which the protection scheme is installed. The creation of dead zones or “blind spots” have been avoided wherever possible.

Each zone substation utilized protection and control relays principally from the same manufacturer, i.e. ABB for main and GE for back up, and selected from the same range or family of products. For the secondary designs duplicated protection schemes are considered, therefore the protection relays shall be of different manufacturer (or at least utilize different operating algorithms/platforms) to avoid common mode failures. We also considered protection functions implemented within a multi-function relays to be completely independent of other ancillary functions the relay may perform, such as communications, so that the protection function will continue to perform reliably even when the ancillary functions fail, while providing appropriate local and remote alarm indications. Duplicated protection schemes, designated X and Y, are physically segregated as far as practicable to reduce the probability of simultaneous failure. This arrangement included different voltage transformers, current transformers and DC power supplies and dummy circuit breaker trip coils. X and Y protection schemes for the same item of primary plant or equipment has been located within the same panel/cubicle. In addition to that, all secondary equipment is decided to be synchronized using time synchronizing features such as IRIG-B or GPS clocks.

Wherever possible and appropriate miniature circuit breaker (MCB) are used and removable and isolatable fuse links for AC and DC circuits are also used for AC and DC distribution system, and for wiring purposes, (both AC and DC) the incoming supply to all MCBs connected to their bottom terminals and to the load side connected from their top terminal.

Following drawings, as described in the table 3 and named from Figure 7 to Figure 24 are the single line protection design drawings done for each bay, equipment. considering the protection and control segregation that could applied as the best practice for this SAS design criteria considered for VUZSAS. The panel assembly as the panel general arrangement done according to its protection SLD as for the final protection and control design review.

Table 2 describes the name of SLD and its protection Panel’s GA drawing with the protective equipment allocated for 66/22kV model zone substation. That is to understand its best practice selected and applied for the design similar to Utility industry in Victoria.

Figure Description	SLD Protection Faction	Protection Panel
Figure 7, Figure 8	66kV VUZS No1 Line & CB	Panel No 1
Figure 9, Figure 10	66/22 kV Transformer 1 & CB	Panel No 2
Figure11, Figure 12	22kV Bus 1 & CB	Panel No 3
Figure 13, Figure 14	22kV Feeders	Panel No 4
Figure 15, Figure 16	66kV VUZS No2 Line	Panel No 5
Figure 17, Figure 18	66/22 kV Transformer 2	Panel No 6
Figure 19, Figure 20	22kV Bus 1 & MEF, BUEF	Panel No 7
Figure 21, Figure 22, Figure 23, Figure 24	SCADA, RTU & AC/DC Supply, 110VDC X & Y Distribution	Panel No 8

Table 2 : Individual protection SLD and the panel design drawing

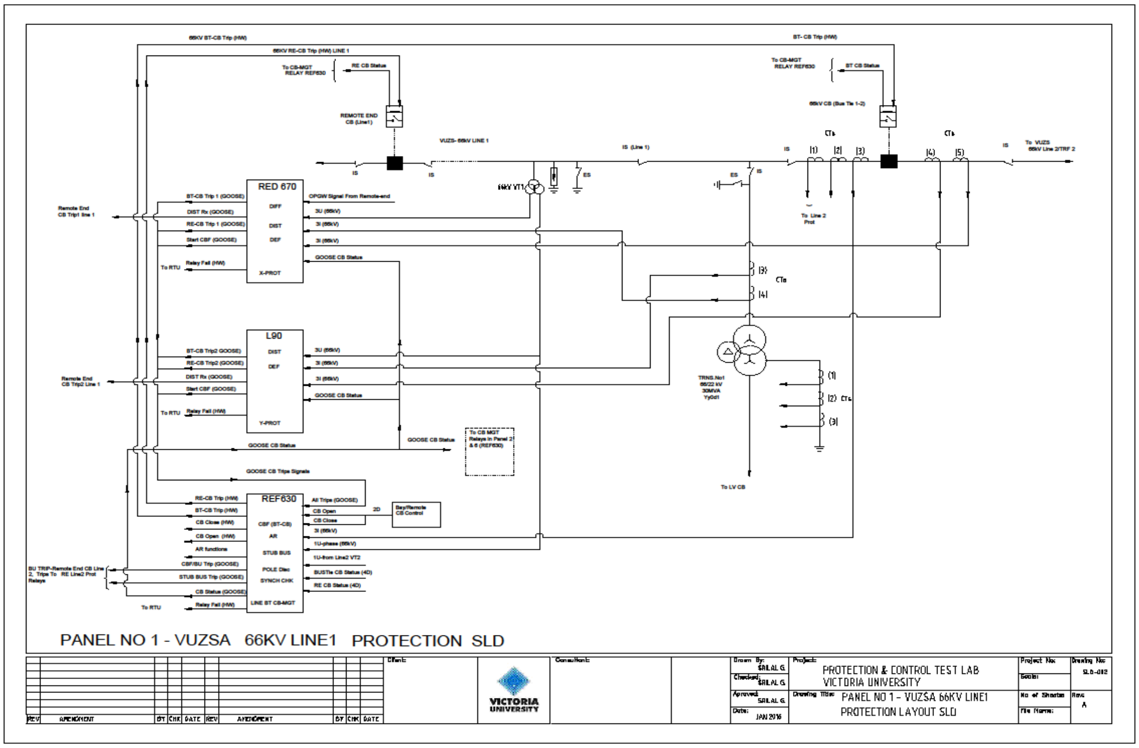


Figure 7: Protection SLD for 66kV VUZS No1 Line & CB

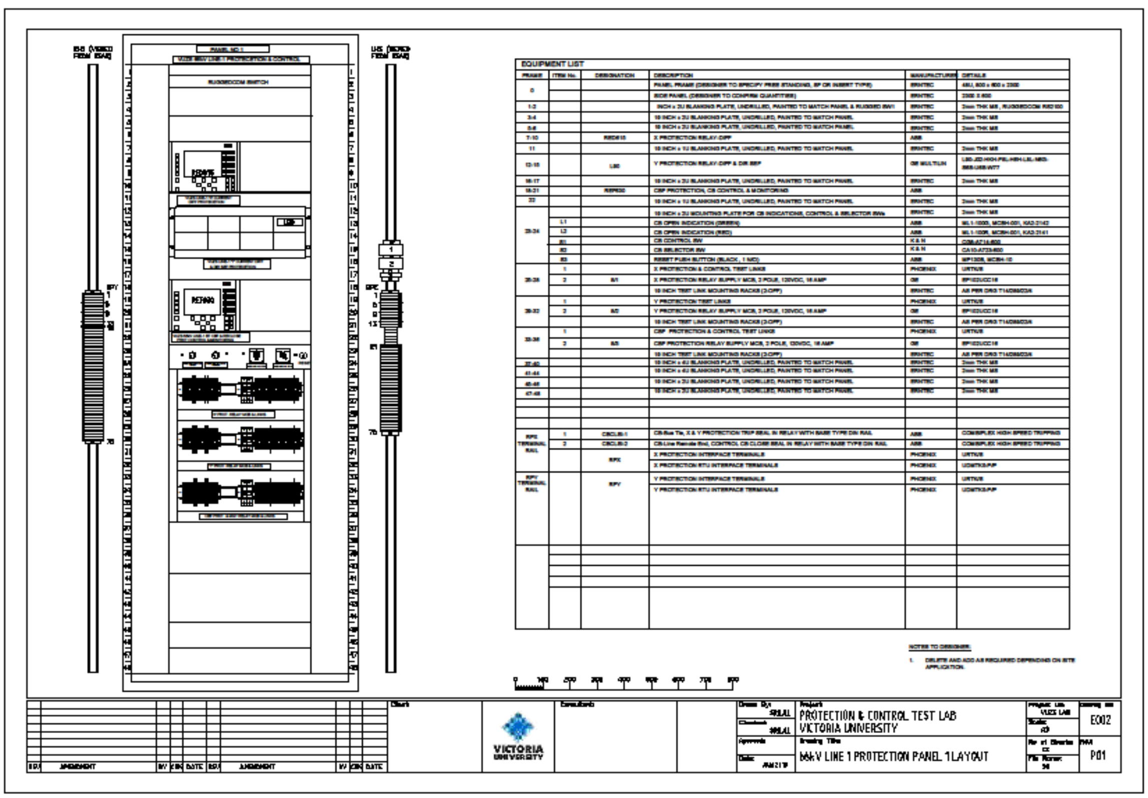


Figure 8: Protection Panel No1 for GA for 66kV VUZS No1 Line & CB

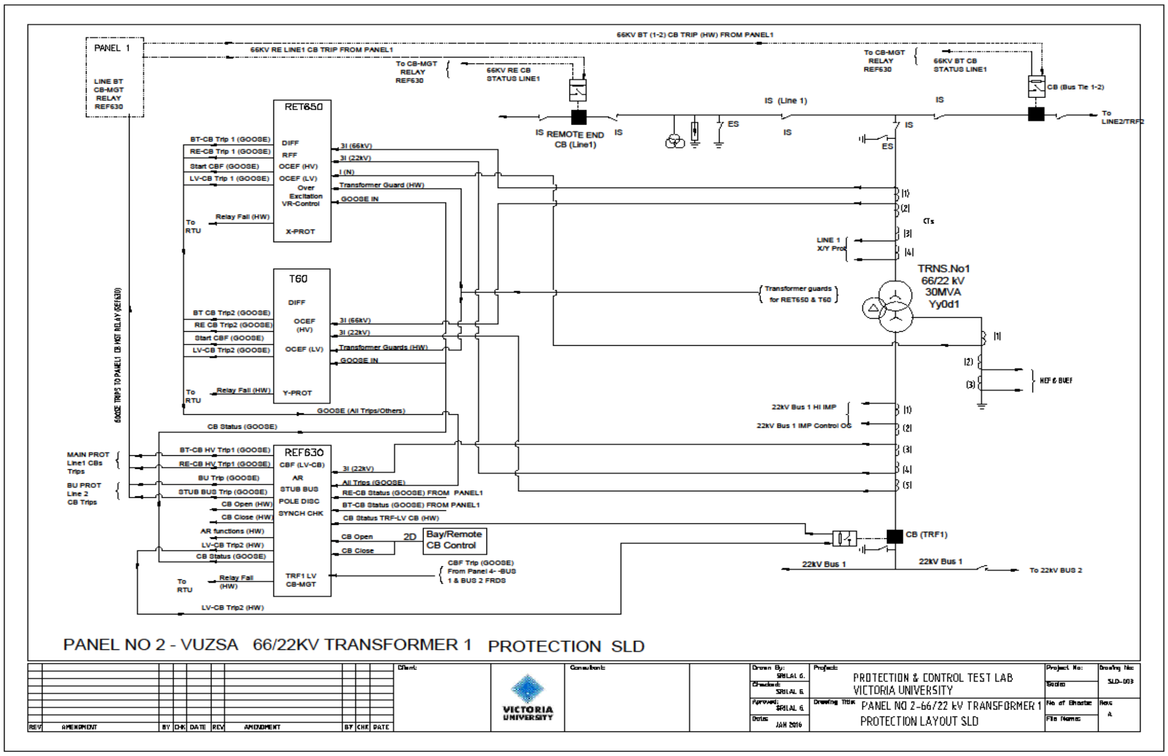


Figure 9: Protection SLD for 66/22 kV Transformer 1 & C

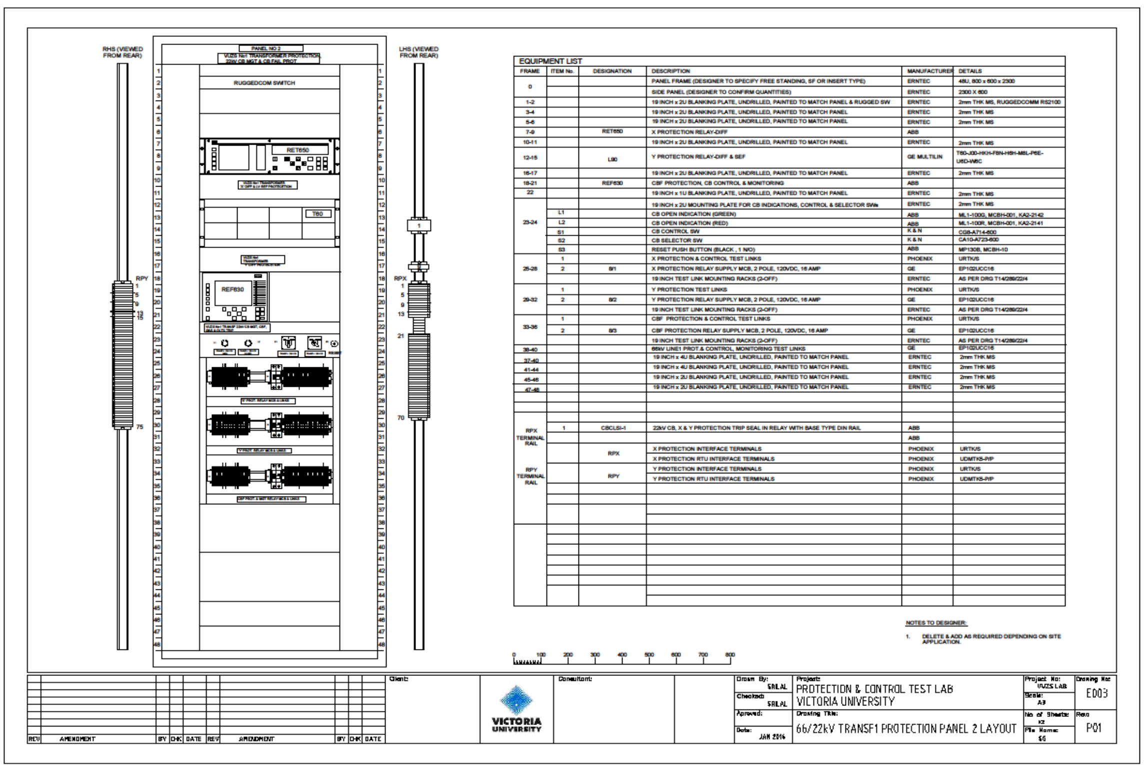


Figure 10: Protection Panel No2 GA for 66/22kV Transformer 1 & CB

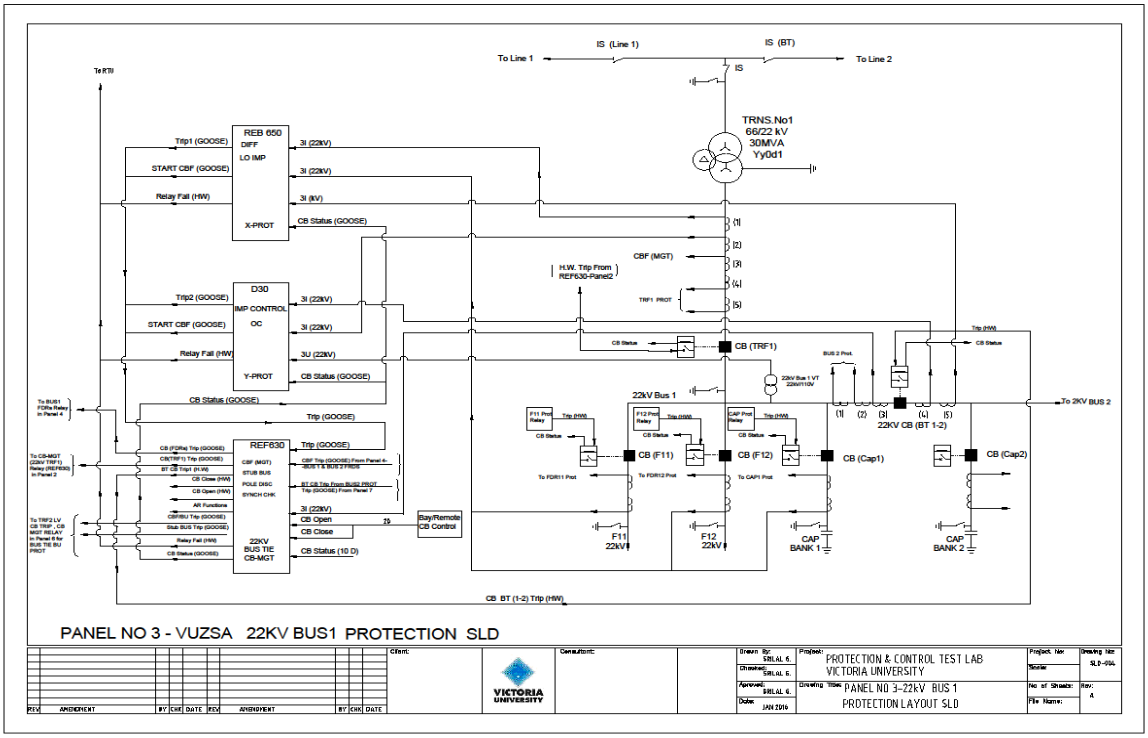


Figure 11: Protection SLD for 22kV Bus 1 & CB

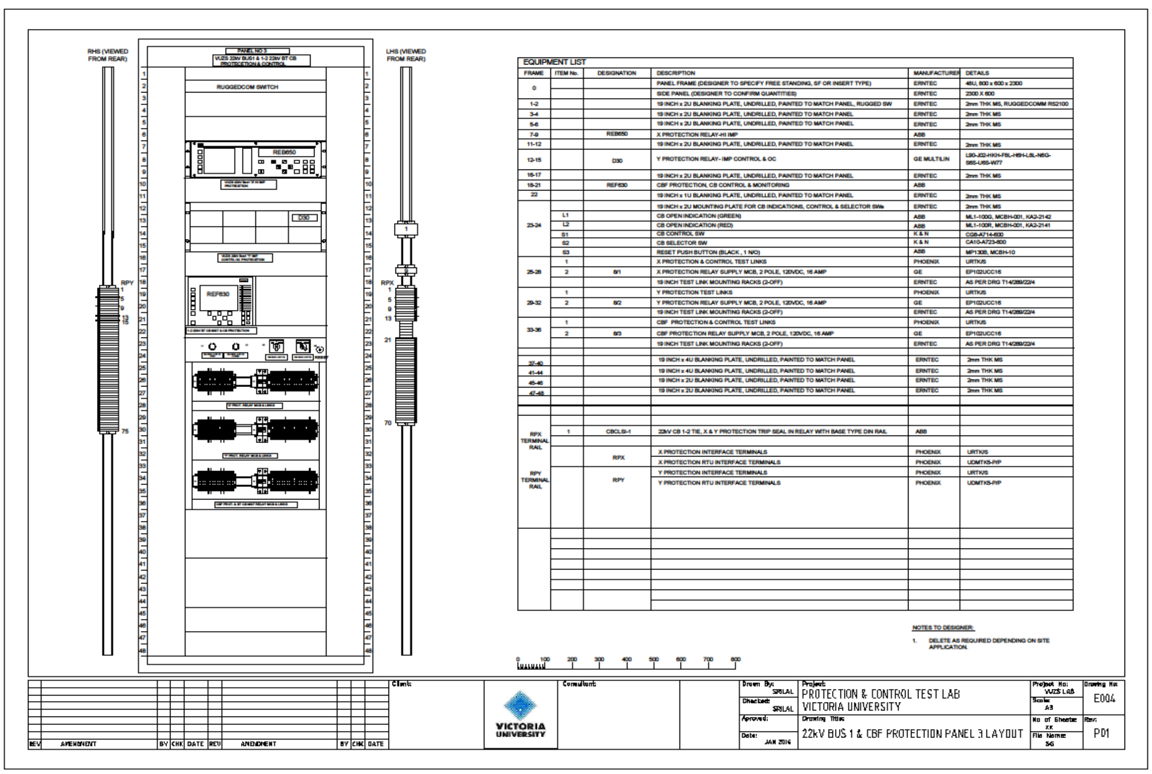


Figure 12: Protection Panel No3 GA for 22kV Bus 1 & CB

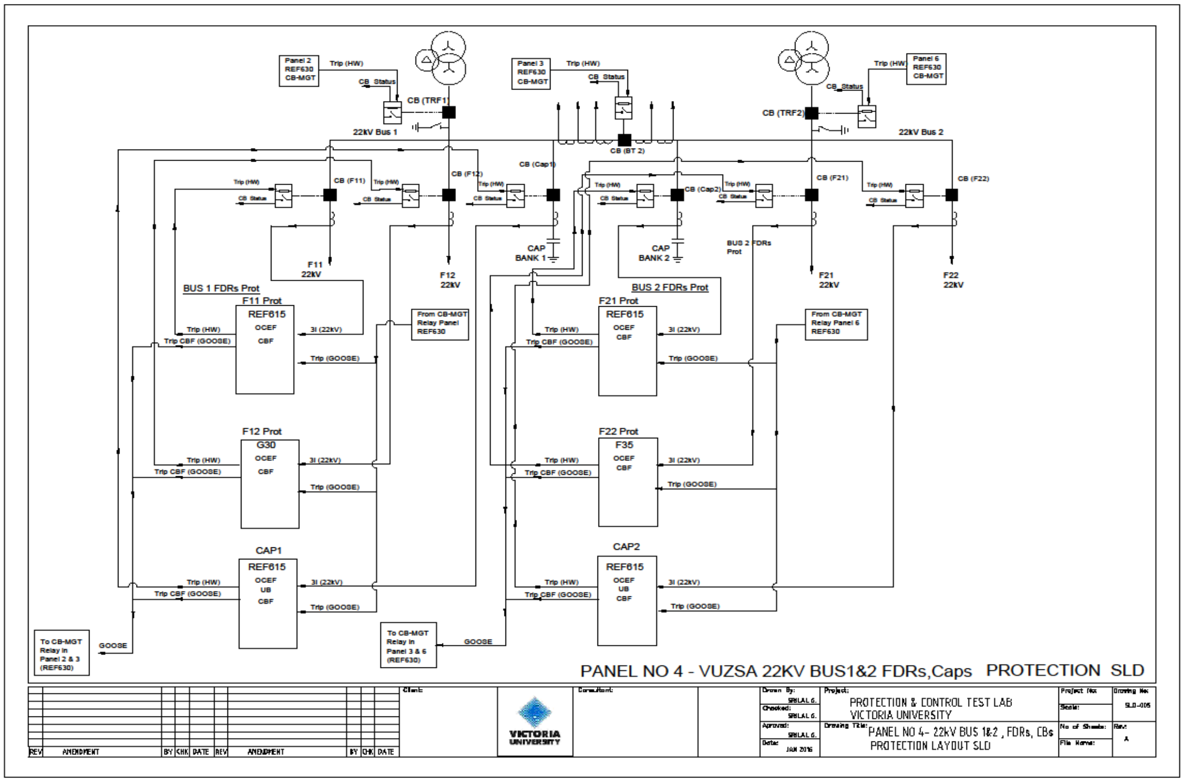


Figure 13: Protection SLD for 22kV Feeders

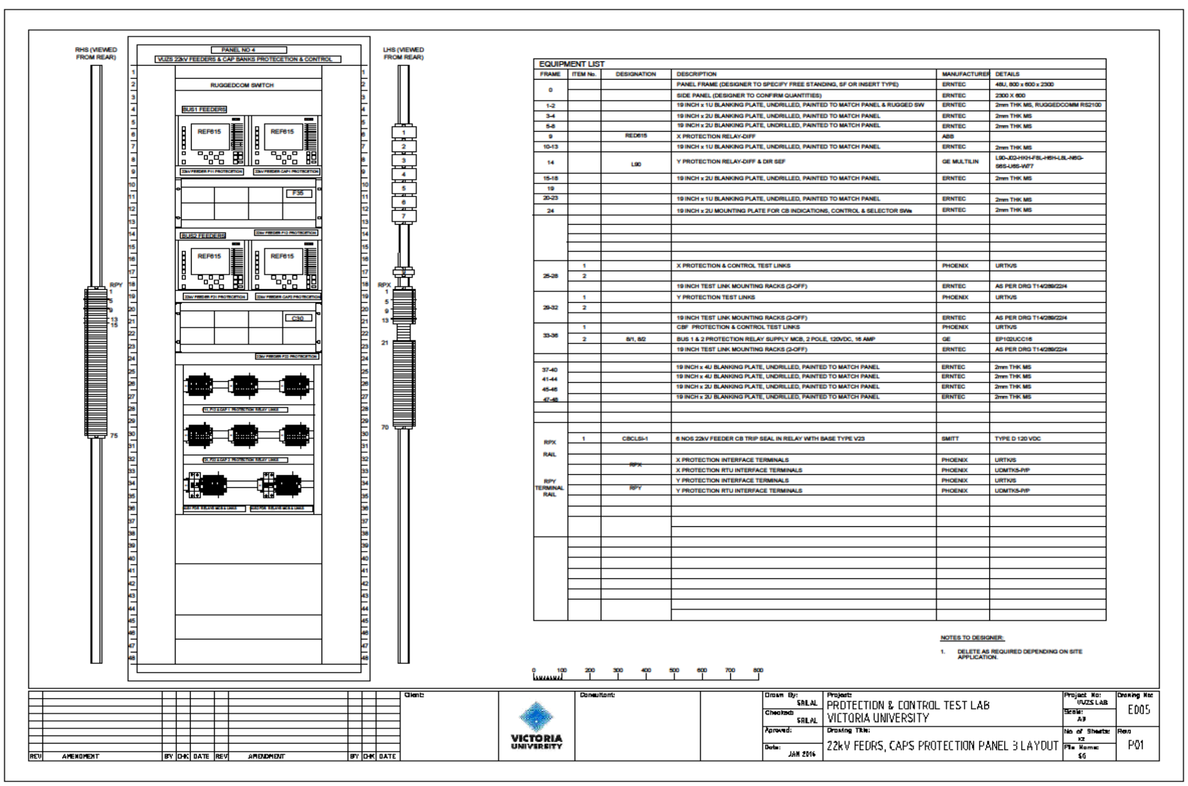


Figure 14: Protection Panel No4 GA for 22kV Feeders

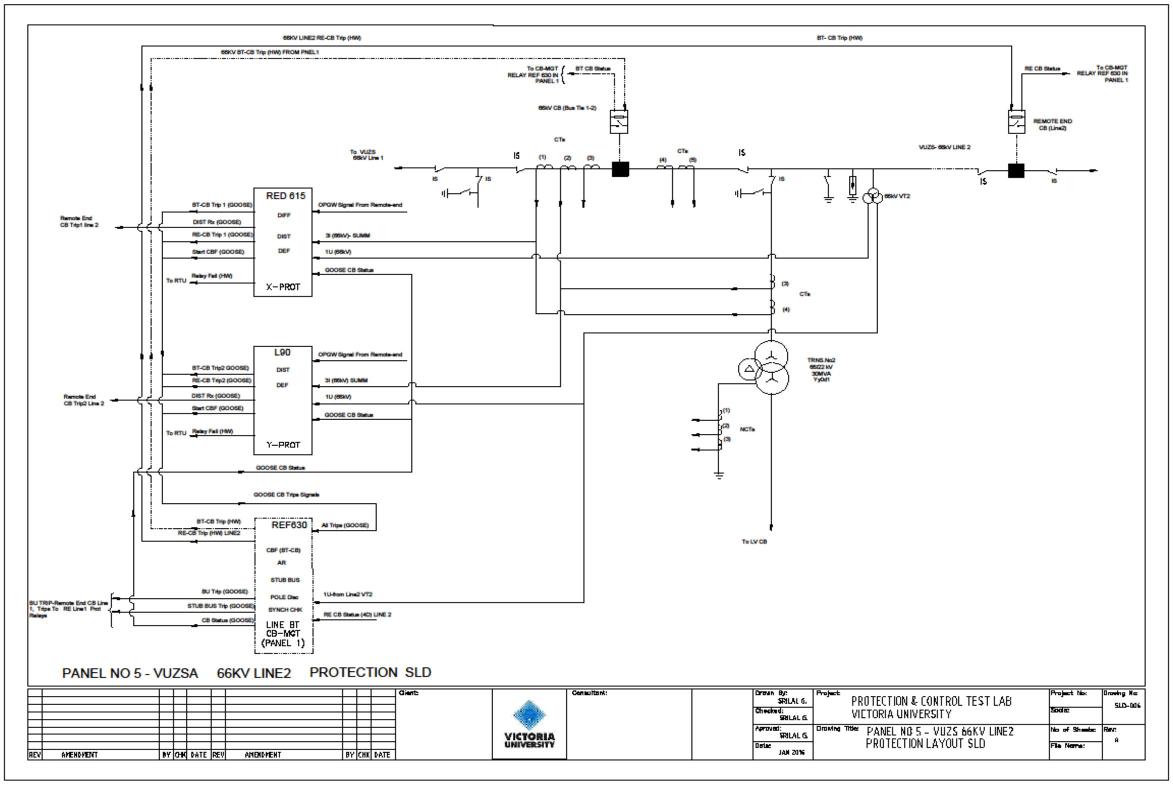


Figure 15: Protection SLD for 66kV VUZS No2 Line

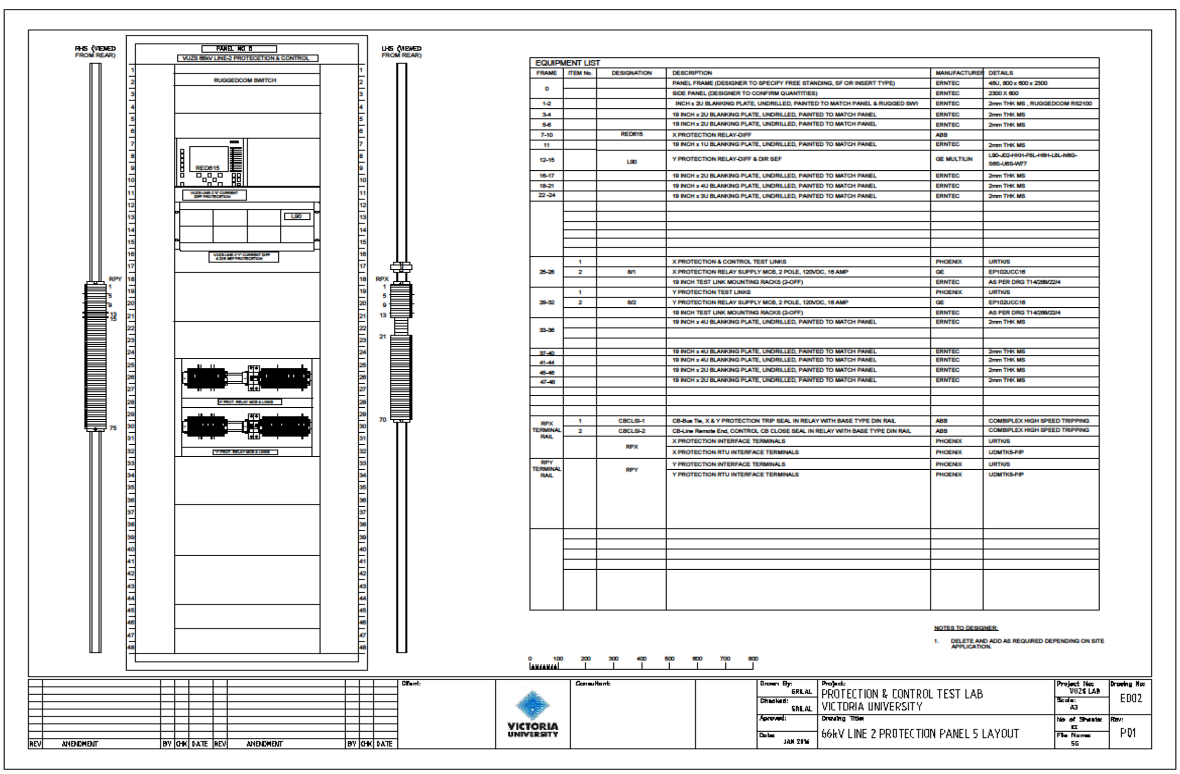


Figure 16: Protection Panel No5 GA for 66kV VUZS No2 Line

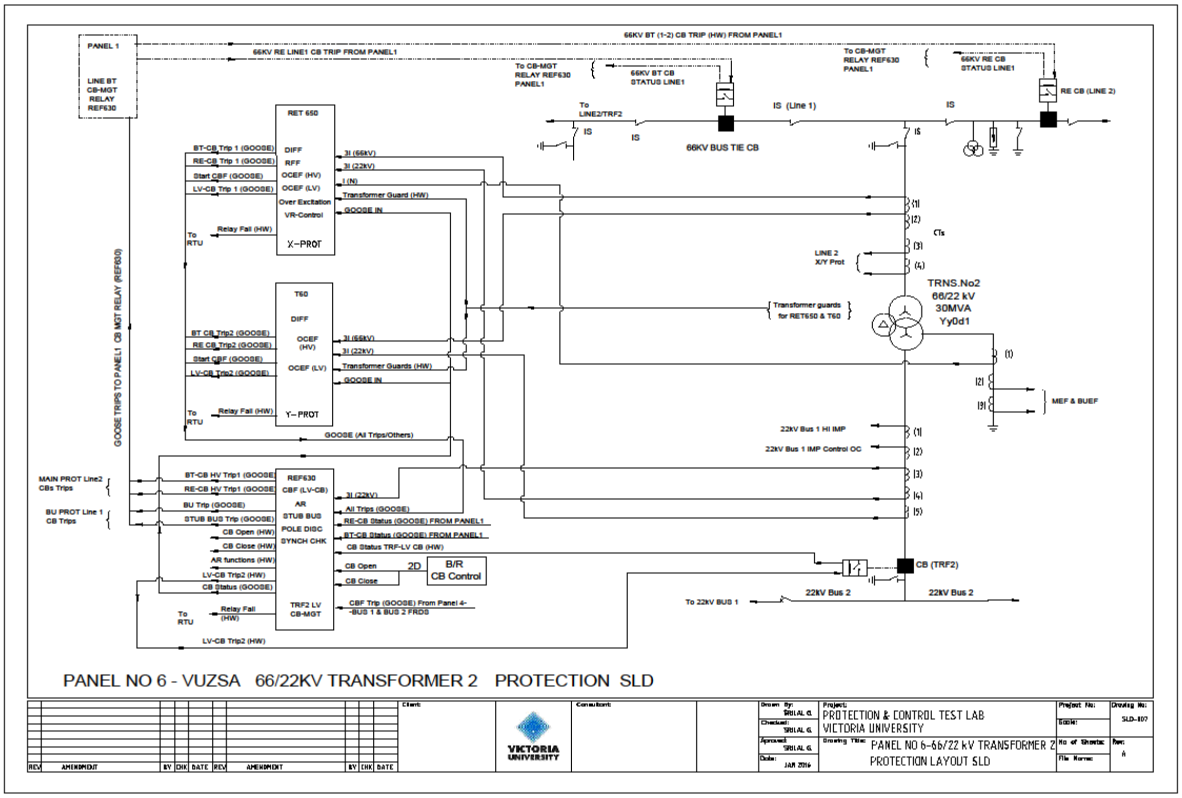


Figure 17: Protection SLD for 66/22 kV Transformer 2

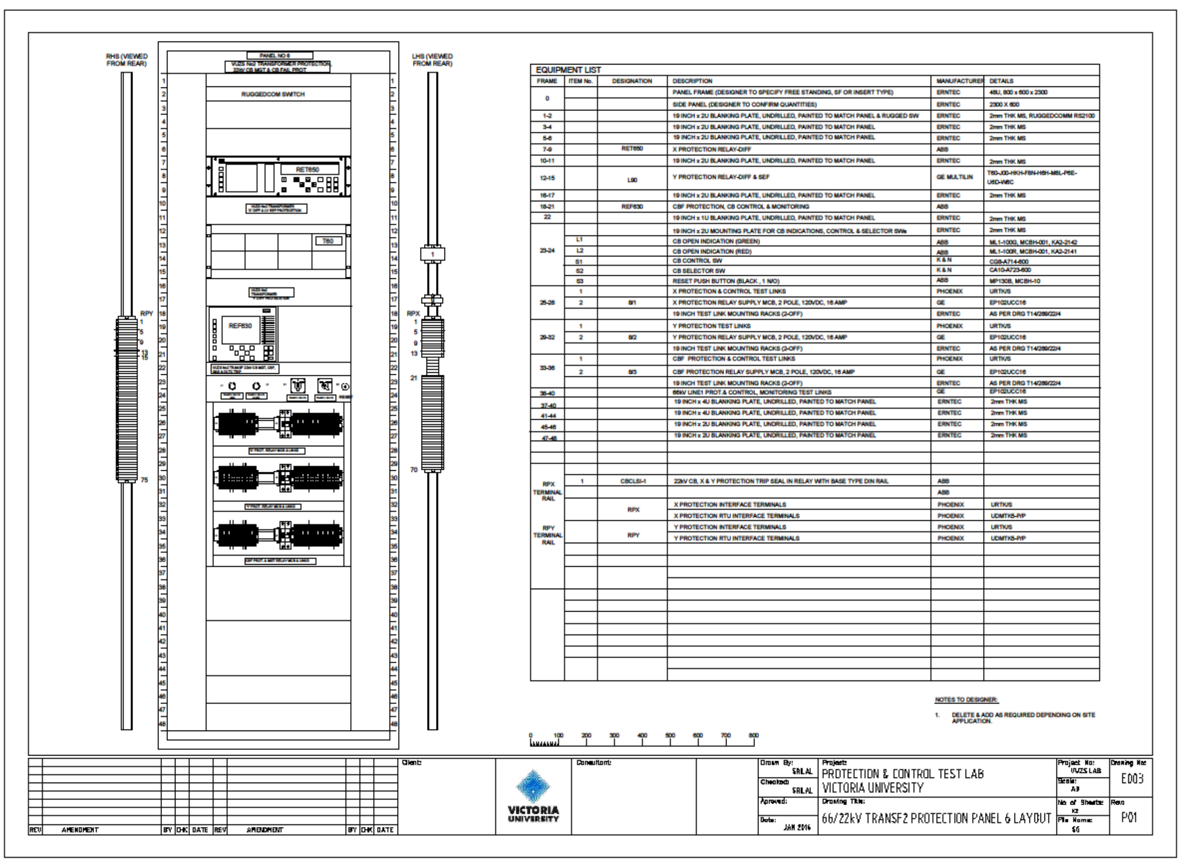


Figure 18: Protection Panel No6 GA for 66/22 kV Transformer 2

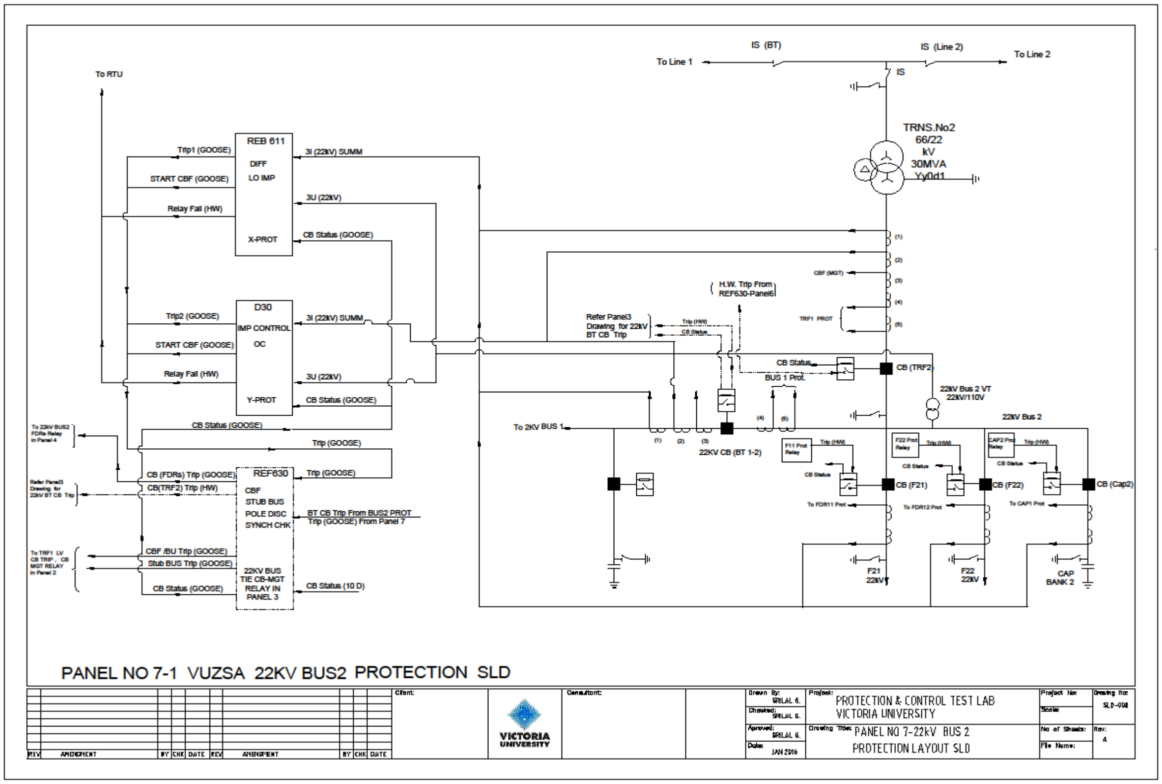


Figure 19: Protection SLD for 22kV Bus 1

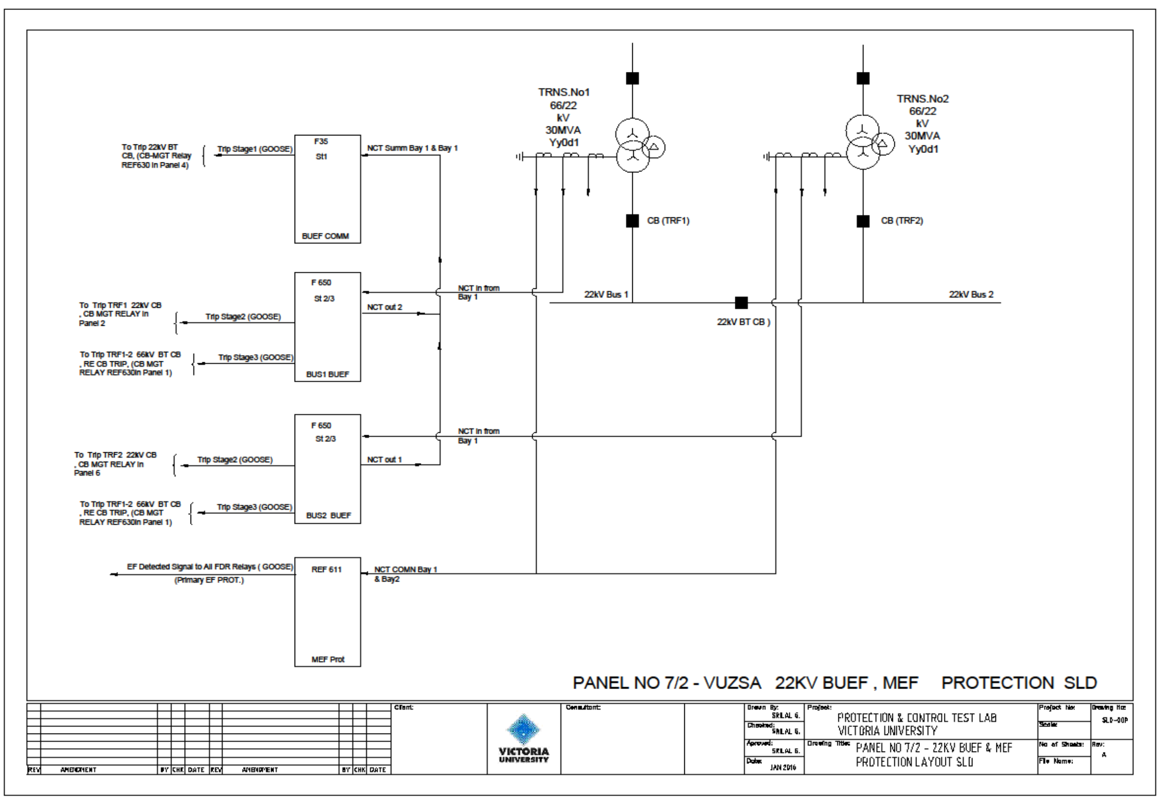


Figure 20: Protection SLD for 22kV MEF, BUEF

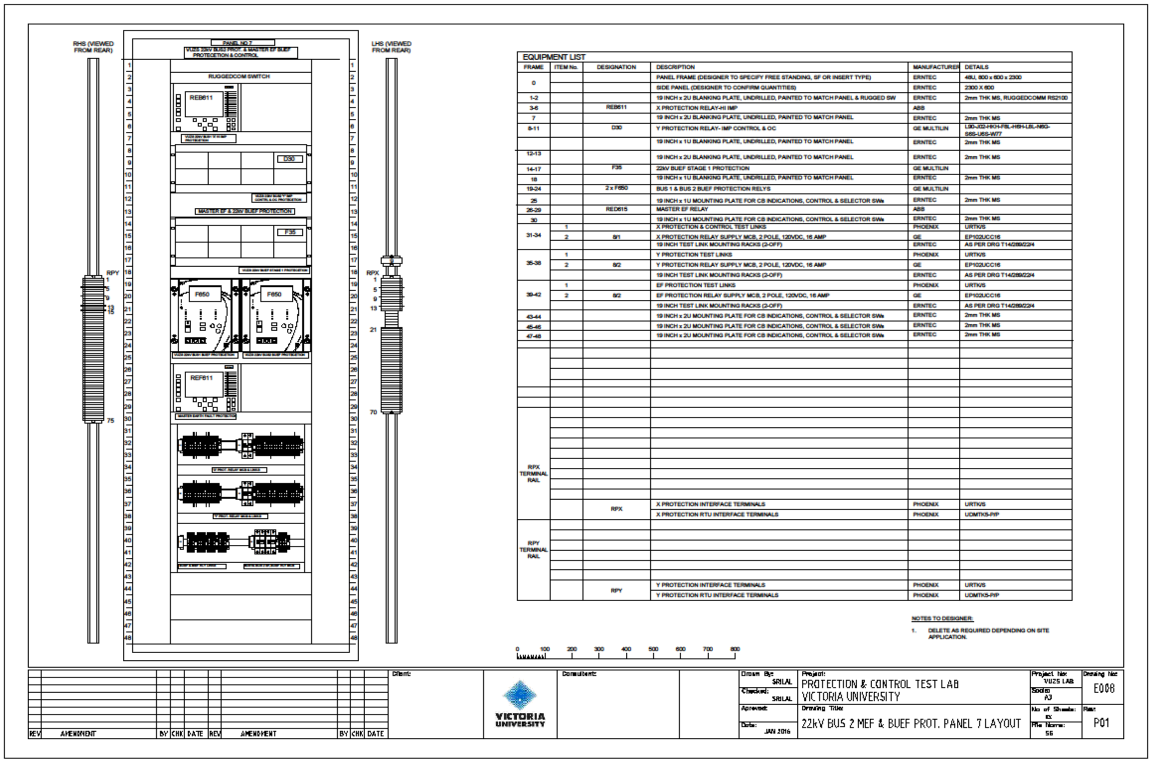


Figure 21: Protection Panel No7 GA for 22kV Bus 1 & MEF, BUEF

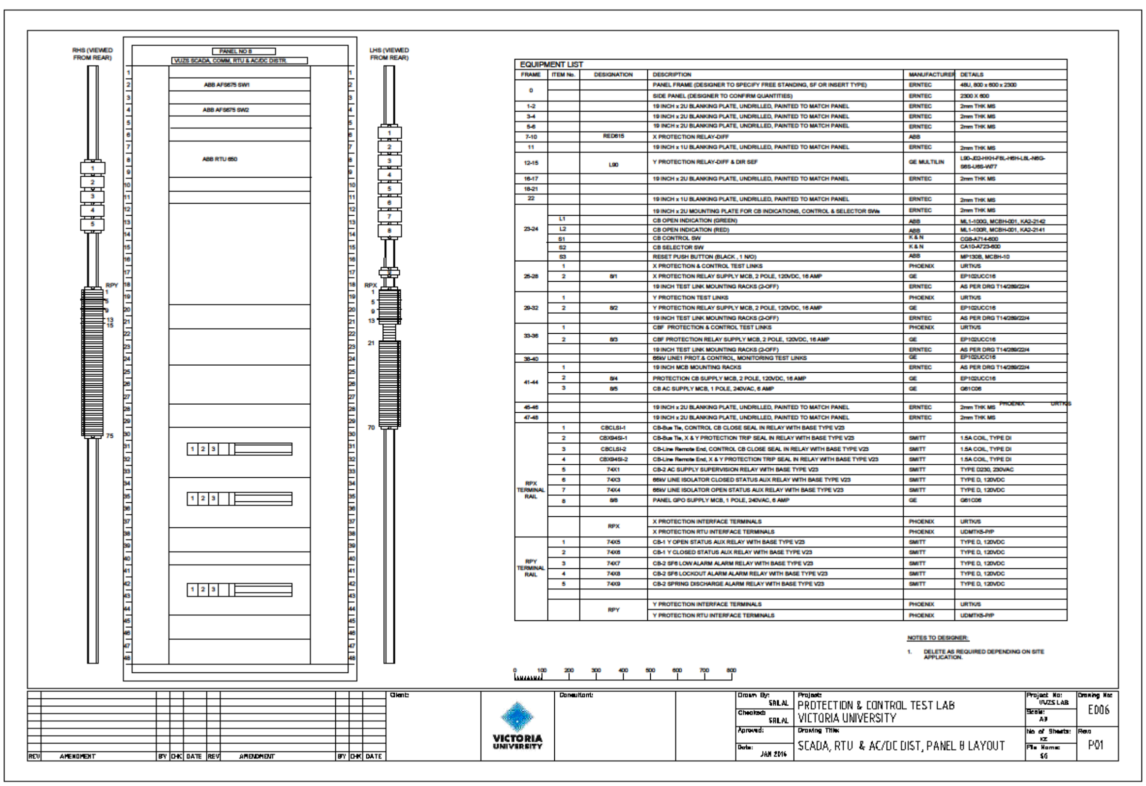


Figure 22: Protection Panel No8 GA for SCADA, RTU & AC/DC Supply

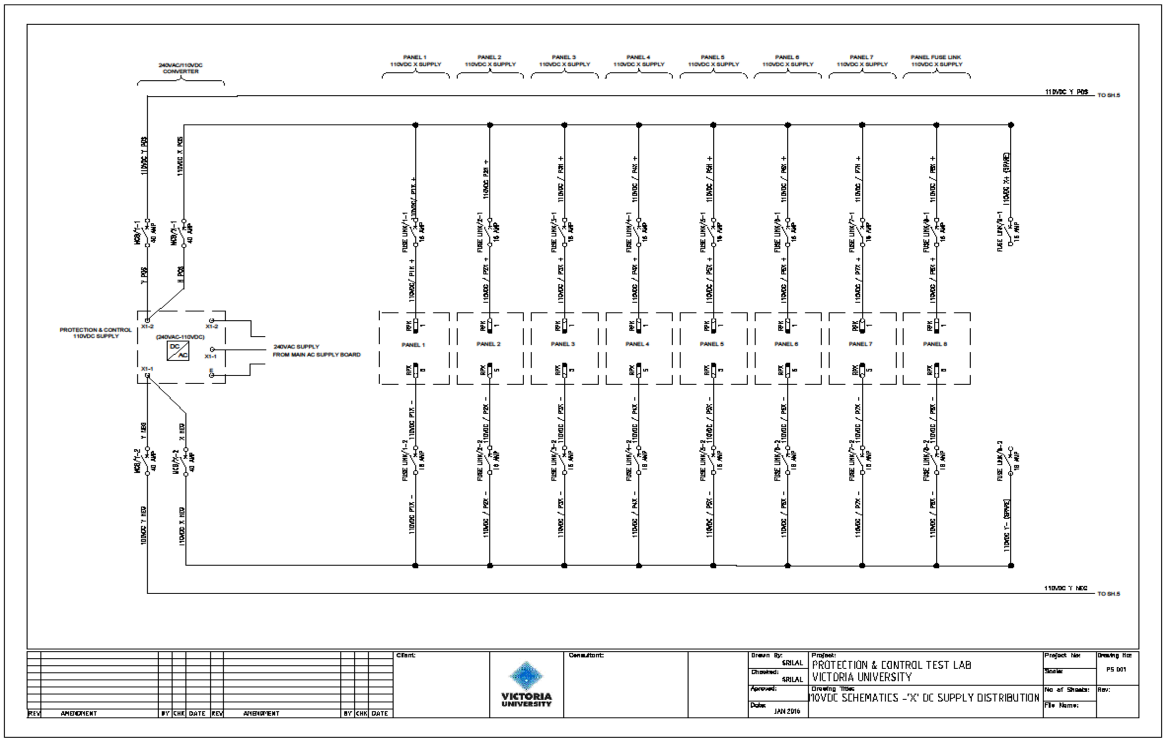


Figure 23: 110VDC Distribution – ‘X’ Protection in Panel No8

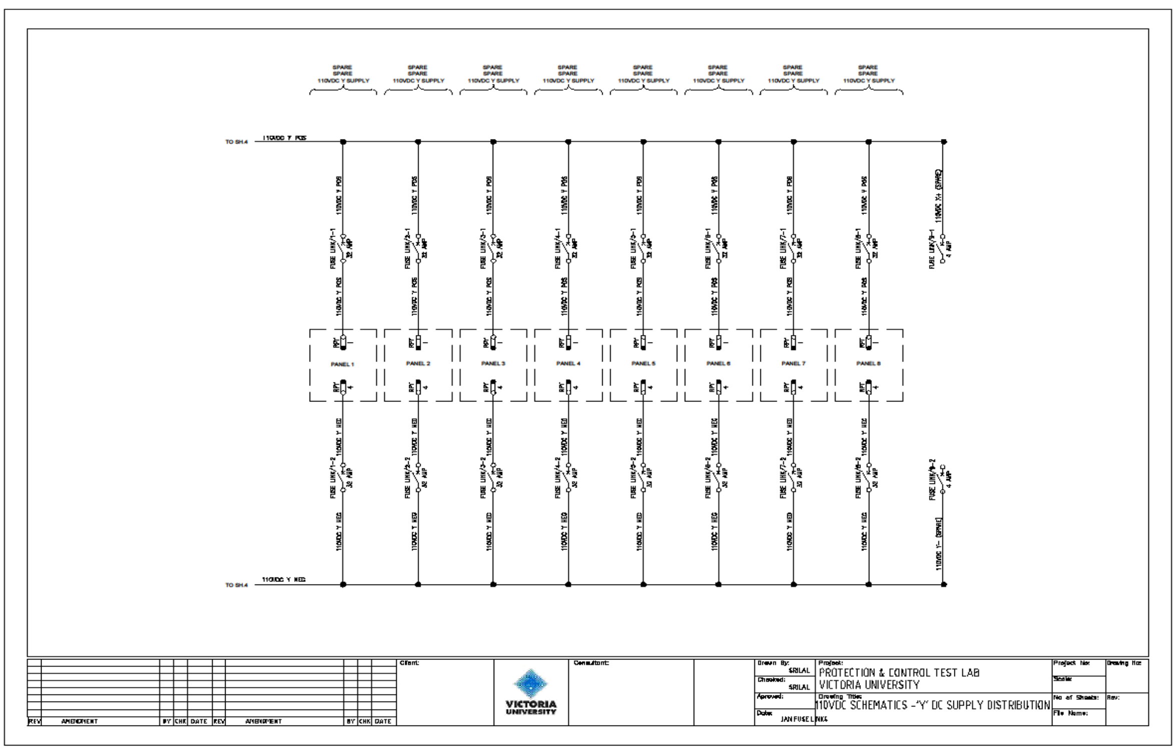


Figure 24: 110VDC Distribution – ‘Y’ Protection in Panel No8

4.3 Substation Automation and Relay Communication

4.3.1 Introduction to Substation Communication Systems

The International Electrotechnical Committee (IEC) Technical Committee (TC) 57 was built up in 1964 considering a dire need to deliver universal norms in the field of correspondences between the hardware and frameworks for the electric power process, including telecontrol, teleprotection and every single other media transmission to control the electric power framework. IEC did think about gear perspectives, however increasingly more framework parameters. This extension was adjusted to get ready benchmarks for power framework control gear and control frameworks, including supervisory control and information procurement (SCADA), vitality the executive’s framework (EMS), circulation the board framework (DMS), dispersion computerization (DA), teleprotection and related correspondences.

The specialized specialists of twenty-two taking an interest nation have perceived that the expanding rivalry among electric utilities because of the deregulation of vitality markets requests increasingly more of the frameworks. The mix of hardware and frameworks for controlling the electric power process into coordinated framework arrangements is expected to help the utilities 'center procedures. Gear and frameworks must be interoperable, and interfaces, conventions and information models must be perfect to achieve this objective.

4.3.1.1 EPRI & IED

The Electric Power Research Institute (EPRI) has existed since the 1970s to create innovations to support electric utilities. It oversees innovative work ventures with assets provided by those utilities as gathering and different sources. Since the 1980s EPRI has perceived the potential advantages of a brought together plan of information interchanges for every working reason over the whole utility endeavor. They concentrated on the simplicity of joining a wide scope of gadgets and frameworks; and the resultant sharing of the board and control data among all branches of the utility association. EPRI dispatched the North American Utility Communication Architecture (UCA) venture, which distinguished the necessities, the general structure and the interchanges innovations and layers to actualize the plan. The UCA activity works under comparative contract and suggests for usage of interfaces, conventions and information models. It is normal that upon finishing, the IEC TC 57 will receive these proposals and make them a subset of the IEC 61850 Standard.

The way to institutionalization is interoperability among merchants and frameworks. Specifically, noteworthy to all are on-going discourses of utilitarian interoperability, equipment and programming interfaces, conventions, information models and compatibility. Imaginative reconciliation improvements inside multifunction microchip-based transfers and other electronic gadgets (IEDs) have made better approaches for gathering and responding to information and utilizing this information to make helpful data. Power suppliers are confronting requests to build efficiency and make electric power more secure, progressively dependable and increasingly conservative.

This can be done when electric manufacturers provide innovative, simple to use, robust technologies to protect, automate, control, monitor and analyses power systems. An essential element of this strategy is the development of important communications technologies and protocols. At the point when coordinated together, transfers and IEDs become an amazing, efficient and streamlined Instrumental and Control (I&C) framework, fit for supporting all parts of electric power insurance, mechanization, control, checking and investigation. Correspondences processors, Remote Terminal Unit and Programable Logic Controllers are utilized in mix automation systems everywhere throughout the global utilities. The number of Utility Communication Architecture (UCA) based IEDs for protection and control available on the market is continuously growing and they are starting to appear in installations around the world.

There are some significant differences between UCA based IEDs and conventional microprocessor based protective relays. This requires good understanding of the fundamentals of communications-based substation protection devices and at the same time the availability of proper configuration tools that will make it easy for the user to adopt the relay for its application in the substation. This is especially important for peer-to-peer communications-based protection and control functions.

The material is organized in 8 chapters. After Introduction of the International Electrotechnical Committee and its objectives, the initiatives taken by the Electric Power Research Institute are identified followed by development of Intelligent Electronic Devices and the development of multifunction microprocessor-based relays. A separate chapter is dedicated to communication principles where various terminologies and architectures are identified. Numerous terminologies are described so that the student or power network operator can have an Engineering book that is easily understandable, and which can be referred to easily. Various architectures are considered that may very well be appropriate for different scenarios. A separate chapter is included on Protocols. In this chapter issues such as how communications processors communicate to each other within the entire power network are identified in detail. The application part of this book covers design and implementation of Universal Middleware to support real-time communication services over substation communication networks.

Intended to link various power networks via LAN & WAN communication and information embedded power networks, this book is authored from both university and power network operator's perspective. This book is aimed at the audience of application, design and Research & Development Engineers in Power System Communications as well as university graduate and continuous education students. [21]

4.3.2 Introduction to IEC 61850 Standard

4.3.2.1 IEC 61850 – The Emerging worldwide standard.

IEC 61850 standard ensures the following features:

- Complete communication profile is compatible and based on the availability of the existing IEC/IEEE/ISO/OSI communication standards [4].
- The protocols used will support self-descriptive devices. It should be open and should have a positive possibility to add a new functionality.
- The standard should be based on data objects and have an association with the electric power industry.
- Communication syntax and semantics depends on the use of data objects in relation to power systems.
- Communication standard acknowledges the implications of the substation being one node in the power grid, i.e. of the SAS being one single element in the overall control of the power system.

Why a new standard?

Gateways, or other protocol conversions, largely solve the problem of incompatibility between protocols, but they however also add extra equipment to the system. Moreover, they also introduce delays and possibly errors along the communication paths. Where gateways are not used, huge number of protocols are not desired from the point of view of both the users and the manufacturers. To handle these protocols in a utility, need proper training.

Need for interoperability

- Common standardized data model
- Common standardized service model
- Common standardized protocol
- Common standardized communication architecture
- Common standardized engineering data exchange
- Common standardized conformance tests

The goal of the IEC 61850 standard

Interoperability: the ability for IED`s to share and exchange information among one or several manufacturers.

Free Configuration: Free allocation along with the support of different philosophies will be there e.g. it will work equally well for centralized system (RTU) and decentralized systems (SCS).

Long Term Stability: The standard shall be future proof in terms of communication technology and system requirements

GOOSE Messages

Goose messages are directly embedded into Ethernet data packets and works on publisher-subscriber mechanisms. It is designed to be brand independent and it fully supports IEC 61850 for a truly interoperable approach within the substation network

Development of Ethernet

The first step towards the development of LAN in the year 1976 was the high-speed communication using packet switching (X.25). Earlier in the year 1970, Xerox had come up with a proposed standard physical communication for local computers. Later, in 1980, Xerox collaborated with Digital and Intel to publish the first specification for physical network communication. The Ethernet specification (then called DIX- Digital, Intel, Xerox) had a network speed of 10 megabits per second (10 Mbps). It had cables, connectors, and electrical characteristics used for communicating. Ethernet used the term local area network (LAN) as it was intended for systems located within a proximity of a mile.

IEEE 802 Standards

It is also a set of standards and it governs the networking along with addressing the bottom layers of the OSI model- the Physical Layer and the Data Link Layer. In this protocol (IEEE 802), the Data Link layer is broken down into two sub-layers which are Media Access Control (MAC) and Logical Link Control (LLC).

Firstly, Media Access Control (MAC) sub-layer is liable for identifying and using the physical node address of each device on a network. It also arbitrates the access to physical transmission media on a LAN (adjusted through the Physical Layer).

Secondly, Logical Link Control (LLC) is the top sub-layer of the Data Link Layer and it serves as a link between software entities commonly known as service access points. It provides a common interface to the MAC sub-layer.

TCP

- It is a connection-oriented transport protocol that sends data in the form of an unstructured stream of bytes.
- It was first developed by the US Department of Defense to connect several different networks designed by different vendors into a network of networks (the "Internet")
- The packets that are transmitted to a destination node is done by TCP (it provides a sending node with the delivery information), [2].
- If the data is lost during transmission (source to destination), then TCP retransmits the data until either a timeout condition is reached or until successful delivery is achieved.
- It detects errors and supports lost data to be retrieved.
- TCP recognizes duplicate messages and will get rid of them accordingly.
- For instance, the sending computer is transmitting too fast for the receiving computer, then TCP will initiate slow data transfer (flow control mechanism).
- The name given to the package of subroutines that provide access to TCP/IP on most systems is called "Sockets".

IP

- It is the primary layer 3 protocol in the Internet suite.
- For transmission of data over networks with different sizes, IP provides error reporting and fragmentation called datagrams.

- It represents the heart of the Internet protocol suite.
- IP addresses are unique globally. For example, 32-bit (4 bytes) by convention is expressed by converting each bite into the form of a decimal number (0 to 255) and separating the bytes with a period (192.168.40.00)
- IP address is divided into three parts which are network address, subnet address, and host address.
- Class A networks provide only 8 bits for the network address field and are generally used for a very large network. Whereas, in case of Class B, it allocates 16 bits, However, Class C allocates 24 bits for the network address field. [21]

4.3.2.2 IEC 61850 Series:

IEC 61850-1: Introduction and Overview

- Introduction and overview of IEC 61850

IEC 61850-2: Glossary

- Collection of Terms

IEC 61850-3: General requirements

- Quality requirements
- Environmental conditions
- Auxiliary services
- Other Standards and Specifications

IEC61850-4: System and Project Management

- Engineering Requirements
- System lifecycle
- Quality Assurance

IEC 61850-5: Communication requirements for functions and device models

- Basic requirements
- Logical nodes approach
- Logical communication links
- PICOM concept
- Logical Nodes and related PICOMs
- Performance
- Functions

IEC 61850-6: Configuration description language for communication in electrical substations related to IEDs

- Overview on intended system engineering process.
- Definition of system and configuration parameter exchange file format based on XML containing primary system schematic (single line) description along with communication connection description.
- IED capabilities includes allocation of IED logical node to primary system.

IEC 61850-7-1: Basic communication structure for substation and feeder equipment- Principles and models

- Introduction to IEC 61850-7-x
- Communication principles and models

IEC 61850-7-2: Basic communication structure for substation and feeder equipment- Abstract communication service interface (ACSI)

- Description of the ACSI
- Specification of the abstract communication services
- Model of the device database structure

IEC 61850-7-3: Basic communication structure for substation and feeder equipment- Common data classes

- Definition of logical node classes and data classes; logical node classes are composed of data classes.

IEC 61850-8: Specific communication service mapping

- Mapping(s) of services used for communication within the whole substation

IEC 61850-9: Specific communication service mapping

- Mapping(s) of services used for the transmission of sampled analogue values

IEC 61850-10 Conformance testing

- Conformance test procedures
- Quality assurance and testing
- Required documentation
- Device related conformance testing
- Certification of test facilities, requirement and validation of test equipment.

4.3.2.3 IEC 61850 – Communication Networks & Systems in Substations

Substation Configuration Language

It may be defined as a formal description of the communication in a substation. All types of communication pertaining to configurations are supported by one neutral and formal description which is Substation Configuration Language (SCL). This description can serve as a pillar for engineering and automatic testing.

Parts of SCL files:

- Header
- Substation
- Communication
- IED
- Data Type Templates.

Types of SCL files:

1) **IED Capability Description (ICD) file:** It contains a single IED section and it defines complete capability of an IED.
2) **System Specification Description (SSD) file:** It has 3 parts which are Substation part, Data type, and logical type. It contains complete specification of a SAS.
3) **Substation Configuration Description (SCD) file:** It contains substation, communication, IED and Data type template sections. Both .SSD file and .ICD file contribute to the formation of SCD file.
4) **Configured IED Description (CID) file:** It used for communication between IEDs and can be considered as a SCD file stripped down to what the concerned IED need to know.
5) **Instantiated IED Description (IID) file:** It contains only the data for the IED being configured (IED section and IED data type templates) and defines the configuration of one IED for a project.
6) **System exchange Description (SED) file:** This file is to be exchanged between system configurators of different projects. It is a subset of SCD file with additional engineering rights for each IED as well as the ownership (project) of SCL data.

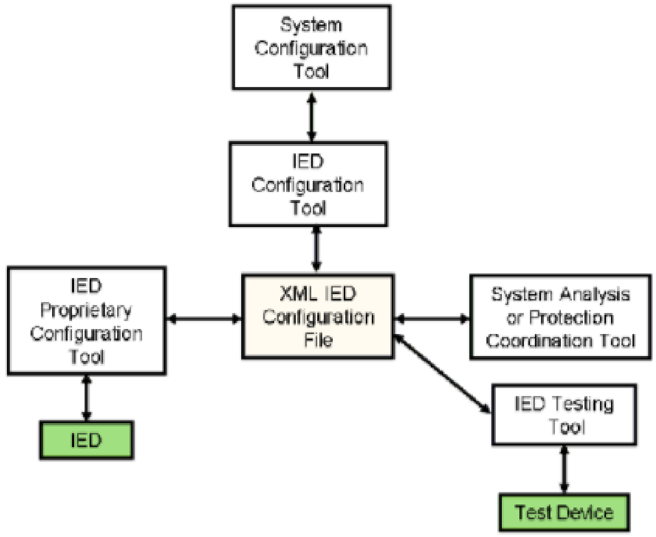


Figure 25: SCL based configuration process

OSI 7 Layer

The Open Systems Interconnection model (OSI model) is a theoretical model that shows and features the communication functions of a telecommunication or computing system without attention to its underlying internal structure and technology. One of its aim is the interoperability of diverse communication systems with standard protocols.

	Layer	Protocol data unit (PDU)	Function
7	Application	Data	High-level APIs, including resource sharing, remote file access
6	Presentation	Data	Translation of data between a networking service and an application; including character encoding, data compression and encryption/decryption
5	Session	Data	Managing communication sessions, i.e. continuous exchange of information in the form of multiple back and forth transmissions between two nodes
4	Transport	Segment (TCP)/ Datagram (UDP)	Reliable transmission of data segments between points on a network, including segmentation, acknowledgement and multiplexing.
3	Network	Packet	Structuring and managing a multi-node network, including addressing, routing and traffic control
2	Data link	Frame	Reliable transmission of data frames between two nodes connected by a physical layer
1	Physical	Bit	Transmission and reception of raw bit streams over a physical medium

Table 3: The table divides a communication system into abstraction layers

Layer levels:

1. Application – Provides a lot of interfaces for applications to use to access organized administrations.

2. Presentation – Converts application information into a conventional configuration for system transmission and the other way around

3. Session – Enables two gatherings to hold progressing correspondences, called sessions, over a system

4. Transport – Manages the transmission of information over a system

5. Network – Handles tending to message for conveyance, just as deciphers sensible system locations and names into their physical partners

6. Data Link – Handles unique information outlines between the Network layer and the Physical layer

7. Physical – Converts bits into signs for active messages and changes over signs into bits for approaching messages.

Comparison with TCP/IP model

The design of protocols of TCP/IP does not matter itself with strict hierarchical encapsulation and layering. TCP/IP doesn't recognize four broad layers of functionality which are borrowed containing protocols such as:

- The scope of the software application;
- End-to-end transport connection;
- Internetworking range;
- The scope of the direct links to other nodes on the local network.

In spite of these differences, these layers are often compared with the OSI layers in the ways which are described below:

- The Internet application layer includes the layers such as OSI application layer, presentation layer, and most of the session layer.
- End-to-end transport layer includes OSI session layer along with OSI transport layer.
- The internet layer is a subset of the OSI network layer.
- The link layer includes OSI data link layer along with physical layers, also OSI`s network layer.[21]

4.3.3 Substation Communication Basic Principle

4.3.3.1 Terminologies

Substation Control and System Integration

The SAS is the control of intensity framework contraption tasks to replace the human elements of perception, choice and activity. Substation computerization alludes to utilizing shrewd electronic gadget (including IEDs in general) information inside the SAS directions from the clients outside of the substation control center, which is also called remote client, to access the power framework appliances inside the substation.

Framework mix is the demonstration of conveying information to and from or amongst numerical protective relays in the fault and condition detection framework and remote clients. The power system joining alludes to consolidating information from the numerical protective relays that are nearby to a substation so there is a solitary purpose of contact for all the I&C information in the particular substation. This single purpose of contact at that point intervenes remote and neighborhood substation control. Since genuine substation mechanization depends on substation mix, the terms are frequently utilized conversely. There is frequently a requirement for different single purposes of contact to serve various client associations or give repetition. The single purpose of contact is an I&C gadget going about as a customer/server, programmable rationale stage, portal, switch, dial-out gadget, correspondence CBs, time management telecaster, or a mix of all above.

Substation Automation Systems

Items from numerous industries are utilized to perform substation computerization and control. The remote terminal units (RTUs), communication switches, meters, bay modules, and convention entryways from the supervisory control and information obtaining (SCADA) industry; PLCs from the procedure control industry, transfers and correspondence processors from the security business, and PCs from the workplace condition.

Substation controller and sound controller are terms regularly used to allude to gadgets that perform information securing and control of IEDs and contain neighborhood I/O. The correspondences processor is the main substation controller that can play out all the substation mechanization errands. The correspondences processor is additionally the main gadget that is intended to meet the cruel natural conditions as the transfers themselves. SCADA and procedure control industry items are not intended to satisfy these ecological guidelines

Network System for Active Data

The interchanges business utilizes words network system for a gadget which goes about as an ace, or customer, recovering information from certain gadgets and afterward goes about as Network or as a slave, or server, transfer information via different gadgets. The customer and server network for active or dynamic information gathers, also advances information regularly dependent on ace survey rate or by exemption. This information incorporates security information, metering information, computerization information, control information and supervisory information.

Network System for Archived Data

A power system file in Network system gathers and records authentic information from few relays and RTUs and PLCs. This information incorporates framework profiles, occasion reports, successive events recorder (SER) reports, control excellence information and protection superiority information; these Infor give a reasonable picture of power network performance. The client recovers information if they are advantageous for future references as such they can be archived at any time on request.

Information Concentrator

An information collector centers makes database of a substation by gathering and thinking active information from a few gadgets. In this style, fundamental sub-sets information after numerous Intelligent Electronic Devices are sent to an ace over one information exchange. The information concentrator file authorizations information starting with one IED then onto the next when they are not associated distributed.

Message broker

A message representative gathers and keeps whole communications from a few sources. Instead of thinking and concentrate just a subcategory of the information, the message merchant gathers the whole communication including heading, substance and blunder check eliminator. The communication dealer at that point goes about as a specialist information by arranging the message to be sent to where and when. This design, a whole communication is traded amongst two gadgets which can't legitimately or straightforwardly be associated.

Programmable Logic Platform

The rationale stage accomplishes in programming tradition mechanization rationale conditions. RTUs and PLCs have practically no default computerization capacity. Hence, RTUs and PLCs bolster adaptable programmability, so the end client can make essential mechanization starting from the earliest stage.

Protocol Gateway

A centre point is a relative straightforward multi-port gadget that rebroadcasts all information that it gets on each port to every staying port. It works at the physical layer of the Open System Interconnection (OSI) organize display, so it doesn't utilize any of the information to remaining directing activities. The International Standards Organization (ISO) made the OSI.

Comm Switches

A switch is a smart multiplexing gadget that screens the information connect layer of the OSI organize display. In the event that an information bundle is inadequate or unintelligible, the switch overlooks it and does not communicate it. On the off chance that an information parcel is flawless, the change rebroadcasts it to another port, considering the tending to information incorporated into the bundle and the addresses related with each port of the switch. More up to date switches can work on the Network (Layer 3) or Transport (Layer 4) bundle data.

Switched communication networks are those during which information transferred from supply to destination is routed between varied intermediate nodes. Switch is that the technique by that nodes management or switch information to transmit it between specific points on a network also called as packet switch.

Comm Router

Router is a smart connecting unit used to interface two systems together. It very well may be an unpredictable model, with numerous highlights. It works at the Network layer of the OSI arrange show. In another term, as utilized in the interchanges business it alludes to a gadget that courses information in travel among source and goal. The switch wisely communicates messages got single interchange out port for correspondences port. The goal communication is progressively decided by means of the substance of the message. This is utilized to effectively course SER and different communications over various SAS controllers without influencing existing substation control systems.

Servers

A server gathers information from most of the nearby gadgets and makes a substation database. Frequently a nearby human machine interface designs bundle utilizes information from this database. Servers work at the Application layer of the OSI display.

Dial-Out

This gadget starts discussions or generates summoning information from the local to a distant client. The dial-out incorporates guaranteeing association safety, wiping out the requirement for a devoted correspondences association, and performing spontaneous sign of an unsettling influence with fault area.

Eavesdrop Communication

Listen stealthily correspondences alludes to observing a discussion between two gadgets in the I&C framework and catching and putting away the exchanged information. This is valuable for removing the data without impacting the stream of information between gadgets that may not be accessible.

Copy Protocol Messaging Settings

While picking the top original and in-administration appliances an effective I&C framework, usually important to choose from various merchants and furthermore different vintages or ages of items.

4.3.3.2 Network Architectures

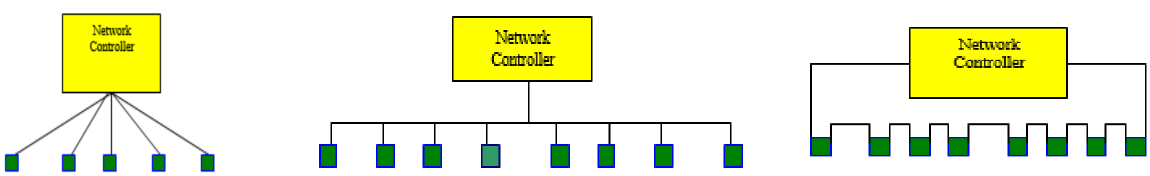
Types of Connections

Direct connect and multidrop are two types of data link connections available to create networks. In a direct connection, there are only two devices connected via network media, which can be metallic, wireless or fiber. Each interface consists of a separate transmit and receive connection at each device. Since there are only two devices, each of them can constantly control the connection on which they are transmitting, and both can know implicitly to which other device they are connected. Several individual direct connections to many IEDs would allow each of them to communicate simultaneously. Many direct connections originating from one device is called a star network topology.

Any protocol, including those designed for multidrop applications, can be used for direct connections in a star topology. Star network designs support a wide range of IED capabilities. Simple, slow communicating devices can coexist with more complex fast communicating relays. Devices from different manufacturers with different protocols can coexist in the same star network because each has a dedicated direct connection.

Open architecture is a term that refers to networks that are interoperable between hardware and software interfaces and therefore among vendors. The star topology is the only design that is truly open architecture and will accommodate multiple protocols, baud rates and network interfaces.

The most common communication architecture used today is the multidrop network. In a multidrop arrange topology, a few gadgets can be physically associated in a transport or ring system and control of the transmit and get association must be arranged. Below pictures illustrate relays connected in a bus and ring topology respectively. A multidrop connection requires that only one device communicate at a time. There are often additional components for terminations and network drop connections, which are vertically down to the individual relays or IEDs. Because all IED/relay share the cable, communications are usually controlled by the network master or a token passing scheme in which IEDs/relays have permission to communicate when they receive the virtual token and then pass the token on when they are done. Peer-to-peer messaging may or may not be available. Sequential polling of each IED/relay usually performs data retrieval by the master.



- Relays/IEDs

Figure 26: Different network architectures; Star Radial & Ring Topology

Software and hardware are used to determine which device has permission to transmit so that data does not collide on the conductor. Since several devices are connected, addressing is necessary within the protocol to identify the source and destination of the data being communicated. This addressing adds overhead in the form of processing time and amount of information that needs to be transmitted thus reducing the data transfer rate. Devices compensate for this by increasing the speed at which they communicate and increasing the amount of communications processing that they perform.

Troubleshooting communication problems on a multidrop network is difficult. Messages from many sources must be captured and deciphered. Direct connections are quickly and easily verified using simple LED indication.

Relays have varying memory and computational capacities and, therefore varying protocol support capabilities. Interactions on a multidrop network must be done at the lowest common denominator and all devices must support the same baud rate and physical connection.

It is important to note that if the mediation of control of data transmission should fail, none of the multidrop devices can communicate. This can be caused by relay communications hardware failing to release control, relay communications software failing to process mediation schemes correctly, or corruption of the network

Long term trend of Networks

The future trend is away from multidrop network and toward star network, eg. Ethernet. Originally this was conceived as a multidrop network using expensive coaxial cable, however widespread use has shown that a star network is far superior. Today all Ethernet networks are built using hubs. A hub acts as a very short bus, which allows one to wire from the hub using inexpensive cable in a star configuration.

With network traffic and use continuing to rise, smarter devices like switches are replacing hubs. A switch can store and forward information making the logical network a star also. Multiple nodes can transmit or receive messages from the switch at the same time. Ethernet has now completed the transformation both electrically and logically in a star network architecture.

Peer-to-Peer Network Architecture

Protection data, for the purposes of security, reliability and speed are highest priority and should be transferred via a single purpose conversation on a channel dedicated to this purpose alone. These functions perform optimally if this data can be transferred every device processing interval, between 1-12 ms.

Typical Integrated Digital Protection and Control System

It consists of several devices interconnected as a network via Ethernet switch/router. Such an arrangement has a ranked structure with distributed intelligence and different level of complexity. The hierarchy however is only functional, as while at the same time it can be flat from the communications point of view, i.e. all IEDs are connected to the same Ethernet network. For large substations with several voltage levels and multiple buses the number of hubs will increase and depending on the requirements for protection performance the hubs can be replaced by switches in order to limit the traffic on the different segments of the substation network.

The primary functions of the IEDs is to protect different substation and power system elements viz. transformers, buses, capacitor banks, motors, lines etc. IEDs perform this basic function only under fault conditions, which is a event with very low probability. However, they need to have sufficient processing power and intelligence. Hence at lower hierarchical level it allows their use for data acquisition, control, monitoring and fault recording system.

At the next level the Bay Controller IEDs provide additional digital and analogue interface with the substation environment and at the same time provide protection and control functions.

At the top level the Substation Controller IED or the substation computer it provides integrated protection and control. It provides substation protection and control functions based on the exchanged high-speed peer-to-peer communications messages and over the substation LAN. It also provides the Human Machine Interface (HMI) functionality with the different IEDs in the substation. It supports alarm and event reporting, data archiving, analysis, monitoring etc. functions. [21]

4.3.3.3 Protocols

A modern power system is one of the largest complexes constructed and operated both in terms of geographical distances as well as generated and transmitted power. Such a system needs precise and high-quality control with protection functions as primary due to the top priority safety reasons. Traditionally protective relays have been electromechanical devices whose purpose was only to protect electrical power systems against system failures. Application of microprocessors to power system relaying has increased the functionality of protective relays and brought new concepts, which considers control, protection and monitoring functions integrated together. In the past decade, new communications schemes have been designed and retrofitted into the substations by the utilities to integrate data from relays and Intelligent Electronic Devices (IEDs) and capitalize on the protection, control, metering, fault recording, communication functions available in digital devices. This chapter describes substation communications and the ongoing communication standardization efforts discussing the IEC 61850 and the Utility Communications Architecture (UCA) standards. [21]

Introduction to Power System Communication:

Many of today's electric utility substations include digital relays and other intelligent electronic devices (IEDs) that record and store a variety of data about their control interface, internal operation and performance, and about the power system they monitor, control, and protect. Nowadays, digital relays are widely replacing the aging electromechanical and solid-state electronic component-type relays and relay systems. Digital relay's popularity comes from their price, reliability, functionality, and flexibility. However, the most important feature that separates the digital relay from previous devices is its capability of collecting and reacting to data and then using this data to create information. [21]

Such information includes: -

- Fault location and fault type,
- Prefault, fault, and post-fault currents and voltages,
- Relay internal element status,
- Relay control input and output status,
- Instantaneous and demand metering,
- Breaker operation data,
- Relay operation data,
- Diagnostic and historical data.

Instrumentation & Control devices, which are built using microprocessors, are commonly referred to as intelligent electronic devices (IEDs). Microprocessors are single chip computers that can process data, accept commands, and communicate information like a computer. IEDs can also run automatic processes, and communications are handled through a serial port like the communications ports on a computer. Some examples of IEDs used in a power system are :

- Instrument transformers
- Transducers
- Remote terminal unit, RTU
- Communications port switch
- Meter
- Digital fault recorder
- Protocol gateway

4.4 Control Function Design Description

Figure 27 shows SCADA Overview of SLD which describes the network architecture designed for the VUZSA project.

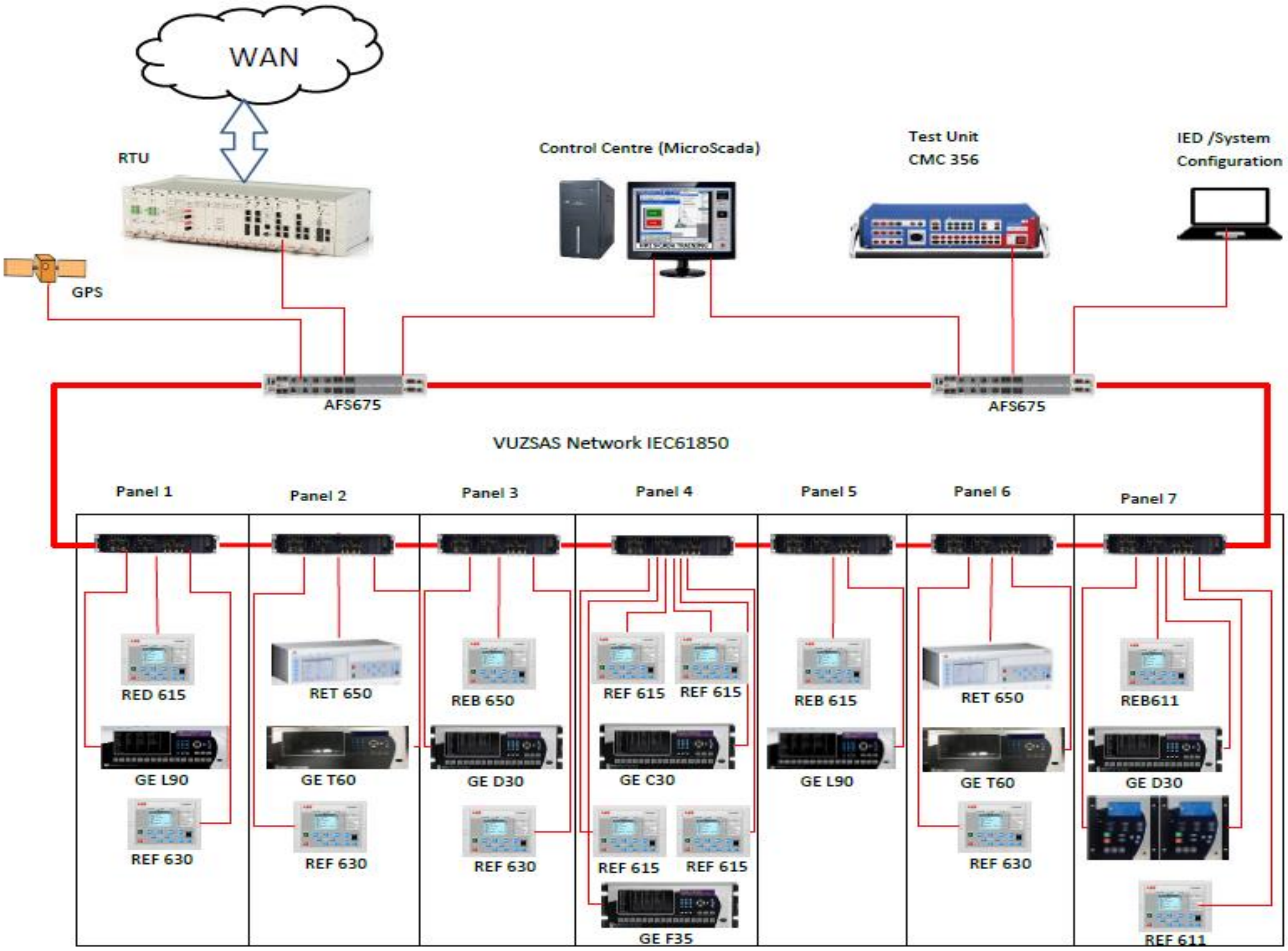


Figure 27: VUZSA SCADA System Architecture

Refer to the above SLD Panel No8 (not shown in the diagram) is included with 2 ABB COMM Switches which called as ‘station switch’, RTU and SCADA, also AC/DC distribution systems.

Refer to the SCADA overview SLD for system architecture used for VUZSAS each panel in the IEC61850 ring has a dedicated Ruggedcom switch which is also called as ‘panel switch’. The ABB SCADA, MicroSCADA PRO is used for the local HMI.

The RTU in the panel No8 will be connected to MicroSCADA PRO from a separate computer located in the Network Operating Center (NOC) which identifies as the entrance of the proposed lab.

To increase the communication availability of the system, each of the switches will be powered by a redundant DC power supply. The two DC power supplies for each switch are proposed to be fed from a backup battery bank.

Each IED will be connected to the switch using glass Fiber optic. Each switch has an extra RJ45 connector for easy access with a Laptop when engineers visit the station.

The RTU560 is connected to the switch using an RJ45 connection. It is the gateway between the IEDs and the Network Operating Centre. The communication protocol on the station bus is the IEC61850-8-1. The communication protocol to the NOC is IEC60870-5-104 over TCP/IP.

MicroSCADA SCS handle the substation Local/Remote authority features directly via the IEC870-5-104 link to NOC. The station local remote switch is installed on the MicroSCADA HMI. The status of the switch is provided to the RTU560.

All substation alarms (such as Relay fail, DC fail, battery health, A/C fail, fire alarm…) will be hardwired to the RTU560 binary input. A final signal list shall be created which includes all conveyed IED information as well station alarms.

If need for research purpose higher degree candidates, remote access will be available to the Substation Control System (local HMI) using Windows Terminal Service feature. It enables the user to remotely connect to the NOS and monitor or operate (depending on their user right) of the other substation. All these are available functions for further research and developments studies of the proposed model zone SAS.

The RTU560 and a LAN time synchronizing clock is proposed to install in the same panel No8. This clock will be operating with SNTP or any suitable protocol.

ABB bay control terminals REC630 are used to provide remote control and indication for the primary plant in each bay at VUSS.

4.5 Substation Control System – MicroSCADA PRO

The MicroSCADA Pro SYS600C is provided by the industry supporter of the project. This is a separate high-performance computer located in the NOC. The MicroSCADA SCS has a redundant connection to the ring via two switches (one switch dedicated to the NOC, the other switch is the RTU560 dedicated switch). The connection to the switch is via RJ45 connection.

According to the manual of MicroSCADA Pro SYS600C has many configurable functions, such as substation supervision, monitoring and control functions are available, for e.g. the HMI will offer the operator powerful SCADA features such as:

- single line diagram with dynamic busbar coloring
- zooming

- panning
- secure control command of all circuit breaker
- Event List (with filtering)
- Alarm List (with filtering)
- Blocking List (with filtering)
- Measurement Reports
- Trends
- System Supervision picture
- Relay Setting Tools
- DR upload
- Context Menu

Also, MicroSCADA offers 4 authority levels, View, Operator, Engineer, Super user

- View can navigate through different display but cannot perform any operation or acknowledge alarm…Password will not be required for access at this level.
- Operator can perform operation and acknowledge alarm. He cannot engineer the system. Note that operation can be limited to certain switches (eg voltage level limitation…)
- Engineer can perform operation (if he belongs to the right operator group) and engineer the system
- Super user can perform operation (if the right operator group) and engineer the system, create and delete users. Every user can change their password

4.6 Monitoring and Control Design

CB Control - The VUZS has the facility available to configure Site/Remote Control selector switch located on the NOC HMI and Bay Local/Remote control selector located on the bay panels. The operator can change the position of the Site/Remote selector to either Site (for control from the NOC HMI), or Remote, for control from the Remote-Control Centers), and also the operator can change the Bay Local/Remote selector to either Bay (for control at the bay level, or Remote, for control from the NOC HMI or from the remote OC.

Below is a table summarizing the Local/Remote switch conditions required for enabling control at different location.

	Site Switch position in MicroSCADA			Bay Switch on Protection Panel	
	Local	Site	Remote	Local	Remote
NOC			x		X
Bay level	x			x	
Device level					

Table 4: CB Control Selection Criteria

A close command can be issued from the push button which will energize the CB close coil, through the ABB REC630

Refer to below, Figure 28, scheme followed for control command logic description:

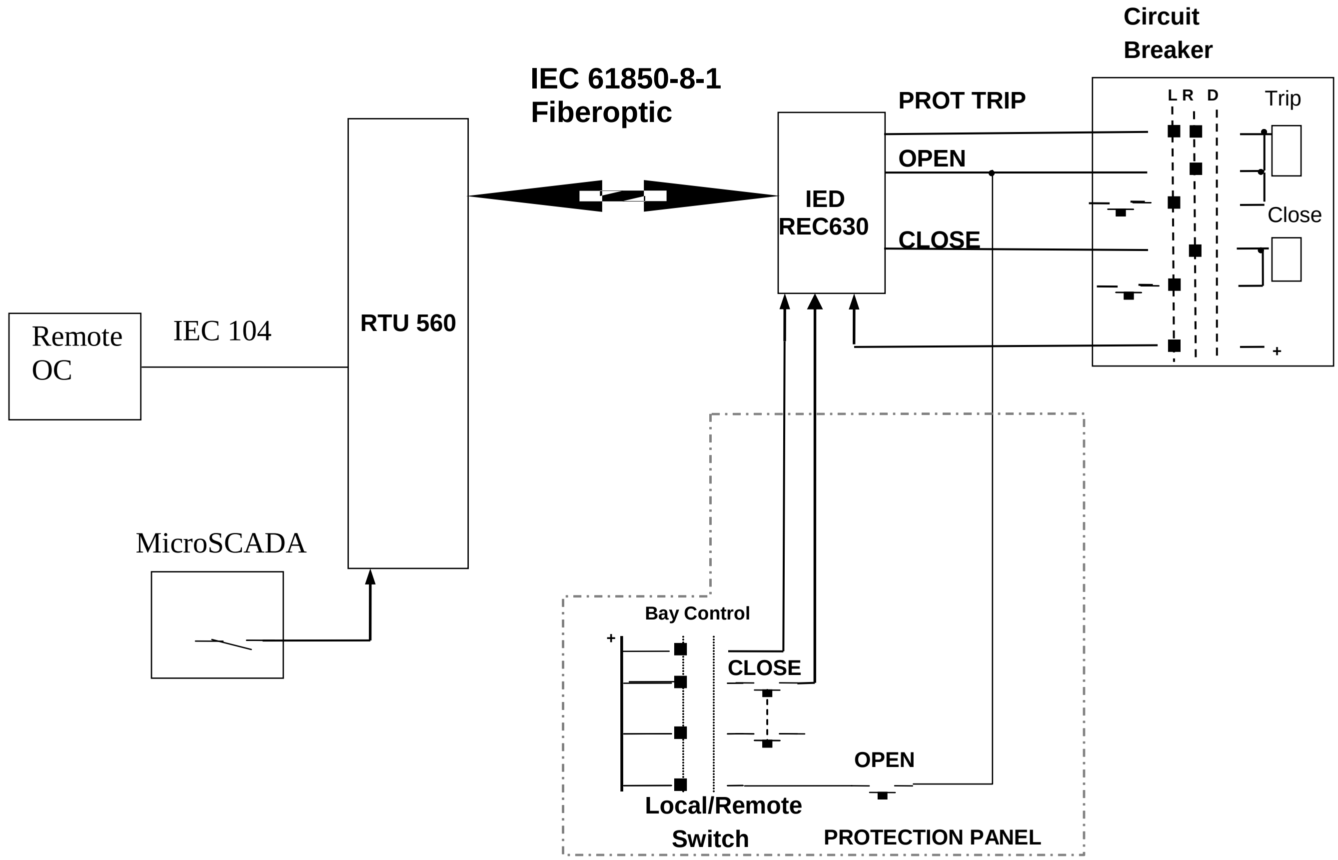


Figure 28: CB Control Scheme from SCADA using IEC61850

4.7 RTU560 (IEC61850) functionality

An ABB Remote Terminal Unit RTU560 acts as a gateway between the substation and the OC.

The RTU560 and a Meinberg synchronizing clock (Time synchro not yet purchased) are installed in a cubicle separated from the protection cubicles as described earlier.

The MicroSCADA HMI system is used to initiate commands, such as opening and closing of the CBs. These commands can be issued from remote locations such as OC or locally, as long as the operator has the appropriate access level. Internal Switch room lighting is also operable via the RTU560 from the OC.

RTU560 redundant CMU concept (Not used but can consider this concept in future):

The main concept is to have one pair of CMU boards for connection to the Network Control Centre, which are critical for the operation of the station. In case of an error condition the RTU560 will switch over to the standby CMU and this CMU starts to take over the tasks after a cold start.

One pair of communication units (CMU) of an RTU560 configuration can be defined as a redundant communication set. In case of an error of an active CMU, the system will switch over to the redundant stand-by CMU, which will continue processing after performing a cold-start.

This new redundancy concept of the ABB AG firmware is different to former releases of the RTU560 and will result in a better availability of the system. For some function modules like archives and PLC it is not useful to have a redundancy because of loss of information for the archive or loss of process control for the PLC. These modules are only installed once in the RTU560A system and so called non-redundant modules.

The RTU560 CMU modules can be defined in three types:

- the active CMU (A), which is the active running device

- the standby CMU (B), which monitors the active CMU and is prepared to take over as active device
- the non-redundant CMU (C), such as the IEC61850 CMU which continues operation all the time

To supervise the status of the RTU560 it is necessary, that the standby CMU and the active CMU monitors each other to be in the situation to take over the other state or not. When for example a standby CMU fails, it is not allowed to switch over, and it is necessary to inform the host about the failure in the standby CMU by the active one. On the other side the standby CMU must detect, when the active CMU fails without any alarm or warning message to take over the active state.

On top of the CMU redundancy as described earlier, the RTU560 for this project also made to be Power Supply Redundant. Any failure in the main power supply will result in the backup power supply taking over supply.

In both the power supply and the CMU failures, the modules can be hot swapped which increases the availability of the system.

4.8 VUZS-Station Auxiliaries

The RTU560 can also monitors other auxiliaries including:

- VU Lab Fire alarm system
- VU Lab Control building temperature and Air conditioning
- VU Lab110V batteries (voltage)

- Personnel entry to the Protection Lab and CCTV Functions

In SCADA following measuring values are also available; MWh. MVAR, Voltage & Currents, System Frequency, Data logging and Fault locater with RTDS.

4.9 AC/DC System Description

4.9.1 AC Supply to panels and cubicles

Two 240Vac volts supply from the AC distribution board of VU Protection Lab, via two MCB are wired to the panels to provide lighting and sockets, and the other is for AC/DC power supply system.

4.9.2 DC Supply to panels and cubicles

110V dc supply is provided for all Protective relays, COMM switches and Controls and monitoring equipment.

AC to DC switch mode converter is separately give two independent 110Vdc circuits, and they are wired separately and segregated as 110Vdc – ‘X’ Protection, 110Vdc – ‘Y’ Protection supply. The panel location is called DC Distribution board.

There are some provisions for DC Battery backup system and will be designed as future work of the lab. It can be done even after the lab is fully functional level.

240Vac to 24 Vdc is separately used for ABB RTU560 System.

5 CHAPTER 5 – TESTING AND EXPERIMENT FOR SIMULATION OF VUZSAS

5.1 VUZS PANEL TESTING

The protection and control equipment offered have undergone for two levels of routine PANEL testing

- Panel tests of the components, routine panel parts tests of the products are performed at the product manufacturing plant of the individual products used in the scheme. The tests are done according the relevant IEC standards applicable to the product.
- Panel tests of the assembled and wired system, the assembled and wired system (in cubicles), which will form the protection scheme, are panel tested in the protection and control lab at VU.

5.2 Simulation Test Procedure

This session consisted of the following before the panels being powered up:

- Equipment checks
- Point-to-point wiring tests
- Insulation test with a 1kV DC insulation tester.
- DC supply tests
- Relay and associated circuit functional tests. This includes injection testing to verify the correct application of relay settings.

The operation test on each protective function is limited to one operating point at the setting of the protection function.

5.3 Real Time Digital Simulation Function Test

5.3.1 What is Real Time Digital Simulator (RTDS): -

- RTDS system consists of rack or multiple racks of processor cards, Network communication cards, Analogue and Digital I/O cards.
- A rack in RTDS has multiple processor card which are connected to a backplane, the backplane is used to allow processors to exchange information between processors.
- It has modular design which gives the flexibility to connect physical I/O devices.

5.3.2 Applications of RTDS: -

- System Testing (Protection, Automation &Control)
- Micro grid Simulation (Islanding/Grid-Connected)
- Power Electronics (PWM Inverters and Rectifiers)
- HVDC/FACTS simulation
- Education & Training

5.3.3 Significant features of the RTDS which has been tried at VUZSA:

- World's 1st real-time digital simulator exclusively designed for power system simulation at Manitoba HVDC Research Centre in 1989. (commercially available in 1993)
- Used for fast, reliable, accurate and cost-effective study of power systems with complex HVAC/HVDC.
- Employs a nodal analysis-based solution algorithm (similar to other industry standard power system simulation program for electromagnetic transient simulation).

- Can simulate Electromagnetic Transient phenomena with the time-step of 2-50 Microsecond with frequency range of 0-3kHz
- Many features and models of RSCAD and RTDS simulator have been developed with response to specific request from the customers (real-world scenario).

5.3.4 Test Bed at VUZSA Lab consisted of Following Hardware and Software:

- RTDS Rack
- RTDS Cubicle
- Ethernet Switch
- Double test units (amplifiers)
- GE- D60 Feeder Protection Relays
- Laptop (RSCAD, F6 Multiple Doble Amplifier)

RSCAD Modules has the following configurable features:

- DRAFT
    - Primary power system equipment and control circuits
    - Power system library
    - Data entries
- RUNTIME
    - Interactive environment allowing user to apply different events (fault, switching).
    - Plots and graphic representations
- T-line
    - User defined characteristics for the transmission line (wave traveling model)
    - Placement of the lines and distances between each phase of the line
- Cable

- Specifying the characteristic for the cable (underground line), sheath, isolation etc.

➢ Cbuilder

- Create user-defined components including graphical representation, data menu and real-time codes.

5.3.5 RTDS Test carried out:

➢ Transmission line Distance (Impedance) Protection function selected for simulation.

➢ Both ends power generation feed, parallel double line transmission system chose

➢ Permissive Overreaching Transfer Tripping (POTT) scheme selected, the trip logic is as per the Figure 29.

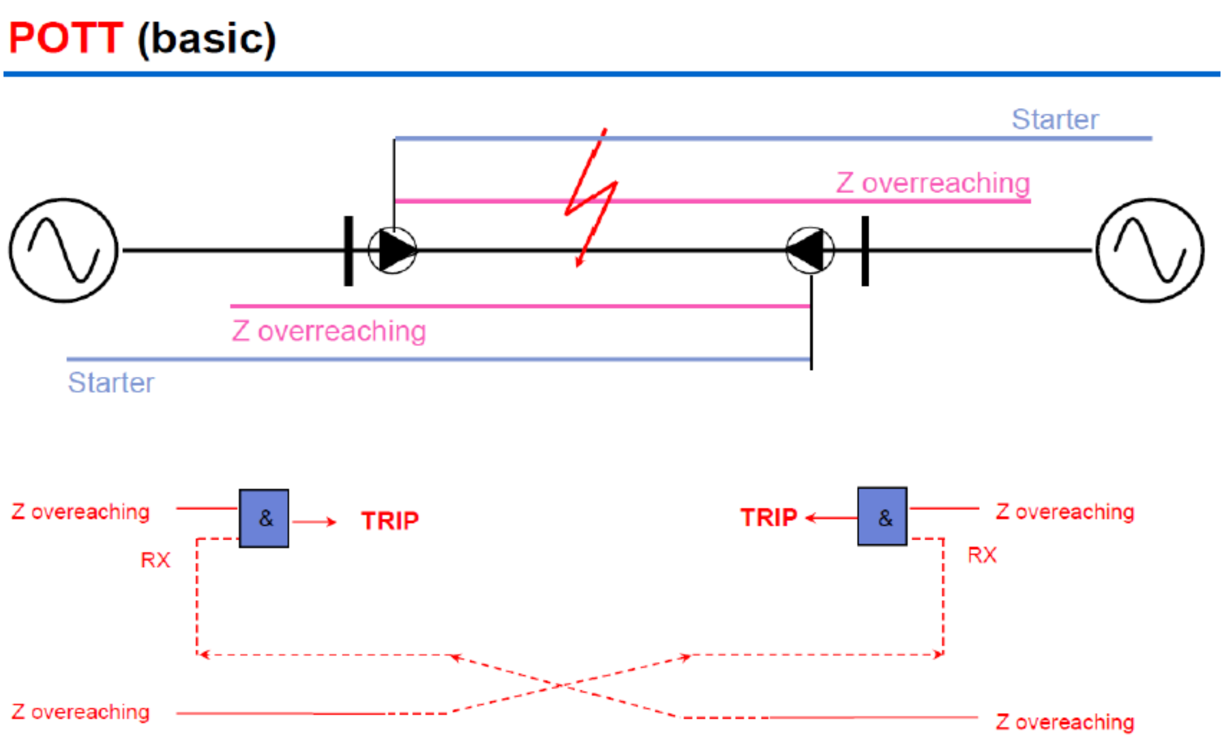


Figure 29: Permissive Overreach Transfer Tripping Basic Scheme

The basic idea for the POTT scheme selections are: to obtain the response of the distance relay element at other end to speed-up decision making, It is a communication-based protection scheme, and Permissive signal must be detected from the remote end for the communication aided trip.

Figure 30 shows the RUNTIME configuration from RSCAD which has the following main functions:

- Interactive environment allowing user to apply different events (fault, switching).
- Plots and graphic representations

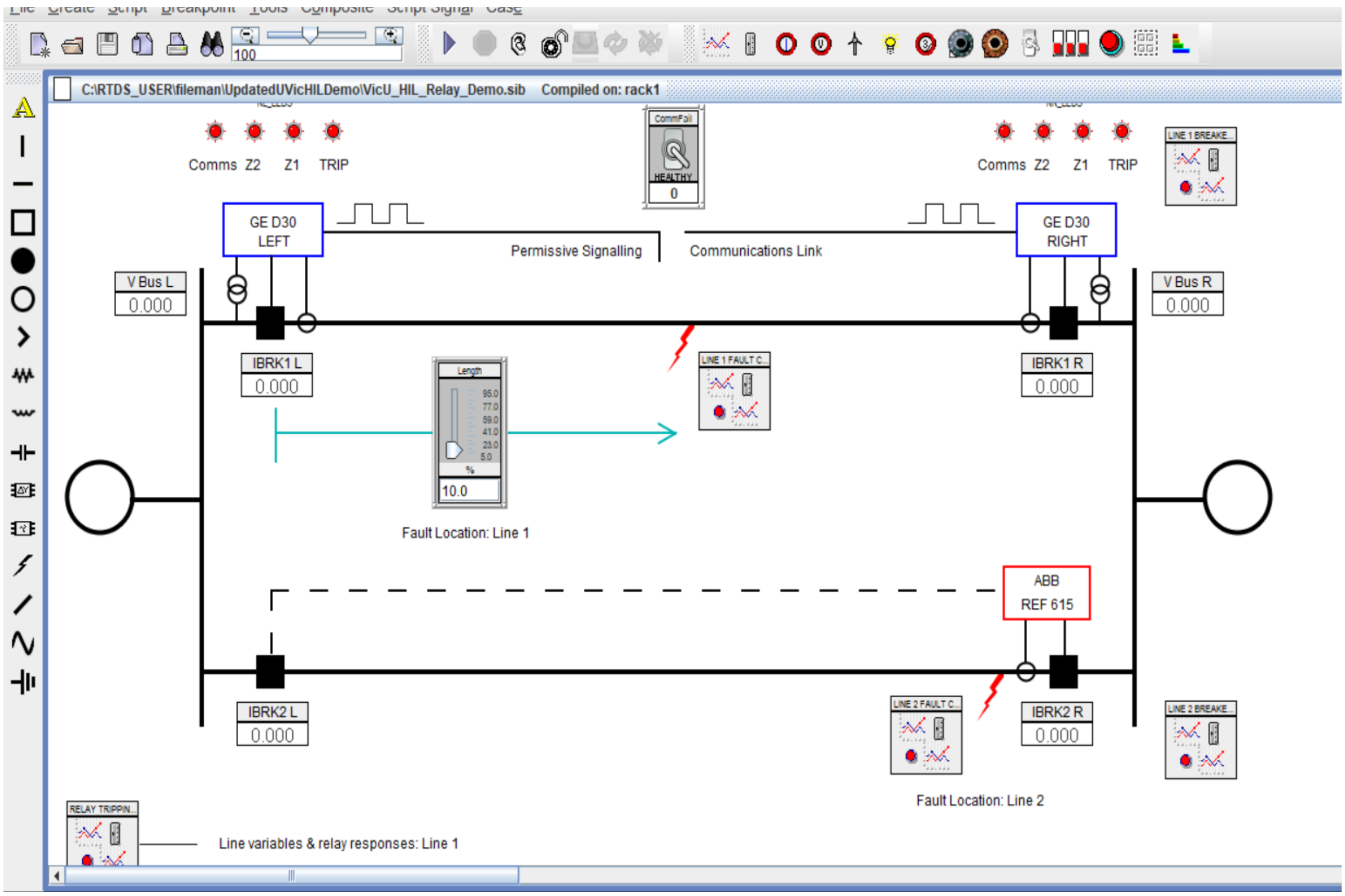


Figure 30: RUNTIME Graphic configuration representation for the Transmission Line

Figure 31 shows protective relay allocations and tripping zones for POTT scheme for transfer inter tripping time testing.

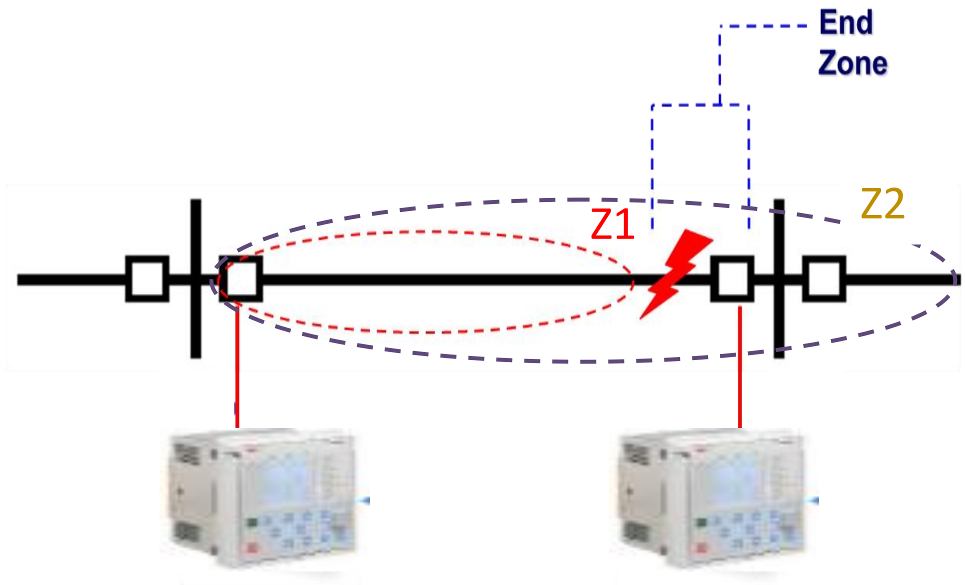


Figure 31 : POTT Scheme and ABB RED615 Feeder protection relays allocation

5.3.6 Experimental Test Results and Discussion

Test bench is successfully set up and the laboratory environment is looked as in Figure 32 below. The setup can be separated into three sections. They are section of simulations, section for amplifiers, and then SAS. Simulations are done by RTDS hardware and operated with Laptop where the software are installed. This Laptop is also used for IED configuration, protection settings, and also for reading disturbance recordings from IEDs. Two ABB RED 615 feeder protection IEDs selected for simulation test, One IED is located at an incoming feeder panel (Panel No1) and the other one at an outgoing feeder (Panel No4). Current and voltage measurements simulations are amplified for IEDs to represent ITs. Substation panel IEDs are used to simulate busbar and feeder protections. Communication between IEDs is setup with IEC 61850-8-1 and both protective devices have capability to operate circuit breakers.

Circuit breakers are possible to operate with tripping function or from IEDs' LCD screen with push buttons.

Figure 32: Protection Relay Testing and RTDS Test Bed is Set up for Simulation Run

Fault Simulation Test Results :

1. Normal operation simulation

	Simulator Values		IED1 Readings		IED2 Readings	
Test Events Description	kV	A	kV	A	kV	A
Normal load simulation -both CBs closed	22	87.5	22	86.7	22	86.8
Normal load simulation -rear end CBs opened	22	65.8	22	65.6	0	0
Normal load simulation – broth CBs opened	0	0	0	0	0	0

Table 5 : Simulation Test Reading

2. EF operation simulation

	Calculated Fault Values		Simulator Values		IED1Readings		IED2 Readings	
Test Events Description	kV	A	kV	A	Trip	Time (s)	Trip	Time (s)
Line-to-ground fault, Phase C, at Rf=500 Ω	22	14.5	22.3	14.0	start	-	Yes	0.325
Line-to-ground fault, Phase C, at Rf=1000 Ω	20	13.1	22.1	12.9	start	-	Yes	0.351

Table 6: Fault Simulation Test Reading

In simulated earth faults, protection devices operated as expected and both IEDs noticed the faults as fault detected.

3. Goose Trip simulation

	IED1Readings		IED2 Readings	
Test Events Description	Operate	Time (s)	Operate	Time (s)
Three Phase Short Circuit and HW trip	Yes	-	Yes	-
Three Phase SC and GOOSE trip	Yes	-	Yes	

Table 7: GOOSE Test reading

Both IEDs operated with Hard wire trip and with GOOSE trip message as expected.

4. Test result summary

- Real time power system simulation successfully done and power meter reading on the relay and SLD also successful. CB switching simulation were successful on SLD.
- Fault creation and fault inception simulation was successful.
- CB tripping at local end and remote end were successful.
- POTT via GOOSE was successful.

6 CHAPTER 6: CONCLUSION

6.1 Introduction

According to previous experiences for utilities engaging in development and implementation of substation automation systems, lack of skilled staff and engineers have been a main reason for delaying their projects. This in fact can impact the timing and costs of the project for IEC61850.As a solution for addressing this issue, Victoria University has been a pioneer to develop and implement a substation automation laboratory which can be a basis for training purposes and research studies.in fact with continuous extension to IEC61850 standard, applications of IEC61850 is looming to prevail in operation of the future smart grids. Therefore, the main objective for development of SAS laboratory is to train and educate future proof engineers who are skilled in development and implementing of smart grids which not only can contribute for development and implementation phase but can have a great impact in performance and operation of the smart grid through its life. Moreover, due to the design and development of the VUZSA laboratory to match real-world scenario in the substations, VUZSA can be an appropriate test bench and facilities for verifications and testing of functionalities proposed by research students.

Since this project proposes the solution to complete the proposed IEC61850 standard power system protection and control laboratory at VU. The concept of this research project is to identify where the project stands now and find solutions to start the initial design and then construction of the lab. The design of this model zone substation protection and control is done by matching the exact requirements and arrangements of zone substation automations in Victoria. The project sets to get involved with the industry support mainly to obtain equipment manufactures know how to implement their technologies. The outcome of this project is a methodological framework to design, construct and commission of the proposed laboratory at VU. This new laboratory with real time simulation will be the first of its kind in Australia and will play a millstone role for VU and the industry in Victoria and countrywide.

6.2 Major Benefits

Some major achievements have been accomplished satisfactorily throughout the research project. They are the completion of conceptual design, detail design and the construction completion of the VUZSA IEC61850 simulation lab. Figure 33 shows the lab as it is now, is the major achievements to start with R & D works in the field of IEE61850.

Figure 33: VUZSA Simulation Lab having completed its first part.

This is the first part of the research project, for this stage all panel works, power supply, relay in/out connections drawings and some partial test for relay configurations have been completed. Also, can mentioned as another benefit that RTDS and amplified CT/VT simulation initial set up and few trial experiments have also been carried out successfully. This has proven GOOSE tripping between two ends of a transmission line are possible

A detailed description of all protection schemes, substation CB tripping matrix, and back up tripping hardware inventory, and wiring schematics used to assemble the VUZSA eight panels are elaborated in Chapter IV under VUZSA Functional Design Descriptions. Traditional copper wiring for inter trip circuits on relays to isolate circuit breaker coils, are reduced dramatically, and rely only GOOSE messages that are sent across fiber optic cables to relay trip contacts. Therefore, this research project will prove several benefits for SAS designs including reduced wiring costs, higher data performance and automated link status.

6.3 Future Work

SAS lab needs the future works for it continues development. The framework could be stretched out by adding more functionalities to the model substation system as future developments.

- Time Synchronization (SNTP, PTP) can be added to simulate WAP and Adaptive protection functions to be simulated with created time synchronized environment.
- A fault detection and clearance would be good extension. Fault indications and remote controllable disconnectors would be great to add to simulation model.
- In displayed implementation of the subsequent SAS research center, the usefulness of substation doesn't present functionality of real substation automation so keep adding real scenarios the lab function will improve.

- Additionally, shortcoming administration capacities could be added to the computerization research facility, which are executed in the reenactment model.
- IED can be updated with better and new version of their software from time to time. but this is not necessary, because laboratory teaches the fundamentals from protection control and monitoring SAS functions.
- To complete VUZSA system as a real substation automation with IEC61850, outputs of all protective relays, RTU, SCADA, Dummy CBs are needing to be wired, configured and set as real substation.
- CB trip matrix and GOOSE matrix of VUZSA need to create before final configuration is done for the substation commissioning.
- Dummy CB with IEC61850 compatibility needs to install for real GOOSE Trip analysis.
- Configure all substation primary data and relay setting need to be configured fully on Real Time Digital Simulation system (OPAL-RT HYPERSIM) and RTDS
- DC Battery bank design and install to be used as real substation back up power system and be connected to RTU for status.
- Upgrade IEDs for IEC61850-9-2 for process level simulation of RTDS
- Process Bus components (PMU, Data Concentrator Unit)
- Consider the research are for Cyber security, i.e. IEC61850-10

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