University of Southern Queensland

Faculty of Health, Engineering and Sciences

A Test Facility for Assessing the Performance of IEC 61850 Substation Automation Designs

A dissertation submitted by

Matthew Julian Hogan

in fulfilment of the requirements of

Courses ENG4111 and ENG4112 Research Project

toward the degree of

Bachelor of Engineering (Electrical/Electronic)

Submitted: October, 2014

Supervisor: Dr Tony Ahfock

Abstract

Substation Automation Systems have undergone dramatic changes since the introduction of powerful micro-processing and digital communications devices over Ethernet based networks within the substation. Smart, multifunctional relays, known as Intelligent Electronic Devices, or IEDs, have replaced the traditional panels which contained multiple protection relays, control equipment, metering and status indicators.

ActewAGL Distribution, a power utility company servicing Canberra, Australia, has recently decided to undertake a review of its substation automation systems throughout its electrical network. As a result, ActewAGL Distribution has decided to investigate the IEC 61850 – Communication Networks and Systems in Substations standard, by constructing a test facility to assess its performance and capability with the view of implementing the standard into its 132/11kV zone substations network in the near future.

This report details the literature review, design, construction, and performance evaluation that was undertaken on the IEC 61850 substation automation designs developed with the use of the test facility.

The major achievement of this research project has been the successful development and evaluation of a substation automation system that utilised the IEC 61850 standard incorporated with multiple vendor devices.

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Student Name: **Matthew Julian Hogan**

Student Number: **0050063230**

Signature

30 / 10 / 2014

Date

Acknowledgements

Firstly, I wish to thank my academic supervisor, Dr Tony Ahfock, for his guidance and support throughout this project. His feedback and ideas have been greatly appreciated which has helped to reaffirm my approach to the project.

I would also like to thank my ActewAGL Distribution colleagues in the secondary systems and protection sections for their assistance and inputs over the past twelve months.

Finally, I owe a great deal of thanks to my family and friends for their patience over the last 7 years, in particular my wife Erin, and children Isabelle and Liam for their love, support, encouragement and understanding when I needed to work late or be in my "den" at home until all hours. Thank you, I couldn't have completed this without you.

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Nomenclature and Acronyms

The following abbreviations have been used throughout this report:

AIS	Air Insulated Switchgear
CT	Current Transformer
DNP3.0	Distributed Network Protocol
GIS	Gas Insulated Switchgear
GOOSE	Generic Object Oriented Substation Event
GWh	Giga Watt Hour
HMI	Human Machine Interface
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
I/O	Input / Output
kV	Kilo Volts
LAN	Local Area Network
LN	Logical Node
RTU	Remote Terminal Unit
SAS	Substation Automation System
SCADA	Supervisory Control and Data Acquisition
SNTP	Simple Network Time Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TC57	Technical Committee 57
TJ	Tera Joule
VT	Voltage Transformer

CHAPTER 1 - INTRODUCTION

1.1 Company Information

This project is supported by ActewAGL Distribution.

ActewAGL Distribution is an electricity distributor operating in Canberra, Australian Capital Territory, Australia. It owns and operates the electricity network in the ACT and the gas network in the ACT, Shoalhaven and Queanbeyan regions, through which it serves 307,356 customers over an area of 4,412km^2. It supplies approximately 3,011 GWh of electricity and 5,834 TJ of gas per year.

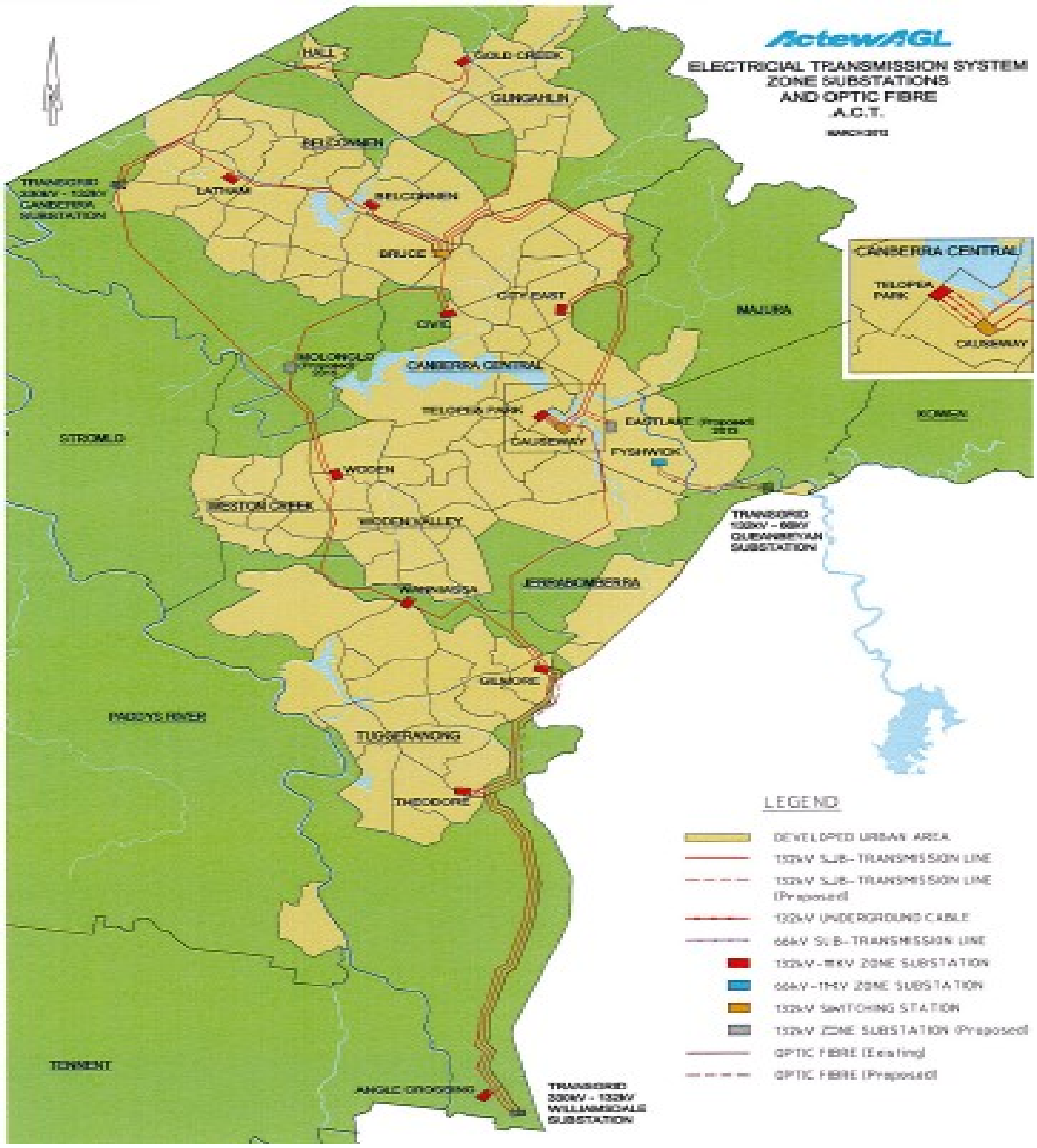
As of November 2013, ActewAGL Distribution had net assets of $1.2 billion with around $825 million in the electric and gas networks. ActewAGL currently has a workforce of 1200 employees. (ActewAGL, 2014)

ActewAGL Distribution was founded on the 3rd October 2000 when the Australian Gas Light Company (AGL), and Australian Capital Territory Electricity and Water (ACTEW Corporation), an ACT Government owned enterprise, entered into Australia's first utility joint venture. As of January 2014, it was equally owned by Jemena Networks (ACT) Pty Ltd and the ACT Government. (ActewAGL, 2014)

The electrical network that ActewAGL Distribution manages comprises of 14 zone substations with operating voltages of 132/11kV or 66/11kV and 4,506 distribution substations that have operating voltages of 11kV/415V.

All 14 zone substations are automated, while many of the distribution substations are in the process of being, fully automated.

Figure 1-1 provides an overview of ActewAGL Distribution's zone substation and 132kV transmission line network.



Source: (ActewAGL DIstribution , 2014)

Figure 1-1 – ActewAGL Distribution Zone Substations and 132kV Transmission Line Network

1.2 Project Justification

ActewAGL Distribution has recently undertaken a review of its substation automation systems (SAS) along with the protection and control equipment operating throughout its electrical network, as part of its substation modernisation project.

ActewAGL Distribution uses a variety of substation automation protocols, of which many are proprietary protocols that require custom communication links and software.

These pose challenges when establishing communication links to equipment between different vendors. This has required ActewAGL Distribution to use communication merging units in order for the substation automation system to operate. Merging units affect the efficient reliable operation of substation automation systems as they create more points where potential failure can occur.

To address these risks to substation automation systems, ActewAGL Distribution has decided to investigate a new standard, the "IEC 61850 Communications Networks and Systems in Substations" with the view of implementing the standard in its zone substation network in the future.

This decision was primarily reached due to two key points:

(1) The need for major upgrades to three distribution zone substations, namely;

- Woden Zone Substation,
- City East Zone Substation,
- Belconnen Zone Substation

(2) As part of a major upgrade to ActewAGL's oldest distribution zone substation, Civic, in October 2013, IEDs were installed that support the IEC 61850 standard. This ensures future compatibility should the decision be made to modify the substation automation system.

Due to the complexity and time requirements of such a project, it was decided that a test facility be constructed in order to evaluate a fully compliant IEC 61850 substation automation system design. ActewAGL Distribution has decided to pursue this test facility itself to enable it to use multiple vendors over the one single vendor.

This test facility will also have a secondary function, which is to provide Protection and Commissioning field staff with a training platform on the IEC 61850 standard and associated IEDs that ActewAGL Distribution has implemented.

1.3 Project Objectives

The objective of this project is to construct a test facility for assessing the performance of IEC 61850 substation automation designs. The detailed project specification is able to be viewed at Appendix A of this report. This project will focus more closely at the protection and control side of the IEC 61850 standard. This test facility will be used by zone substation designers, engineers, protection and commissioning office and field staff to understand the IEC 61850 standard.

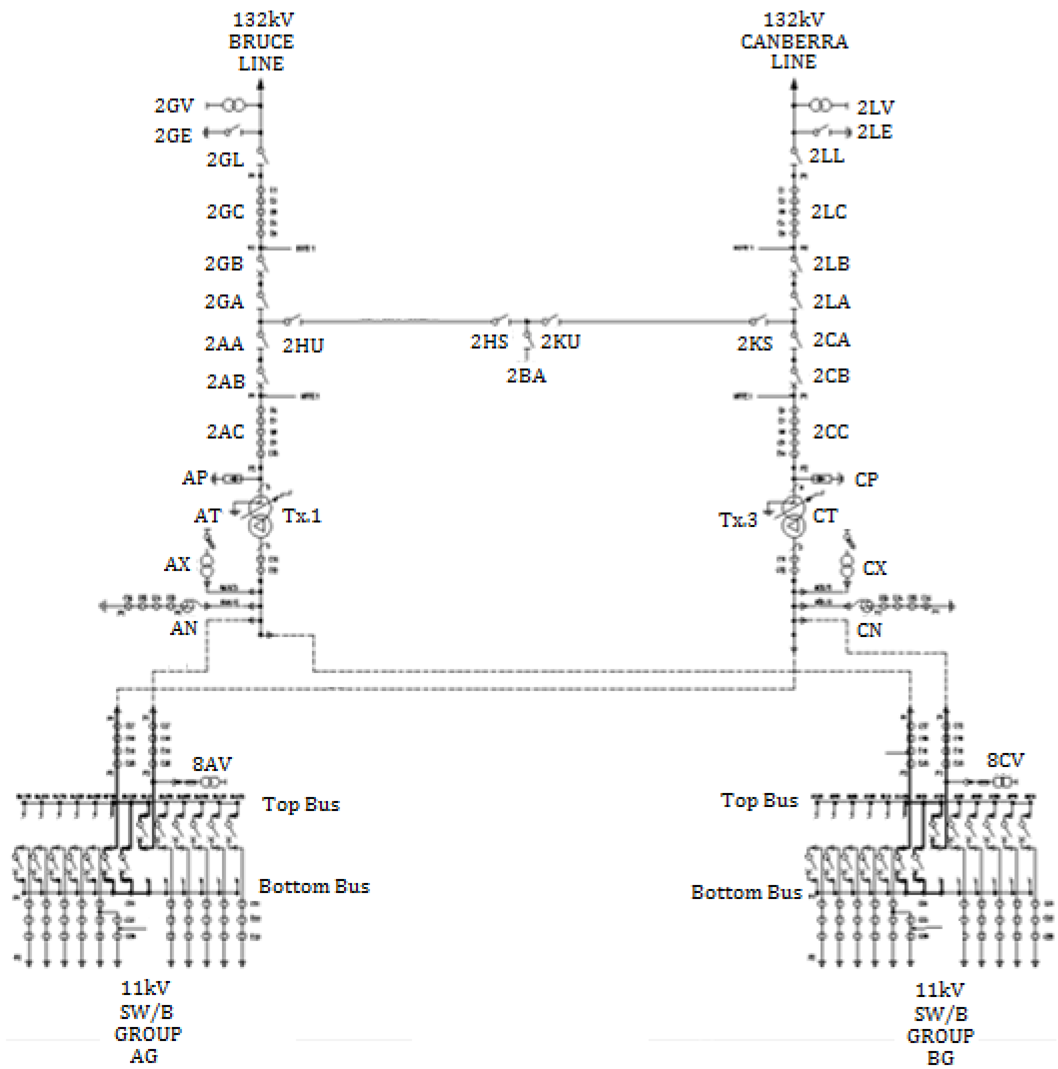
It is then the intention that this test facility will aid ActewAGL Distribution's goal of an IEC 61850 compliant substation automation system that can be implemented as part of the impending distribution zone substation modernisation project, over the next five to ten years.

The Substation Automation System that the test facility will be modelled on is a typical ActewAGL Distribution, two 132/11 kV power transformer distribution zone substation, as shown in figure 1-2. This configuration has been chosen as it is an easier configuration to implement and learning outcomes are able to be generated faster.

Another reason that this configuration has been chosen is due to the probability that the next 132/11 kV distribution zone substation, which is due to commence construction in 2016, will be constructed with this two transformer configuration. The test facility will be constructed as a one 132/11 kV power transformer distribution zone substation. This has been decided because of both time and space limitations. As a result, the remaining part of the test facility will be simulated by using IED configurator/simulator software to mimic both control and protection functions.

Once this test facility is operational, it will be extensively evaluated and its overall performance benchmarked to both the IEC 61850 standard and ActewAGL Distribution's own internal regulations to determine if the substation automation systems should be implemented in ActewAGL Distributions electrical network.

Upon completion of this testing, cost and performance comparisons will be carried out to determine if the implementation of this standard can be justified over the current designs in service.



Source: (ActewAGL DIstribution , 2014)

Figure 1-2 – ActewAGL Distribution Two Transformer 132/11kV Zone Substation Layout

1.4 Intended Audience

The intended audience of this report is:

- Project Supervisor – Dr. Tony Ahfock;
- USQ Academic Staff and Students;
- Secondary Systems Strategy, ActewAGL Distribution; and
- Protection Technical Field Staff, ActewAGL Distribution.

1.5 Structure and Content

Chapter 1 – Introduction: provides a brief background of ActewAGL Distribution and the project objectives.

Chapter 2 – Project Essentials: identifies the deliverables and phases involved in the project. Safety considerations for both personnel and plant are also discussed.

Chapter 3 – Background Information: defines substation automation systems and gives an overview of the various systems used by ActewAGL Distribution. The IEC 61850 standard is presented to gain an understanding of the information required to design both a test facility and a typical two transformer zone substation.

Chapter 4 – Literature Review: examines the literature that has been written on both the IEC 61850 standard and how the construction of a test facility can greatly increase its understanding. Some benefits with regards to adopting the IEC 61850 standard are also discussed.

Chapter 5 – Methodology: describes the step by step process that this project will follow to meet its expected outcomes.

Chapter 6 – Design and Implementation: presents the functioning test facility and further work carried out on a preliminary design for a two transformer 132/11kV zone substation.

Chapter 7 – Performance Evaluation: assesses the performance of the test facility which will be used in order to implement an IEC 61850 compliant design. The knowledge and understanding gained from this process will be used to design future IEC 61850 compliant substation automation systems for ActewAGL Distribution's electrical network.

Chapter 8 – Cost Evaluation: the costs associated with the equipment, installation, engineering and commissioning time for both the current substation automation systems in place and the compliant IEC 61850 designs will be assessed and costing figures given.

Chapter 9 – Conclusions: finalises the dissertation and summarises the outcomes and achievements of the project.

CHAPTER 2 – PROJECT ESSENTIALS

2.1 Chapter Overview

This chapter provides an outline of the deliverables, milestones and safety considerations necessary for successful completion of this project.

2.2 Project Deliverables

The following project deliverables have been completed as part of the Project Planning stage:

- Project Specification (included as Appendix A – Project Specification);
- Project Investigation (background information– refer to chapter 3, and literature review – refer to chapter 4); and
- Project Methodology (detailed breakdown of all work – refer to chapter 5).

The following project deliverables will be completed as part of the Project Execution stage:

- Test Facility Design and Construction (Appendix B);
- Test Facility Commissioning and Testing;
- Design a IEC 61850 compliant Substation Automation System for a typical ActewAGL Distribution 132/11 kV Zone Substation with the use of the test facility;
- Cost and Performance Comparisons with IEC 61850 Designs vs Current Designs;
- Analysis of Results; and
- Conclusion and Recommendations.

2.3 Project Phases

This project can be broken down into three main stages. Table 2-1 shows these stages along with its time frame.

Table 2-1 – Project Phases

TASK	STAGE	START DATE	COMPLETION DATE
1	Preliminary Works *(Planning, Design & Construction)*	25th February 2014	20th June 2014
2	Project Execution *(Test Facility Performance & IEC 61850 Design)*	1st July 2014	23rd October 2014
3	Dissertation Preparation	23rd September 2014	24th October 2014

Stage 1 involves the background research, literature review and gaining a thorough understanding of the IEC 61850 standard. Some of this work will also interact with stage 2 if the need for planning or design modification is needed.

In stage 2, the theory and knowledge gained in stage 1 will be put into practice, with the construction and evaluation of the test facility. Once the test facility is commissioned, it will be used to assess new IEC 61850 substation automation system designs that are currently in the design concept stage. It is then intended to undertake a preliminary IEC 61850 compliant design which may be implemented in one of the following ways:

- An existing zone substation that is due for upgrade as part of the modernization project; or
- A new 132/11kV zone substation that is currently proposed for construction in late 2015 – early 2016.

The third and final stage in this project is the preparation of the dissertation. The completion date given in Table 2-2 is the due date for submission.

Gantt charts are provided in Appendix C which shows all activities and their associated timeline/deadlines.

2.4 Project Milestones

Table 2-2 shows the important milestones along with each tasks due date. These dates have been determined by the University of Southern Queensland.

Table 2-2 – Project Milestones

TASK	MILESTONE	DUE DATE
1	Project Topic Approved	12th March 2014
2	Project Specification Approved	19th March 2014
3	Preliminary Report Submitted	4th June 2014
4	Partial Draft Dissertation Submitted	17th September 2014
5	Final Dissertation Submitted (Project Completion)	30th October 2014

2.5 Project Safety Considerations

This project involves three main stages; design, construction and evaluation. While this project is being delivered, the hazards and risks change with each stage of the project. Although this project will take place entirely within ActewAGL Distribution's Greenway Southern Services Centre, hazards and risks to public, personal and property must still accounted for.

A completed hazard and risk assessment used throughout this research project is given in Appendix D.

2.5.1 Public and Personal Safety

This project will entirely take place in a designated testing area at ActewAGL Distribution's Greenway Southern Services Centre. This means that only ActewAGL Distribution personnel with a need to use the test facility will have access by means of card swipe identification. The names of these personnel were forwarded to ActewAGL Distribution's facility management and business systems divisions. This was a requirement placed on the test facility by management as the project represents a considerable amount of capital expenditure and therefore the facility's future viability and operation must be safeguarded.

Also, as there will be live voltages and some exposed terminals present within the test panels themselves, it is mandatory that a detailed risk assessment be undertaken with all relevant personnel present each time work or testing is to be carried out in the test facility.

This risk assessment will adhere to ActewAGL Distribution's own workplace procedures, namely: FSW005 Hazard and Risk Assessment Form, Task Specific Safe Work Method Statements and ActewAGL Distribution's Electrical Safety Rules, specifically Section 3 – *General Safety Rules* and Section 5 – *Work in the Vicinity of Electrical Apparatus*. (ActewAGL Distribution, 2013)

2.5.2 Property Safety

The risk to property that may be by this project is damage to the test facility panels or the hardware installed in them. Incorrect installation of the test facility panels or incorrect use of the installed hardware from associated testing instruments being used for the test facilities evaluation could cause damage beyond repair.

To ensure the safety of the property, a visual inspection of all hardware, regardless of whether it is being used or not, is to be carried out as part of and noted on the Hazard and Risk Assessment form. Also, all testing equipment, such as secondary injection test sets and measurement devices are to be checked to ensure that an in-date calibration identification is displayed.

It must be noted and understood that a considerable amount of capital expenditure and resources have been put into this test facility and as such, damage to these assets must be minimised to ensure the test facility is available for use at all times.

As a minimum, this test facility is to be treated as a laboratory environment by all who use it. ActewAGL Distribution management have stated that it will be the subject of periodic audits to ensure both its viability and justification. This has been mandated due to space at the Greenway depot being a precious commodity.

CHAPTER 3 – BACKGROUND INFORMATION

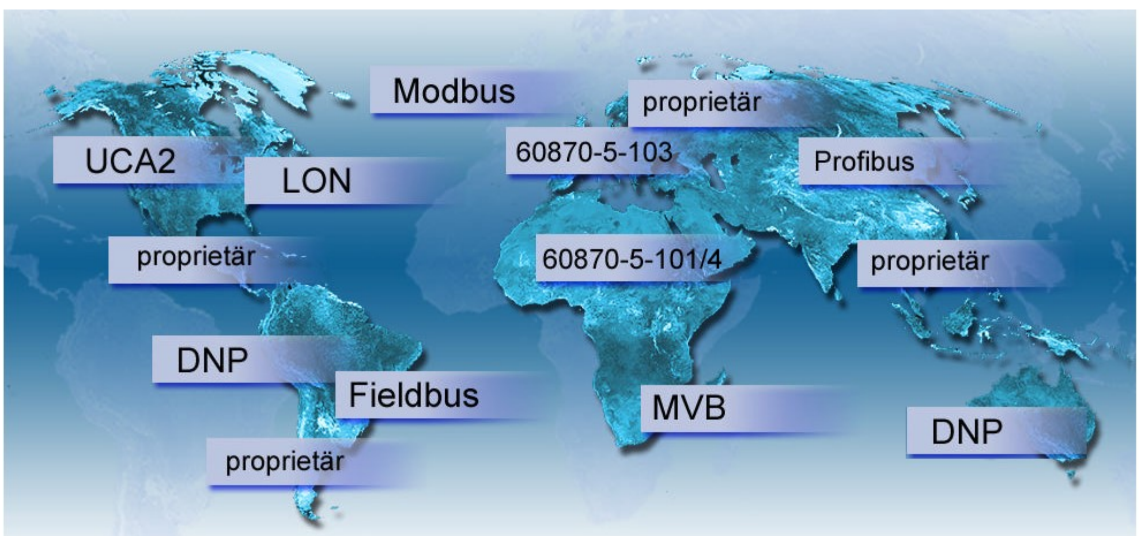
3.1 Chapter Overview

This chapter gives an overview of Substation Automation Systems and how they have developed to the present day. The Substation Automation Systems currently in service in ActewAGL Distribution's network and an overview of the IEC 61850 standard will also be outlined.

3.2 Substation Automation Systems

Matsuda, et al, 2011, defines Substation Automation Systems (SAS), as "a system that provides automation functions for the control, monitoring and protection within a substation."

There are currently over 50 protocols for substation automation worldwide. Some have been superseded and many are coming to the end of their useful life, Figure 3-1 gives an overview of some more common substation automation systems



Source: (DNP Users Group, 2011)

Figure 3-1 – An overview of the Different Substation Automation Systems Protocols Worldwide

Electrical substations play a very important part in a power system and the substation automation system enables the on-line monitoring and control of both primary, (transformers, busbar, CTs, VTs and circuit breakers), and secondary equipment, (IEDs, metering devices, communications), in the substation. Table 3-1 gives an overview of the substation automation system functions.

Table 3-1 - Overview of Substation Automation Systems Functions

Basic Functions	Typical Examples of Functions
Monitoring Functions	• Monitoring of switchgear status, tap position and status of transformer and tap changer, status of protection and control equipment, etc. • Monitoring of electrical quantities, e.g. current, voltage, frequency, power and reactive power, etc.
Control Functions	• Control of switchgear and transformer tap • Synchronism check and interlocking • Voltage regulating control and voltage reactive power control
Recording Functions	• Recording the monitoring data and manipulation/control of facility/device • Fault record of facility and device disturbance record
Protection Functions	• Protection for transmission line, transformer, busbar, generator, distribution • Feeder, shunt reactor, shunt capacitor, etc.

Source: (Patel, 2005)

3.2.1 The Requirement for Substation Automation

Mackiewicz states that "applications of substation automation systems date back to the early 1980s and were first implemented by Siemens. These systems were fairly basic and utilised hardwired connections and simple communication methods such as telephone-switching based remote units". Mackiewicz further claims, "many utilities actually spend up to 10% of the total cost of the substations on the substation automation system for a number of reasons. It is cheaper in the long run to have a fully automated system rather than have staff on-site 24 hours a day, 7 days a week. Other considerations are safety, to both the general public and maintenance or field switching crews. The operation of high voltage equipment can in fact be a very dangerous job, therefore every effort to mitigate these potential dangers must be considered."

Each substation contains a number of complex equipment such as high voltage busbar, circuit breakers, isolators and current, voltage and power transformers, some of which are shown in figure 3-2. This equipment often comes with a significant price tag which is another reason why substation automation systems are implemented, in order to protect the substation.

These automation systems greatly improve the reliability of the power system as they decrease the costs of running and maintaining the substation, while providing highly effective operations well up to the life cycle limit of the substation equipment.

In the last 15 – 20 years, technology in this area has improved at a rapid rate, and as such substation automation systems have undergone dramatic changes due to the introduction of powerful micro processing and digital communication devices. These devices, known as IEDs, are not merely a protection relay, they are smart, multi-functional and communicative relays which have replaced traditional protection and control panels that housed the dedicated standalone relays, meters, control switches and status indicators.

Source: (Hogan, 2014)

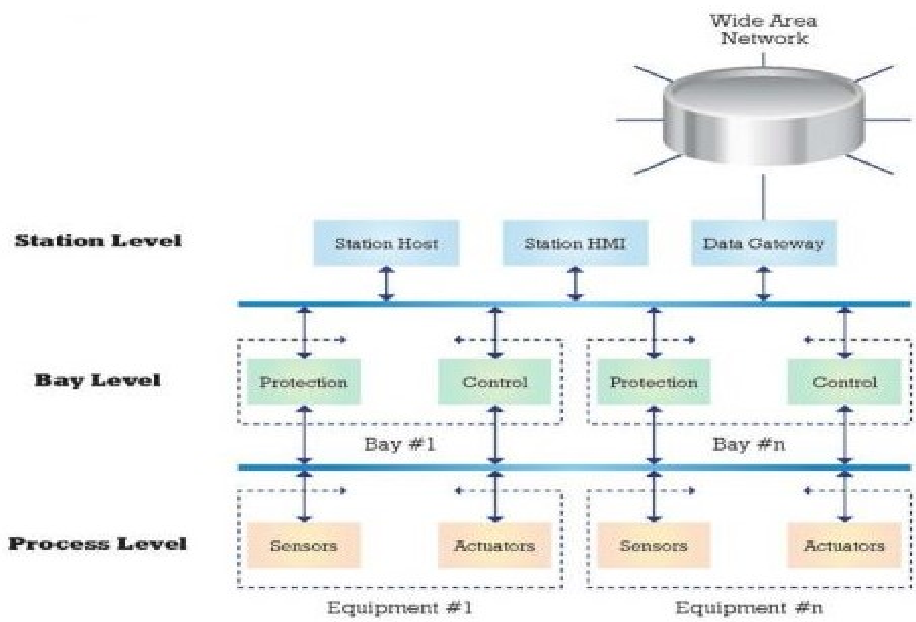
Figure 3-2 – A Typical ActewAGL Distribution 132/11kV Zone Substation Switchyard

This has led to substation automation systems evolving from the simple hardwired connected schemes to systems that utilise IT based solutions, such as Ethernet LAN, that communicate through fibre optic links rather than hardwired copper connections. As a result, the amount of data available from the substation that can be retrieved at the control room has increased substantially.

Substation automation systems give electricity utilities perfect control over every element in the substation. This is especially important during times of abnormal system conditions and during planned maintenance periods where load current can be easily switched or restored with the touch of a button.

3.2.2 Substation Automation System Levels

All functions within a substation automation system can essentially be divided into three levels: the process, bay and station level functions.



Source: (Alstom Engineering, 2011)

Figure 3-3 – Substation Automation Levels

The process level is the lowest level that contains the primary equipment in the substation such as the circuit breakers and current transformers.

The bay level is the middle level which contains the protection and control devices that operate both the primary and secondary equipment. These devices are generally hardwired and carry out operations such as tripping or closing a circuit breaker. This level also sends binary and analogue information such as current or voltage levels and the status of the protected equipment.

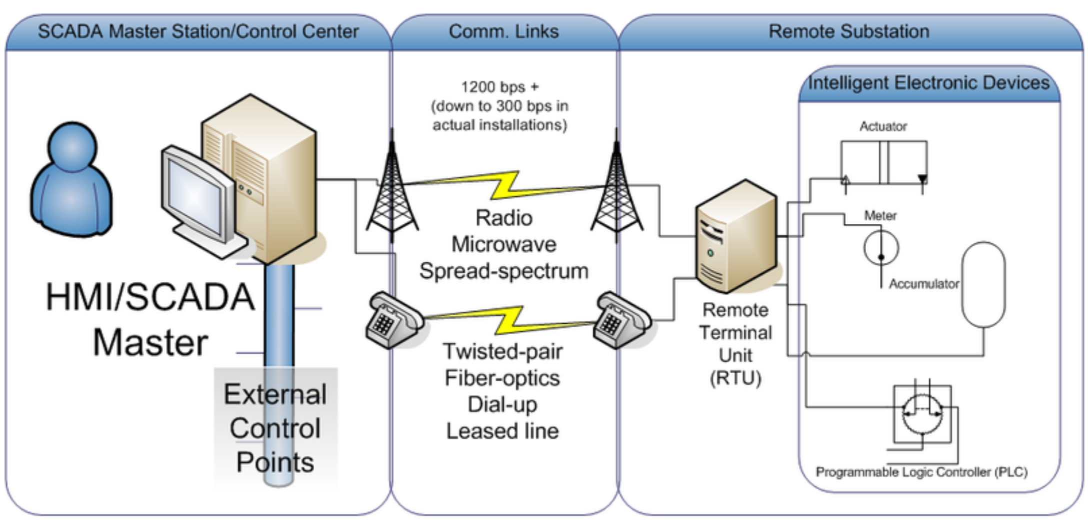
The station level is the upper level where the centralised system computers, human machine interfaces (HMI) and gateway to the network control are located, figure 3-1 gives an overview of the various levels and their functions.

3.3 Protocols Currently Implemented by ActewAGL Distribution

Substation automation systems use communication protocols, which are the language in which equipment and software applications exchange information. Some common protocols currently implemented in ActewAGL Distribution's network are the DNP3.0 protocol, the Modbus protocol and in some very rare instants Alstom's Courier protocol, which is derived from the Modbus protocol, is still used. The DNP3.0 protocol is the primary protocol used by ActewAGL Distribution for its high voltage applications, while the Modbus protocol is mainly used in low voltage applications, however there are some substations that still use the Modbus protocol for communications with the 11kV feeder circuit breakers. A brief overview of both the DNP3.0 and Modbus protocols are discussed below.

3.3.1 DNP3.0 Overview

The Distributed Network Protocol, (DNP3.0) was developed by GE Harris Distributed Automation Products to achieve interoperability between substation computers, RTUs, IEDs and the master station for electricity utilities via an Ethernet network.



Source: www.dcbnet.com, 2011

Figure 3-4 – DNP3 Network Overview

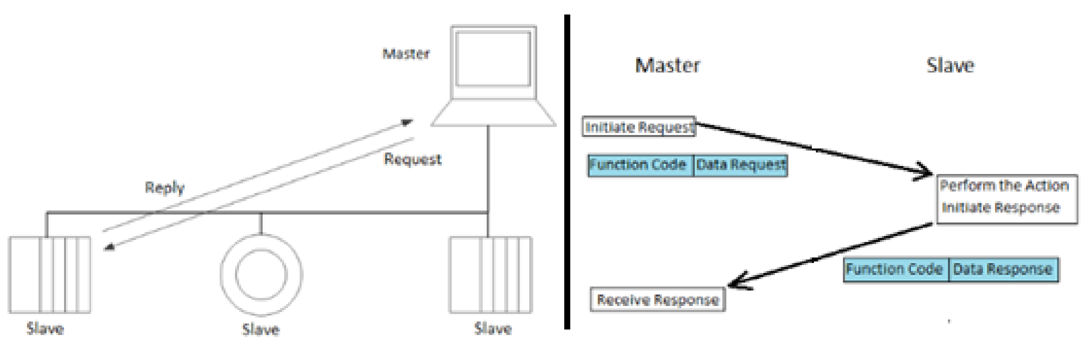
This protocol is actually the precursor to the IEC 61850 standard as it was developed through the work of Technical Committee 57 of the Electro-technical Committee, (TC57). The DNP3.0 protocol is much more robust, efficient and interoperable than the Modbus protocol, however it is much more expensive to implement due to its higher complexity as each data point is first mapped to a DNP index within the IED, then mapped again to the SCADA processor.

DNP3.0's biggest disadvantage is that it is not a very secure protocol. It was not designed to be secure from cyber-attacks targeted at disrupting the power system.

It is currently the dominant substation automation protocol in the USA and Australia, however it is thought that the IEC 61850 standard will supersede DNP3.0 in the next five years. (DNP Users Group, 2011)

3.3.2 Modbus Overview

Modbus is a serial communications protocol that is currently owned by Schneider Electric. It was first released in 1979 by Modicon PLC, and was primarily built for use with its own industrial grade programmable logic controllers, PLCs. It is essentially a master-slave protocol that allows the master to read or write bits of data in the registers of the slave devices. It was designed to use a simple serial connection but the protocol has now evolved to make use of Ethernet.



Source: www.schneider-electric.com, 2008

Figure 3-5 – Basic Modbus Network and Data Transaction

3.4 The IEC 61850 Standard Overview

In the early 1990s, the Electric Power Research Institute (EPRI) and the Institute of Electrical and Electronics Engineers (IEEE) commenced work on the earliest form of a single, common automation protocol for electrical power utilities, it was known as the Utility Communications Architecture (UCA). (Mackiewicz, 2006) The EPRIs and IEEEs main goal was to produce an industry standard relating to the integrated control, protection and data acquisition while maintaining interoperability of different devices within the substation environment.

In 1995, after the release of UCA2, the EPRI and IEEE decided to combine their work with the members of the Technical Committee 57 of the IEC - Working Group 10, (IEC TC57 WG 10), in order to produce an international standard for Ethernet based communications in substations. This standard is known as: IEC 61850 – Communications Networks and Systems in Substations standard, which was released in 2004.

The IEC 61850 standard is more than just another communication protocol. It is a comprehensive standard that has been designed from the ground up to allow power utility companies to operate on highly sophisticated networking technologies. The IEC TC57 define this standard as a single, global, future-proof standard for substation communications. (International Electrotechnical Commission, 2012). The functionality that this standard provides is superior to any current or legacy substation automation protocol. It enables the complete integration of all protection, control, measurement and monitoring functions within the substation, and additionally provides the means for interlocking and inter-tripping schemes. (Alstom Engineering, 2011)

The IEC 61850 standard has been adopted extensively throughout Europe and is rapidly expanding into many Asian countries, in particular India and Vietnam. It is also gaining interest in the USA, Australia and African nations where the DNP3.0 protocol is still the dominant substation automation protocol, however many believe that within the next five to ten years, the IEC 61850 standard will become the world leader in substation automation systems. (Childers, 2012)

3.5 Structure of the IEC 61850 Standard

The IEC 61850 standard is made up of ten parts, which are summarised in Table 3-2.

Table 3-2 – IEC 61850 Structure Overview

Part	Title
Part 1	Introduction and Overview
Part 2	Glossary
Part 3	General Requirements
Part 4	System and Project Management
Part 5	Communication Requirements for Functions and Device Models
Part 6	Configuration Description Language for Communication in Electrical Substations Related to IEDs
Part 7	Basic Communication Structure for Substation and Feeder Equipment
Part 7.1	- Principles and Models
Part 7.2	- Abstract Communications Service Interface (ACSI)
Part 7.3	- Common Data Classes
Part 7.4	- Compatible Logical Node Classes and Data Classes
Part 8	Specific Communication Service Mapping (SCSM)
Part 8.1	- Mapping to MMS (ISO 9506-1 and ISO 9506-2) and ISO/IEC 8802-3
Part 9	Specific Communication Service Mapping (SCSM)
Part 9.1	- Sampled Values over Serial Unidirectional Multidrop Point to Point Link
Part 9.2	- Sampled Values over ISO/IEC 8802-3
Part 10	Conformance Testing

Source: Alstom Network Protection & Automation Guide, 2011

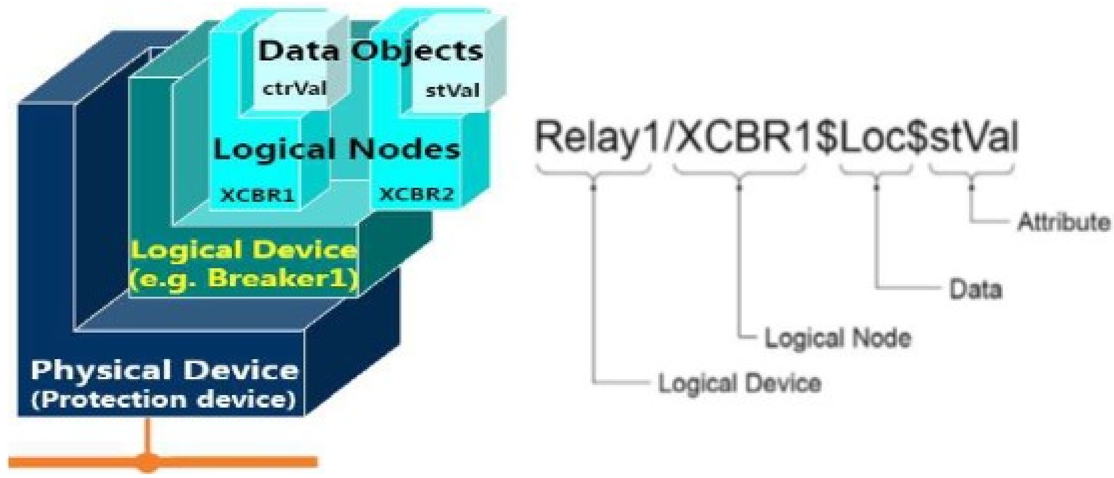
The first two parts introduce the standard and summarise all of the important terms used throughout the standard. Parts 3 through to 6 identify the specific functional requirements of the data models, application protocols, data links and physical layers that make up the communication network within the substation.

Part 7 of the standard, which is made up of 4 sub-sections, specifies the communication structure for the substation in detail. It defines the naming conventions of the individual logical nodes in each IED.

Parts 8 to 9 outline the mapping of the logical nodes to various protocols, MMS or via sampled values, for the transmission of data to its intended point. Part 10 defines what must be completed in terms of commissioning and testing in order to qualify as an IEC 61850 conforming product.

3.6 The IEC 61850 Data Model

The way the IEC 61850 standard organises its data model is different to other protocols used in substation automation. It specifies a comprehensive model for how power system devices should have their data organised that is consistent regardless of the make or model of the installed devices.



Source: (Roostaee, et al., 2011)

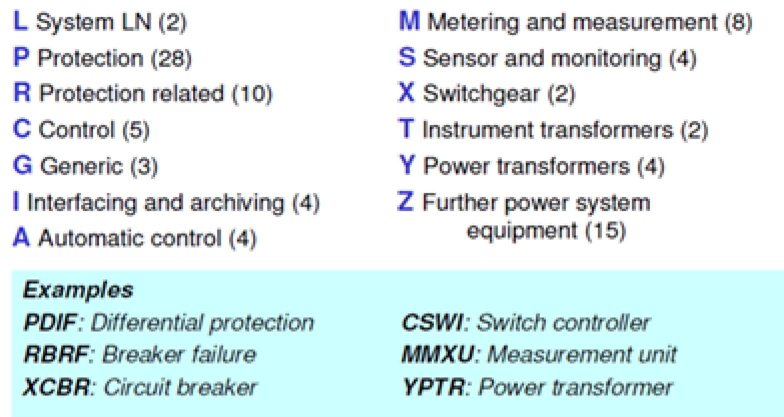
Figure 3-6 – IEC 61850 Device Model Class and Object Name Structure

Figure 3-6 shows a representation of the IEC 61850 data model. This model eliminates much of the tedious non-power system configuration because the IEDs are self-configurable. (Alstom Engineering, 2011) The data model of an IEC 61850 IED can basically be viewed as a hierarchy of information that has a predefined and structured naming convention.

The device model starts with the IED, the physical connection to the substation network which is defined by its IP address. Each physical connection can be made up of any number of IEDs and within each individual IED, there can be hundreds of logical nodes that contain vast amounts of data.

A logical node is a named grouping of data and associated services that is logically related to some power system function. (Schweitzer Engineering Laboratories, 2014) These logical nodes are categorised into 13 different groups and 86 different classes. The names of these logical nodes are standardised in the IEC 61850 standard and cannot be changed.

Figure 3-7 lists the naming convention groups and provides some examples of their meaning.



Source: (Megger, 2014)

Figure 3-7 – IEC 61850 Logical Node Group Descriptions

3.7 GOOSE Messaging

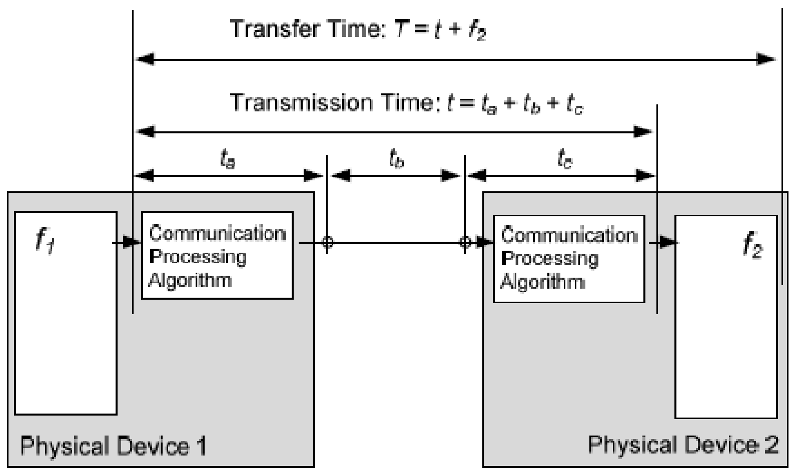
GOOSE is the abbreviation for Generic Object Oriented Substation Event and is a high speed ‘peer-to-peer’ communication protocol used between IEDs within the substation network. (Dolezilek, et al., 2010) The data contained in GOOSE messages can include binary, analog and integer values.

GOOSE messaging works as a publisher and subscriber apparatus to transmit data. When an event occurs, the publisher IED uses a multicast MAC address to notify all other IEDs that are subscribed to the publisher. Data is then sent and, depending on internal logic in the subscriber IEDs, this transmitted data is then used to carry out time critical information such as status changes, auto reclosing initiations, intertripping, interlocking and blocking schemes.

GOOSE messaging is one of the particularly important features of the IEC 61850 standard as it replaces the more conventional hardwired connections, as used with most DNP3.0 and legacy protocols, with station bus communications.

Seeley, 2008, states that the benefits of automation at protection speeds transmitted via Ethernet are numerous. Serial communications dictate the need for separate channels, or the addition of serial multiplexor devices to bridge all types of data, while Ethernet communications allow for various data protocols across the same line more efficiently.

A major benefit of using GOOSE messaging, that this research project will explore, is that because all outgoing data it is already mapped directly to the network layer this effectively reduces the communication header which means that processing through TCP and IP layers is eliminated. This can significantly reduce the amount of multicore cabling that is installed in substations within the ActewAGL Distributions network.



Source: (Roostaee, et al., 2011)

Figure 3-8 – GOOSE Messaging Definition of Transmission Time

3.8 Key Benefits of Adopting the IEC 61850 Standard

Since the introduction of the IEC 61850 standard many power utilities have been impressed with what the standard offers in terms of benefit. The greatest benefit is that it gives a substation automation system interoperability over the complete protection, control and metering schemes.

Some of the key features and capabilities of the IEC 61850 standard that this research project aims to investigate include:

- A virtualized model of the substation that defines the data, services, device behavior and how data is transmitted over the network;
- Multi-vendor interoperability. This allows the best device to be selected for a given role regardless of its vendor;

- High Speed communication between IEDs to enable the fast clearance of fault on the power system;
- Object names of the data for every element of the IEC 61850 standard are standardised in predefined descriptive strings. These elements cannot be altered as an extra security measure;
- A greater amount of data is available after the duration of an abnormal system event. Data is sampled at very fast speed which means that actual waveforms can be captured and repeated using specific software to determine the cause of the event;
- Lower installation costs as devices are able to exchange data using GOOSE messaging over the station LAN rather than over separate wire links for each device. This reduces the costs associated with wiring, trenching and ducting;
- Lower commissioning costs as each device does not require a great deal of manual configuration. In many applications, the only set up required is the network address;
- Lowers the equipment migration costs due to the standard naming conventions and device behavior. A single IED can deliver all protection, control, monitoring and measurement signals which are handled by separate devices in current systems; and
- Lowers any additional costs as adding more devices or applications into an existing IEC 61850 based network are able to be done with minimal impact on existing equipment while they are still in-service.

CHAPTER 4 – LITERATURE REVIEW

4.1 Chapter Overview

This chapter conducts a literature review on the IEC 61850 standard and how the use of a test facility can greatly improve the design, construction and learning outcomes associated with a substation automation system. Case studies of utilities and tertiary institutions using test labs to validate both theory and automation designs are presented and discussed.

Other areas that have been peer reviewed are the use of GOOSE messaging for protection functions, security issues that have been raised with the introduction of Ethernet based systems and what the key benefits of implementing the IEC 61850 standard in a substation automation system are to the power utility.

4.2 Use of a Test Facility to Assess Substation Automation Systems Designs

4.2.1 Elecktro Eletricidade Test Platform

Kimura, et al., 2008, describe the construction of a test platform that Elecktro Eletricidade è Servicos, a large electric distribution utility in Brazil, used to perform testing of its new IEC 61850 substation automation system design as part of its substation modernization project of 30 substations.

He describes "a complete replica of a typical substation automation system was created in the supplier's automation laboratory to perform the platform tests of the project. All circuit breakers, disconnect switches, sensors, etc., were simulated in this system." The objectives of this test platform were to conduct all of the approval tests on the system, to validate the systems as IEC 61850 compliant and to exhaustively verify the consistency of the logic schemes for each of the 30 substations prior to the first being re-energised.

Kimura, et al., 2008, states further that, "the use of this test platform accelerated the commissioning tests and reduced the errors that would normally be found during field tests or site acceptance testing. Based on this alone, the use of this test platform prior to implementation was justified as it proved to be a valuable tool."

Source: (Kimura, et al., 2008)

Figure 4-1 – Elektro Eletricidade e Servicos' Test Platform

4.2.2 Endeavour Energy Proof of Concept Facility

Young & Cole, 2013, discuss how Endeavour Energy, an electric power utility that services most of NSW, established a proof of concept system in order to create their first IEC 61850 compliant substation, East Richmond 33/11kV zone substation.

This system was created due to a tight project deadline of 18 months and the realisation that the time available on site would be insufficient to fully test and understand all the new concepts being implemented by IEC 61850, which could have been a risk to the project completion date.

This proof of concept system was created primarily to allow Endeavour Energy to customise an IEC 61850 compliant substation automation system to its electrical network needs as well as testing the overall performance prior to implementation along with the training of staff.

Source: (Young, et al., 2013)

Figure 4-2 – Endeavour Energy Proof of Concept System

A major benefit that was also noted with an IEC 61850 proof of concept system is that it is not necessary to change any wiring or connections of the test platform to prove different substation automation systems due to the exchange of information between IEDs is conducted through GOOSE messages, which means, only relatively simple IED setting changes are required.

Young and Cole also made the point that the proof of concept system ensured that all the logic schemes were validated prior to the beginning of the SAT and commissioning which meant no modifications were required and project delays resulting from the protection and SCADA personnel were virtually none existent.

4.3 Use of a Test Facility to Enhance IEC 61850 Learning

4.3.1 Jamia Millia Islamia University Substation Automation Laboratory

(Thomas, et al., 2011), stated that since the introduction of the substation automation laboratory at the Electrical Engineering Department of the Jamia Millia Islamia University, New Delhi, students undertaking the elective fourth year substation automation system course have seen a remarkable increase in their grades. The department puts this down to access to the laboratory at every class where the theory can be put into practice.

One of the department's senior lecturers, Dr. A Prakash, states "the substation automation laboratory plays a very important role in enhancing students' practical knowledge and their deeper understanding of the theory lessons by providing hands on experience." Of particular note was a series of experiments that were performed in the laboratory such as simulating the retrofitting of panels with IEC 61850 compliant IEDs and integrating these with existing control centre software.

4.3.2 STRI Consulting Test Laboratory – Gothenburg Sweden

STRI Consulting, a leading independent Swedish company that specialises in high voltage testing and power systems, has developed an accredited IEC 61850 training course which is delivered in a purpose built test laboratory in their offices in Gothenburg. At any one time, up to 30 people can be trained on the IEC 61850 standard using the test laboratory and it caters for a variety of people, from operational field staff through to substation and SCADA engineers. (Megger, 2014)

Source: (Megger, 2014)

Figure 4-3 – STRI Consulting IEC 61850 Test Laboratory

The training also demonstrates commissioning and maintenance skills that are new to the vast majority of people attending the training. An electrical engineer, who attended the training and specialises in power system automation is quoted as saying, "This was a genuinely practical and useful way to learn about IEC 61850. It's all very well reading about the standard and discussing it, but nothing even comes close to actually using IEC 61850 equipment in a supportive learning environment. I find it hard to believe I learned so much so easily in a short time." (Megger, 2014)

This paper clearly justifies how important it is to have a facility or laboratory in order to gain the necessary skill and understanding of the IEC 61850 standard before attempting its implementation.

4.4 GOOSE Messaging for Protection

Thomson, 1985, defines the three fundamental roles of any power system protection scheme as being:

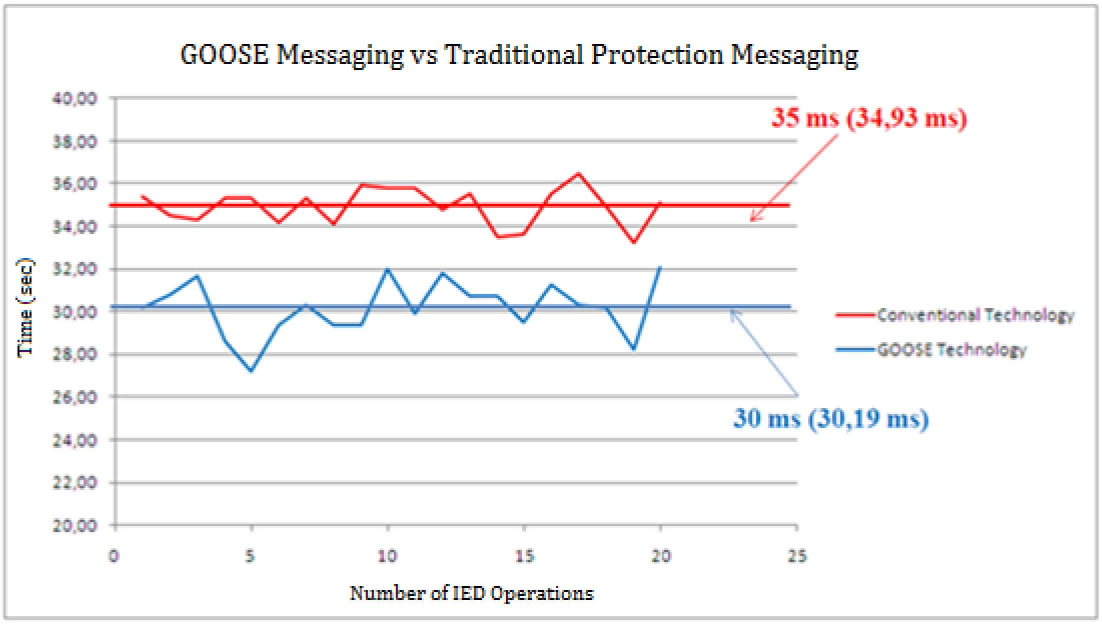
- **Speed** – The protection must clear the fault in the minimum amount of time;
- **Discrimination** – Only the protection scheme closest to the fault should operate; and
- **Reliability** – The protection scheme operates as it should in abnormal conditions.

In order to achieve this, many hardwired multicore cable connections are required which can, in some cases, cause the protection scheme to slow down. Through the use of their test laboratory, Elecktro Eletricidade è Servicos discovered that fault clearance times were reduced due to the implementation of GOOSE messaging.

Elecktro Eletricidade engineers believe that due to these shorter fault times placing less stress on the electrical equipment, their lifetime may actually be extendable. This is yet to be actually confirmed but their equipment conditional monitoring seems to be suggesting this is the case.

Research conducted by Atienza & Moxley, 2009, found that in older substations that had recently been upgraded in the USA, circuit breaker clearance times were improved from an average of 150 – 500ms in delay, down to under 100ms by using GOOSE messaging during a power system fault. Figure 4-4 shows the results of their findings with regard to using GOOSE messaging over conventional hardwired methods.

Their research also found that the amount of thermal damage caused by a short circuit is directly related to the duration of the short circuit and that this does have adverse effects on equipment life spans.



Source: (Childers, 2012)

Figure 4-4 – Comparison of Conventional Technology vs GOOSE Technology Speeds

Elecktro Eletricidade è Servicos were also able to establish that the use of the IEC 61850 GOOSE messaging protocol reduced the number of copper cables used in the substation modernisation project by 50 percent when compared to traditional solutions and improve critical protection operations, such as circuit breaker failure tripping, much faster. (Kimura, et al., 2008)

Young & Cole, 2013, describe a possible problem with the use of GOOSE messaging for protection. They discuss normal isolation procedures that currently occur in Endeavour Energy's normal daily routine and how this practice must change in order to mitigate any inadvertent tripping of equipment. They state, "in previous substations, hardwired connections were used that had dedicated termination points, a fuse or slide able link for example, which were quite easy for field staff to access. Using GOOSE signals, required a complete rethink of these practices.

Through the use of the proof of concept system, field testers were given training and were able to include GOOSE blocking measures as part of their existing test plans, which made the testing of these systems much safer." Gauci, 2013, suggest that studies undertaken by Schneider Electric show that by implementing a GOOSE based protection scheme over a conventional hardwired scheme can actually save the substation engineer's configuration time by up to 72% and can save up 45% in hardwired copper connections.

4.5 Cyber Security Considerations

Alstom Engineering, 2011, defines cyber security in substations as "protection against unauthorised disclosure, transfer, modification, or destruction of information and/or information systems, whether accidental or intentional."

Premaratne, et al., 2009, discuss that when communications were first introduced into the substation environment for control and automation, they were fully contained within the substation and based on proprietary protocols. Because of this they enjoyed inherent security, meaning they were "secure by isolation" as the substation was not connected to the outside world and "secure by obscurity" due to it being very difficult to hack into the proprietary protocol.

In recent times however, substation automation systems have become more sophisticated and multiple substations can be interconnected with open networks such as a corporate network or the internet, which use open protocols for communication. These open protocols mean that the security from isolation and obscurity once bought can no longer be assumed which leaves the network vulnerable to so called cyber-attacks.

There are many standards which now deal with substation cyber security which are outlined in table 4-2. (Alstom Engineering, 2011)

Table 4-1 – Substation Cyber Security Standards

Standard	Country
NERC CIP	USA
BDEW	Germany
ANSI ISA 99	USA
IEEE 1686	International
IEC 62351	International
ISO/IEC 27002	International
NIST SP800-53	USA
CPNI Guidelines	UK

The substation communication security requirements that relate to the IEC 61850 standard are described in the standard IEC 62351, clause 6: Data and Communication Security – Security for IEC 61850.

This standard talks in depth of methods of router level, firewall level, gateway level security and encryption keys that should be implemented in some form. This project will adhere to this standard due to the fact that the test facility will have a connection to ActewAGL Distributions central control room.

CHAPTER 5 – METHODOLOGY

5.1 Chapter Overview

This chapter gives an overview of the methodology used throughout the duration of this project. In order to make this process easy to carry out, it has been divided up into three parts; the design, construction and evaluation of the test facility.

5.2 Methodology Structure

This research project will follow the step by step methodology as outlined below.

i. Research the relevant background theory on the IEC 61850 standard in order to gain a thorough understanding of it.
ii. Research the required hardware to be installed in and as part of the test facility.
iii. Procure all hardware to be installed in the test facility.
iv. Research and learn the software for each different device family installed in the test facility.
v. Undertake a design specification brief with key stakeholders.
vi. Draft as-built drawings for construction of the test facility using Computer Aided Design (CAD) software.
vii. Commissioning and acceptance checks.
viii. Performance evaluation of test facility and IEC 61850 substation automation system designs.
ix. Use test facility to design a substation automation system that is IEC 61850 compliant. *(For a typical ActewAGL Distribution 132/11kV two transformer zone substation)*
x. Prepare design submission to key stakeholders for review and approval.
xi. Prepare findings for dissertation submission.

5.2 Methodology Detail

A more detailed explanation of the methodology structure set out in section 5.1 is given below. As this project encompasses many disciplines within the electrical engineering field, a large amount of time has been dedicated to research in the methodology.

i. Research will be carried out on the IEC 61850 standard prior to any design work commencing. As this standard and its implementation is completely new to ActewAGL Distribution, it is important to have a thorough understanding of it in order to its commissioning in the field. This research stage will take the majority of time early in the project.
ii. The hardware that is to be installed in the test facility will be the same that is to be installed in any new or existing zone substation. Because of this requirement, careful evaluation and consideration of multiple vendors will be undertaken to ensure the correct hardware is sourced for both criteria.
iii. Based on the hardware selected for use in the test facility, all the devices will be procured through the relevant vendor. This stage must be completed promptly as any delays with this hardware can jeopardise the successful completion of this research project.
iv. Each vendor has its own software that is used for the configuration of that device. It is necessary to understand these different software in order to configure the device setting and any logic schemes that may be associated with them. Evaluation of this software will also illustrate any potential limitations of a device.
v. Extensive discussions will be held with the key stakeholders in terms of what they want to see from the design and evaluation of the test facility. The success of this test facility will ultimately depend on the outcome of these discussions.
vi. Once all parties agree on the test facilities make up, drawings completed with the use of CAD will be issued for the construction of the test facility.
vii. Commissioning and acceptance tests will be carried out on the test facility that adhere to ActewAGL Distributions policies. It has been decided that a large amount of time will be given to this task as it serves a learning

experience for all staff and will give an indication of commissioning times for an on-site installation.

viii. When all commissioning works have been finalised, the test facility will be configured with an IEC 61850 compliant design to be evaluated. Extensive testing will be undertaken which will be covered chapter 7 of this report. Once this is complete, cost and performance comparisons will be carried out that would justify the use of IEC 61850 compliant designs for ActewAGL Distribution’s network.

ix. The information and learnings that the test facility has given will be used to design a complete IEC 61850 compliant design from top to bottom. A typical two 132/11kV transformer zone substation arrangement in ActewAGL Distributions network will be designed.

x. The design work undertaken above will be passed to the key stakeholders in the substation design section at ActewAGL Distribution for consideration and review. It is ultimately this section that will approve an IEC 61850 compliant substation automation system design for implementation into the electrical network.

xi. Upon completion of the above tasks, all work will be reviewed and then formatted for this dissertation’s submission on the required project deadline date.

CHAPTER 6 – DESIGN AND IMPLEMENTATION

6.1 Chapter Overview

This chapter gives an overview of the design, hardware selection and construction of the test facility. Discussed in detail are the reasons for the hardware selection, the guidelines that the test facility is to be built to and its pre-commissioning checks prior to it being used to assess IEC 61850 compliant substation automation system designs. The substation automation designs developed with the use of the test facility will be implemented into ActewAGL Distributions electrical network.

6.2 Hardware Selection

The system hardware installed in the test facility comprises of the following devices:

- Protection and Control relays, or IEDs;
- Industrial Ethernet switches;
- GPS clock;
- 125V DC Power Supply;
- Remote Terminal Unit; and
- Optic Fibre Cabling.

It has been decided that only devices that can be installed in a common 19 inch rack arrangement will be evaluated.

6.2.1 Protection and Control IEDs

ActewAGL Distribution's protection philosophy is based on the provision of duplicate redundant systems operating simultaneously to mitigate failure and ensure availability under all normal and abnormal system conditions. These duplicate redundant systems are driven by a risk based philosophy of providing an *"n – 1"* contingency. This implies 'A' and 'B' protection schemes for each zone of protection with separate DC power supplies to mitigate the risk of any system failure.

It is also important to note that these duplicate protection schemes are to be procured from two different vendors. Through an extensive selection assessment on a number of vendors and their products, the 'A' protection IEDs will be sourced from "Vendor A" and the 'B' protection IEDs will be sourced from "Vendor B".

Also due to the project's time constraints it was decided that using familiar IEDs rather than introducing new devices would allow more time to use the test facility, rather than also needing to learn a new device and its quirks.

In order to assess each different device vendor equally and fairly, a selection criteria was utilised. The selection criteria is designed to be simple. The fundamentals of power system protection are not being rewritten throughout this evaluation process.

The criteria allowed ActewAGL Distribution to identify the strengths and weaknesses in each IED in order to suit the needs of both the test facility and the future implementation of the final substation automation system design.

The IED selection criteria included:

- IED Functionality;
- IED Reliability;
- Supply and Delivery Time Frames;
- Ease of Use (ActewAGL protection field staff consulted);
- Vendor Support (Other power utilities consulted); and
- Overall Cost per Unit.

Table 6-1 shows the seven vendors that were selected and asked to submit their IEDs to be part of the IED evaluation process.

Once all IEDs were subjected to the above criteria, Schweitzer Engineering Laboratories, (SEL), were chosen as the IEDs for the "A" protection schemes and Schneider Electric were chosen as the IEDs for the "B" protection schemes. Another advantage of using these families of IEDs was the familiarity of field staff with the selected vendors IED families.

Table 6-1 – IED Vendor List for Evaluation

Vendor	IED	Function
ABB	RED620 IEC RET620 IEC REF615 IEC	132kV Line and Bus Zone Protection 132/11kV Transformer Protection 11kV Feeder Protection
Alstom	Alstom P441 Alstom P747 Alstom P645 Agile P40 Series	132kV Line Protection 132kV Bus Zone Protection 132/11kV Transformer Protection 11kV Feeder Protection
GE Multilin	L90 B95plus T60 F60	132kV Line Protection 132kV Bus Zone Protection 132/11kV Transformer Protection 11kV Feeder Protection
Schneider Electric	MiCOM P443 MiCOM P643 MiCOM P145 MiCOM P545	132kV Line Protection 132kV Bus Zone and 132/11kV Transformer Protection 11kV Overhead Feeder 11kV Underground Feeder
Schweitzer Engineering Laboratories	SEL-411L SEL-487B SEL-487E SEL-351S	132kV Line Protection 132kV Bus Zone Protection 132/11kV Transformer Protection 11kV Feeder Protection

Table 6-2 below lists the IEDs that have been selected used for the various protection and control schemes in the test facility. Pictures of these selected IEDs are shown in Appendix E

Table 6-2 – Test Facility Protection and Control IEDs

Panel	Protection Scheme	Description	Vendor and Model
1	132kV Line Distance	"A" Protection	Schweitzer SEL-411L
		"B" Protection	Schneider MiCOM P443
2	132kV Bus Zone	"A" Protection	Schweitzer SEL-487B
		"B" Protection	Schneider MiCOM P643
3	132kV Transformer	"A" Protection	Schweitzer SEL-487E
		"B" Protection	Schneider MiCOM P643
4	Overhead 11kV Feeder	"A" Protection	Schweitzer SEL-351S
		"B" Protection	Schneider MiCOM P145
5	Underground 11kV Feeder	"A" Protection	Schweitzer SEL-351S
		"B" Protection	Schneider MiCOM P545

The 132kV line distance protection IEDs, (*SEL-411L and MiCOM P443*), is used for fast and selective fault clearing of transmission lines. Each IEDs protection scheme is divided into three zones of operation which is for grading purposes.

This means that only the IED which is closest to the fault actually operates, however other IEDs zones may start to operate without tripping.

The 132kV bus zone protection IEDs, (*SEL-487B and MiCOM P643*) is used for high speed tripping on faults within the bus bar zones of a switchyard. Fault current levels in this zone can reach extremely high magnitudes therefore quick operation of equipment is vital.

The 132/11kV transformer protection IEDs, (*SEL-487E and MiCOM P643*) are used for fast fault clearing of short circuits within the transformer. Also integrated in this IED is the Buchholz protection, which will trip the transformer circuit breakers in the event of oil or gas surges and low oil levels in the transformer tank.

The 11kV feeder protection IEDs, (*SEL-351S, MiCOM P145 and MiCOM P545*) are used for fault clearing on all out going lines. These IEDs feature auto-reclosing capabilities, circuit breaker monitoring and circuit breaker failure protection.

6.2.2 Industrial Ethernet Switches

ActewAGL Distribution currently use the Siemens RuggedCom industrial Ethernet switches in all of their newly constructed or renovated substations.

Source: (www.siemens.com, 2014)

Figure 6-1 – Siemens RS400 Ethernet Switch

These switches have proven to be reliable with no major issues being identified. In order to keep the Ethernet switches standardised, the RS400 series will be used in all substations.

6.2.3 GPS Clock

The time synchronisation of the substation will be carried out with the Tekron TCG 02-E GPS clock. This device receives a UTC time and date signal from an orbiting satellite through an antenna mounted on an external wall of the test facility. The GPS clock is then connected to Ethernet switch 1 via an optic fibre cable. This was preferred over an IRIG-B connection as communications speeds were viewed as adequate with fibre.

This detail may change once fully implemented. All other switches and devices are then able to obtain the UTC + 10 which is equivalent to the Australian Eastern Standard Time and date through their own optic fibre or Ethernet connection at their respective switch.

Source: (www.tekron.com, 2014)

Figure 6-2 – Tekron TCG 0.2-E GPS Time Clock

6.2.4 125V DC Power Supply

The Cordex CXCR 125/220VDC is the preferred rectifier module and charging unit used within ActewAGL Distribution substations as it provides a complete system monitoring and control of the substations DC power system. It is easily set through the front LCD panel or by a computer with a standard web browser such as internet explorer.

Source: (www.alphatechnologies.com, 2014)

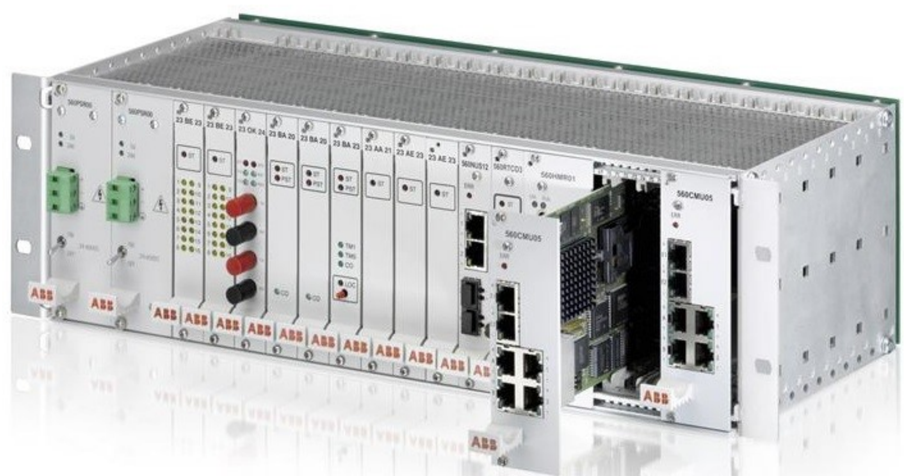
Figure 6-3 – Cordex 125V DC Rectifier Battery Charger Unit

Other power supply units that were evaluated took up complete panels in comparison. These units also allow the replacement of faulty rectifiers while the unit is still in service without any loss off supply to the DC power system.

6.2.5 Remote Terminal Unit

ActewAGL Distribution currently uses the Foxboro RTU50 series for its remote terminal units, RTU, throughout its zone substation network. Due to the reduction in wiring that has been experienced with the IEC 61850 standard, it has been decided that the ABB RTU560 will be implemented in the test facility as the space taken up by the ABB RTU560 device is one third of that of the current devices installed.

The ABB RTU560 is a modular design that has greater flexibility and redundancy measures than the Foxboro RTU50 giving it greater reliability. These units also have the ability to communicate with the test facility via the IEC 61850 standard and the ability to send this data to ActewAGL Distributions system control via an optic fibre link through the servers at the Greenway Depot using the DNP3.0 protocol. This will enable the test facility to have real time access to status and control points via an Enmac web viewer screen.



Source: (ABB Australia, 2014)

Figure 6-4 – ABB RTU560 Remote Terminal Unit

6.3 Test Facility Design and Construction

Construction began on the 20th February and was completed on the 15th April 2014. This process was very much a learning experience for all involved as ActewAGL Distribution had not undertaken a project like this for many years and much of the construction works involved were only known to a select few. The design of this test facility has been carefully considered to integrate all of the components required to demonstrate the capabilities of the IEDs, the IEC 61850 standard and to be able to perform extensive testing on new substation automation systems. In depth consultation with various ActewAGL engineering staff and IED vendors was undertaken prior to any design work commencing.

Major issues that were identified and needed to be resolved were:

- Ethernet Network Topology – a mesh topology was decided best by all parties;
- Time Synchronization – Optic fibre over the LAN was preferred over IRIG-B;
- Cyber Security – IEC62351 – Power System Data and Communications Protocol standard utilised, due to ActewAGL Distributions network being breached; and
- Understanding the standardised naming convention.

Source: (Hogan, 2014)

Figure 6-5 – ActewAGL Distribution SAS Test Facility under Construction

6.4 Test Facility Commissioning

Commissioning of the test facility started on the 16th April and took a total of three complete days to complete, which was the 18th April 2014. After the completion of all installed devices, termination of multicore cables and fibre optic cables, pre-commissioning checks on the test facility took place included:

- Earthing continuity;
- Multicore termination checks;
- Multicore wire numbering and multicore number checks;
- Fibre optic numbering checks as per fibre optic schedule;
- Insulation resistance testing of all DC and AC wiring *(1000V DC)*
- Polarity checks of DC power supplies; and
- Polarity and rotation checks of the AC power supply. *(Appendix F)*

Once all the above tests were validated all IEDs were acceptance tested with default settings as per the manufacturers specifications installed. Testing was carried out with the use of a Doble F6150 power system simulator and its associated Doble Protection Suite software.

6.5 Test Facility Performance Checks

The IEDs installed in the test facility are very complex as each single unit can perform multiple functions that until recently been handled by numerous electromechanical relays. As a result, the process of evaluating the performance of the various IEDs protection and control functionality is quite difficult and time consuming.

In order to carry out these performance checks, a Doble F6150 power systems simulator with IEC 61850 compatible I/O logic will be utilised to simulate different fault and abnormal system configurations. Doble's own Protection Suite and F6 Test software will be used to conduct the testing and confirm that the IEDs operation is within the regulations as set out in the IEC 61850 standard, in particular section 10 – Conformance Testing, in addition to ActewAGL Distribution's own policies and standards.

Chapter seven of this report discusses the performance and evaluation checks that were conducted on the test facility over the course of this project.

CHAPTER 7 – PERFORMANCE EVALUATION

7.1 Chapter Overview

This chapter outlines the various performance evaluation testing that was conducted on the IEC 61850 standard with the use of the test facility, including the protection, network, time synchronisation and data acquisition.

The test facility highlighted many new substation automation system concepts that could possibly be implemented using the IEC 61850 standard moving forward into the future. These concepts have been rigorously tested with the test facility and are discussed in greater depth.

7.2 Key Outcomes

The use of this test facility saw the successful development and evaluation of a substation automation system that utilised the IEC 61850 standard incorporated with multiple vendor devices. It allowed for various scenarios such as, device and equipment operation, status indication, GOOSE message transfer and potential causes of lost data, device failure, etc. to be fully simulated to ensure the final substation automation system design was both robust and intuitive.

Interoperability between the different families of selected devices was viewed as a key performance indicator for the justification of implementing a fully compliant IEC 61850 substation automation system into ActewAGL Distribution's electrical network in the future.

More detail is given in the following sections on the key areas that were identified as having to be fully evaluated prior to the final approval for implementation from senior ActewAGL Distribution senior management.

7.3 Engineering Process

The major process that was highlighted by this test facility was the fact that before any engineering or construction can occur, the substation automation system philosophy, IED configuration and the substation bus topology must be determined.

7.3.1 Substation Automation System Philosophy

The first decision was to move away from a primary and backup protection philosophy to a duplicated protection philosophy with the majority of RTU and SCADA functions being moved to the IEDs, such as the auto reclose function, interlocking, status indication and system monitoring.

In existing substations within ActewAGL Distribution's network, each protection panel consisted of dedicated relays or equipment for individual functions. With the introduction of micro-processor based devices, all of these individual functions have now been consolidated into a single device. As such, the amount of space required for a typical protection scheme panel has been reduced as shown in figure 7-1.

Source: (Hogan, 2014)

Figure 7-1 – Typical Protection Panel – Existing vs Test Facility

The test facility also showed the importance of the common naming conventions within the individual logical nodes. This was particularly useful as in existing zone substations, the SEL IEDs use the ANSI symbols while the Schneider IEDs used word descriptive text symbols as shown in table 7-1.

The use of this common naming convention was vital during the evaluation phase of this project as the majority of system errors could be traced back to a naming convention or the incorrect data set from a logical node being sent to the HMI giving a wrong status indication or virtual output.

Table 7-1 – IED vs IEC 61850 Naming Conventions Comparison

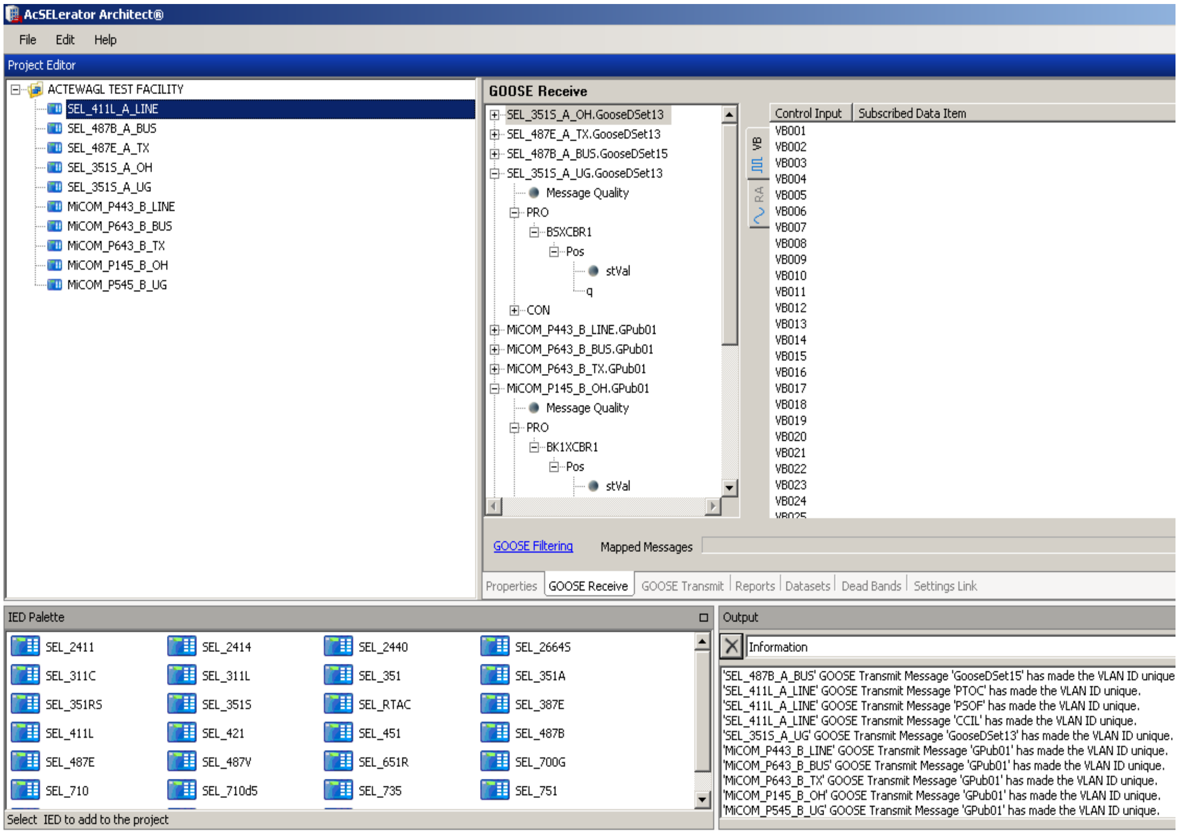
Naming Conventions - IEDs vs IEC 61850

Function	SEL IEDs	Schneider IEDs	IEC 61850
Circuit Breaker Status	52	CB	XCBR
Substation Metering	MET	MSR	MMTR
Interlocking	3	IL	CILO
Line Distance	21	Z	PDIS
Transformer Differential	87T	Idiff>	PDIF
Time Overcurrent (IDMT)	51P	I>	PTOC
Instantaneous Overcurrent	50P	I>>	PTOC
Earth Fault Overcurrent	51N	IN>	PTOC
Sensitive Earth Fault (SEF)	67SEF	Isef>	PDEF

7.3.2 IED Configuration

In order to gain the full benefits of the IEC 61850 standard, it was found that a single substation configuration description, SCD, needed to be used to configure everything within the test facility. Many problems were encountered while using various individual configuration tools and this made it very difficult to decipher some error messages and fix the problem.

The task of configuring these GOOSE messages takes a lot of engineering time initially, however, a recent study by Schneider Electric has shown that there was a time savings of 72% using a common system configuration tool versus configuring each IED individually using the native vendor tool alone. (Gauci, 2013)



Source: (Hogan, 2014)

Figure 7-2 – SCD File Configuration Tool

The SCD tool that was used to configure all of the selected devices was SEL AcSELerator Architect software as it proved to be user friendly when compared to a number of other open free IEC 61850 IED configuration tools.

Each IED has the capability to configure hundreds of GOOSE messages, and is only limited by the I/O processor installed in the IED. To enable an IED to transmit or receive data via GOOSE messaging, a "publish – subscribe" architecture pattern must be configured. In this pattern, the IED that publishes the data over the LAN rather than to a specific device. If another IED is then configured as a subscriber to that data, it then takes the information contained in it and uses it to carry out an associated task.

Figure 7-2 provides an example of the SEL AcSELerator configuration tool.

Examples of the types of data that is now sent by a GOOSE messages in this test facility rather than the conventional hardwired connections that are currently implemented in existing zone substations include:

- Circuit Breaker remote open and close commands.
- Protection setting group enable selection.
- Sensitive Earth Fault protection blocking.
- Live Line Sequence enable command.
- Transformer and High Voltage Busbar tripping.
- Auto Reclose Blocking.
- Standard Circuit Breaker/Disconnector/Earth Switch interlocks.

The test facility demonstrated just how simple it actually is to replace the hardwired connections with the use of a single multi-mode optic fibre cable. This configuration process actually took a lot of the project engineering time as this was the first time for all personnel involved using such a system. However, when compared to configuring individual protection relay settings, as is current practice, the time savings associated with configuring the one IED were seen to offset this amount of time.

It must also be highlighted that future development would not involve such a significant amount of time as the ground work has been done and any further modifications would be able to be completed promptly due to the experience gained from this test facility.

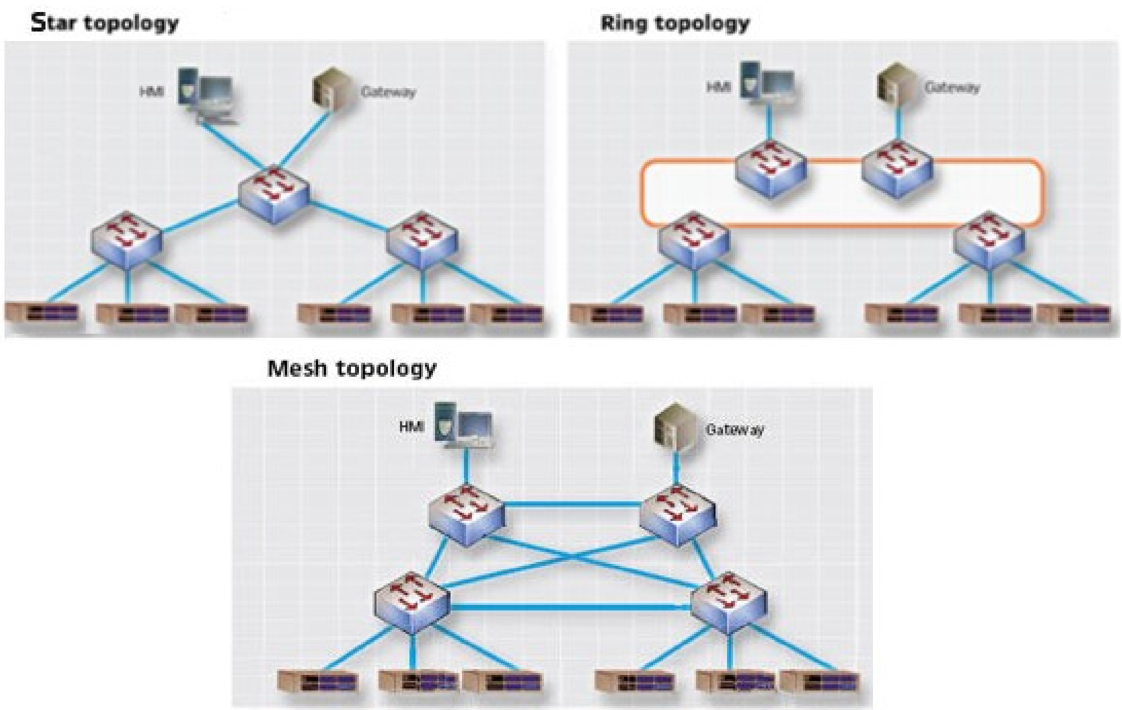
7.3.3 Substation Network Bus Topology

The substation network topology is essentially the way in which devices are connected together. Figure 7-3 shows the three simplest topologies which were considered for the test facility. They are the:

- Star Topology,
- Ring Topology, and
- Mesh Topology

In the star topology, there is a physical connection that connects each device on the network to a central connection, in the case below, it is a supervising switch. The difference with the ring topology is that the physical connection is daisy-chained around the devices to form the ring. The ring topology has a physical daisy-chained connection around the devices in the form of a ring giving a greater network redundancy than the star topology.

The network topology that was ultimately chosen for the test bay and future implemented systems was the mesh topology. This topology is essentially a combination of the star and ring systems with its biggest advantage being that every device is somehow interconnected with another, giving it the greatest network redundancy which means the network can handle any point of failure. This topology also allows for a relatively even distribution of transmission signals, even if a switch should fail.



Source: (PACWorld, 2012)

Figure 7-3 – Substation Network Bus Topologies

7.4 Use of a Substation LAN for Protection

The most noticeable conceptual change with the IEC 61850 standard is the use of GOOSE messages to send protection, control, measurement and monitoring information over a local area network using a station and process bus rather than the usual kilometres of hardwired multicore cable connections.

The use of this LAN has been found to significantly reduce the installation and maintenance costs of the substation automation system as the equipment that is most susceptible to failure, the wiring terminations, are eliminated.

One function in particular that was thoroughly tested was the auto reclose initiation. This function is initiated by the "A" protection IED and is carried out by the "B" protection IED. ActewAGL Distribution's system control mandated that if the auto reclose function was enabled, then it must have reliability should a protection LAN fail.

This was able to be confirmed by switching of supply to the A protection LAN and simulating a fault condition in the A protection IED. The auto reclose initiate was successful and the command was carried out. There was a difference of operation of 620ms when compared to the A protection LAN operational. This was deemed as acceptable as current RTU failure-to-restoration rates have been seen to take up to 5 – 20 seconds depending on the substations location.

The substation LAN in this test facility included the following:

- 16 IED's installed
- 210 GOOSE Message Signals
    - Replacing an estimated 400 hardwired connections
- Approximately 350 Virtual Inputs
- Approximately 2 – 3 pages of programmable logic per IED *(scheme and IED functionality dependent)*

The evaluation carried out with the use of the test facility was vital in determining and confirming the performance of what information should be sent to system control via GOOSE messages when these substation automation systems designs are ultimately implemented.

It must be noted that these statistics are for this test facility only and these numbers would of course increase in a real world zone substation environment. The above figures certainly does give some indication of the savings in time and equipment that an IEC 61850 substation automation system will give ActewAGL Distribution.

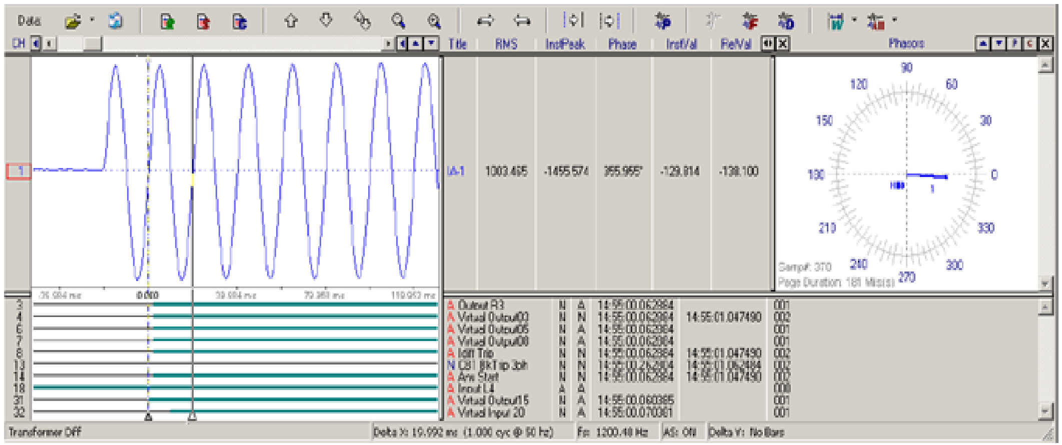
7.5 Time Synchronisation

With the IEC 61850 standard, a large amount of event data is available to be transmitted at a fast rate over the substation LAN from any device connected to it. (Roostaee, et al., 2011) When a substation event occurs, the information must be organised well to ensure no data packages are lost in transfer. Factors that can affect time synchronisation accuracy depend on the traffic load, communication medium and the distance of the substation network. Standard protocols for time synchronisation in substation automation systems are GPS, IRIG-B and 1PPS.

The IEC 61850 standard states that the time synchronisation over the LAN via an Ethernet network must be accurate in terms of milliseconds. Normally, the Network Time Protocol, NTP, or the Simple Network Time Protocol, SNTP, are used for time synchronising the IEDs at both the station and process levels of the substation automation system. ActewAGL Distribution already has some limited experience with SNTP in some 11kV/415V distribution substations, and was selected as the time synchronisation method for the test facility and will be for future implementation of IEC 61850 substation automation system designs.

Testing the time synchronisation in the test facility was showing an accuracy of around three milliseconds where accuracies of five to ten milliseconds were quoted by various vendors. It was decided that even at the worst case of 10ms, this was an improvement on the current protocols used for time synching in ActewAGL Distributions network.

Figure 7-4 shows a simulated transformer differential fault that initiated a trip on the A protection or the SEL-487E IED. The time the fault occurred was time stamped at 12:58:00:040 and the point at which the IED trip contact operated was time stamped at 12:58:00:070 giving a total operation time of 30ms.

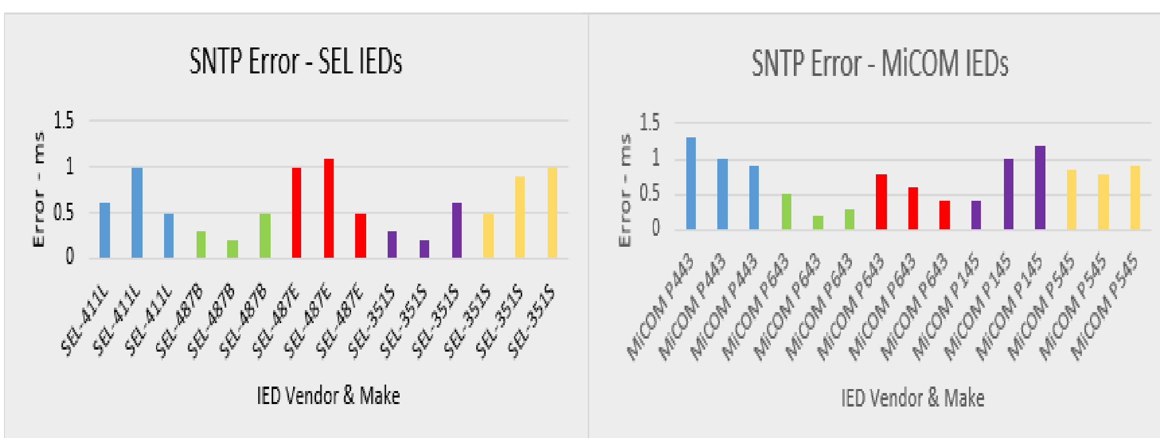


Source: (Hogan, 2014)

Figure 7-4 – Time Synchronisation Testing

This figure may seem high but when it is carefully analysed and when the IED manufacturers average contact clearance time of 25ms is accounted for, the operate time is far superior to any scheme currently implemented in ActewAGL Distribution's network.

In order to test the accuracy of the time synchronisation of the installed IEDs, each one had three consecutive tests conducted on them with a different type of system condition simulated for each different protection scheme. These results can be seen in figure 7-5. The results shown above prove that the time synchronisation of the installed IEDs are extremely accurate. The largest error was seen in the MiCOM P443 – B Protection 132kV Line IED at 1.2ms with an average over both vendors of just over 0.5ms.



Source: (Hogan, 2014)

Figure 7-5 – SNTP Error Rate for Each IED

7.6 Commissioning and Maintenance

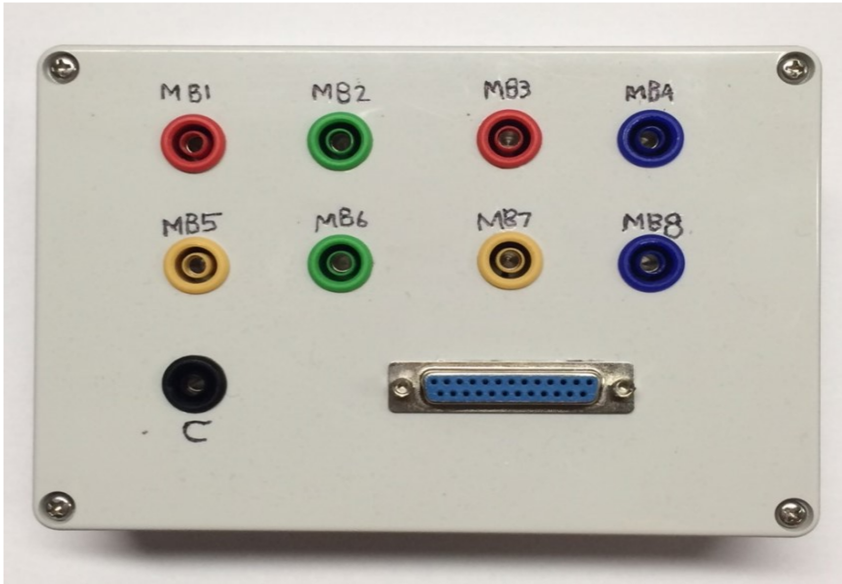
The test facility also brought to light that due to the use of GOOSE signals replacing hardwired connections, there will need to be a change in isolation practices. As a result of the reduction in wiring, due to the IEC 61850 standard, isolation links where various hard wired signals once terminated, are now unable to be used to gain a complete isolation for testing purposes.

In order to fully test the complete protection scheme at commissioning and in maintenance periods, a virtual bit monitor box was designed to facilitate the checking of the various GOOSE message signals. This is done by changing the primary programmable logic scheme in the IEDs to a second scheme which replaces the virtual bits with user defined alarms that will not cause any inadvertent actions to occur. As each monitor bit changes state from low to high, it is able to be seen with the use of a laptop and each IED's native software.

This virtual bit monitor box allows all intertripping, interlocking and auto-reclose functions to be tested without the need to isolate any other in-service IEDs. The virtual bit monitor box used in the test facility is shown in figure 7-6. These changes in isolation practices have now been added to the automated test plans to make the testing process as straightforward as possible.

Fortunately, this process of using GOOSE for protection signalling has proven to be easy to comprehend for the majority of field staff, and for those that may initially struggle with the concepts, the test facility provides a platform to hone their skills and become more comfortable with these new substation automation systems.

The test facility will play an important ongoing role in the commissioning and maintenance of future substations to both field staff and substation designers as they will be able to use the test facility to simulate a complete system by loading the one single configuration file into the devices to be implemented.



Source: (Hogan, 2014)

Figure 7-6 – Virtual Bit Monitor Box

7.7 Engineering Tools

This test facility uses many new engineering and setting configuration tools that ActewAGL Distribution designers and field staff have not previously seen or used before. The test facility allowed all parties to gain hands on training and experience to the new engineering tools in a laboratory environment to ensure that they will work in the real world substation environment and integrate with ActewAGL Distribution's central control room's current GE Enmac platform as well as its anticipated successor, Schneider Electric's Telvent automation platform which is currently due to be rolled out in early 2015.

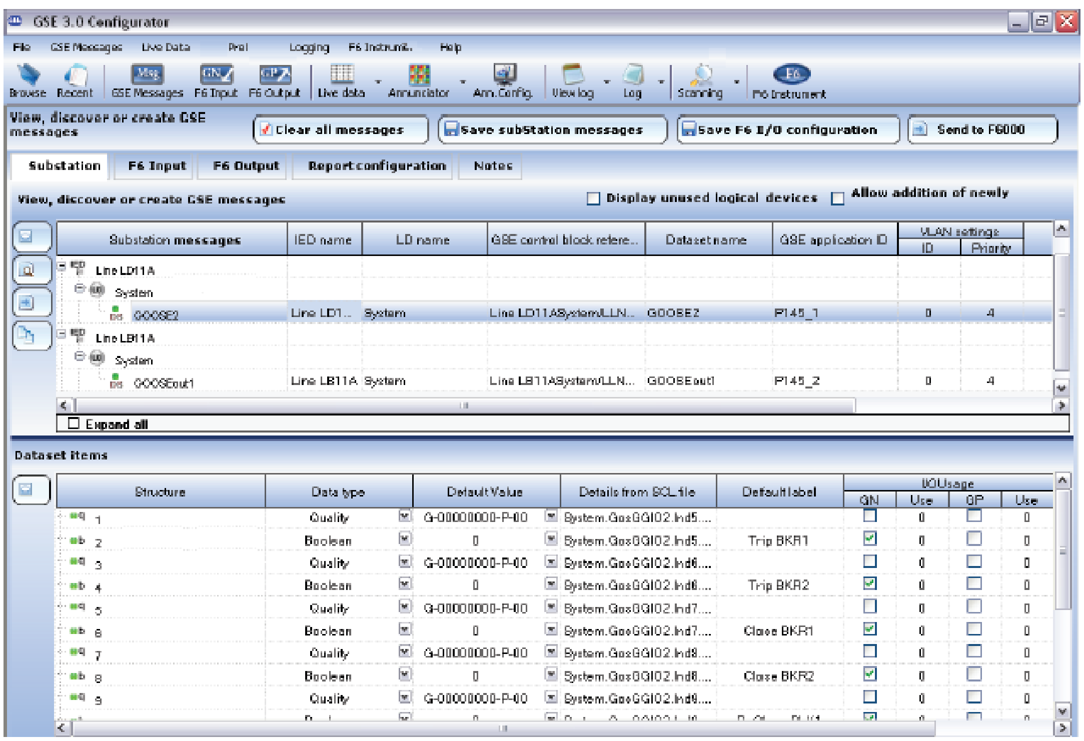
7.8 IED Simulator

The test facility contains sufficient equipment to evaluate the functionality and performance of most substation automation designs that will be implemented in ActewAGL Distribution's network, however, there is still some functionality that can only be tested with every device in place.

In order to achieve this, more devices would need to be installed and this is just not feasible as the costs associated with an entire substation automation system platform would be quite high and justification to senior management was deemed unlikely to be successful.

To combat this problem, the test facility made use of an IED simulator, Doble GSE 3.0, to simulate the GOOSE messaging traffic from the remainder of devices that were not installed in the test facility but would be in a fully configured substation automation system. Figure 7-7 shows the selected Doble GSE 3.0 IED simulator software in use.

This simulator was included in the system SCD file and conditions such as abnormal power system conditions were manually introduced so that auto reclosing, intertripping and interlocking logic could be verified. The use of a simulator such as the Doble GSE 3.0 will permit the complete functionality testing of the chosen substation automation system design prior to it being implemented.



Source: (Hogan, 2014)

Figure 7-7 – Doble GSE 3.0 IED Simulation Software

7.9 Substation Configuration Time Reduction

Schneider Electric have conducted studies that have found that there were time savings of up to 72% using the one configuration tool versus configuring each IED. (Gauci, 2013)

Even with the complexity of the overall substation automation system being greater than anything implemented before, the amount of time it will take to configure future zone substations will reduce. This is able to be achieved by automating as much of the device addressing as possible and eliminating the need to individually configure each IED through the use of a single configuration tool. Currently, any protection relay installed in ActewAGL Distribution's network has up to three files loaded into it by different users with different system programs, these being;

- The relay or IED protection setting file
- The DNP3.0 file – *Integrated into new IEDs, however for older relays this is usually implemented at the RTU with follower relays*,
- The programmable logic file – *currently only implemented on the newer micro-processor type devices.*

This creates issues such as data base management and determining the correct setting version implemented. With the use of the single SCD file, all protection, control and other SCADA functionality is encased in one file as opposed to the individual files with propitiatory software.

7.10 Increased Substation Virtualisation

With the use of the test facility, the substation model can be developed and extensively tested prior to its implementation. This allows for a stronger design and minimal modifications needing to occur onsite.

Virtualisation allows both the substation automation system designer and field technician to focus the design on the functional requirements of the substation and select the appropriate hardware to suit.

This will allow for the development of more innovative and cost effective systems without sacrificing the system functionality. This will allow ActewAGL Distribution to integrate this new automation systems into its electrical network control system, GE Enmac, easily and more efficiently.

7.11 Interoperability

One of the most advanced features of the IEC 61850 standard that has been evaluated with the test facility is the interoperability between devices regardless of the vendor. As previously stated, ActewAGL Distribution's protection philosophy sates that no one vendor can be used for both "A" and "B" protections on any scheme.

The test facility proved that this standard has the capability of delivering vital information between two different families of IED's, those being the SEL and Schneider devices. Other devices were trailed throughout the selection process but these two families of IEDs performed exceptionally well due to the well-defined data format and configuration language rather than being forced to use individual IED proprietary protocols.

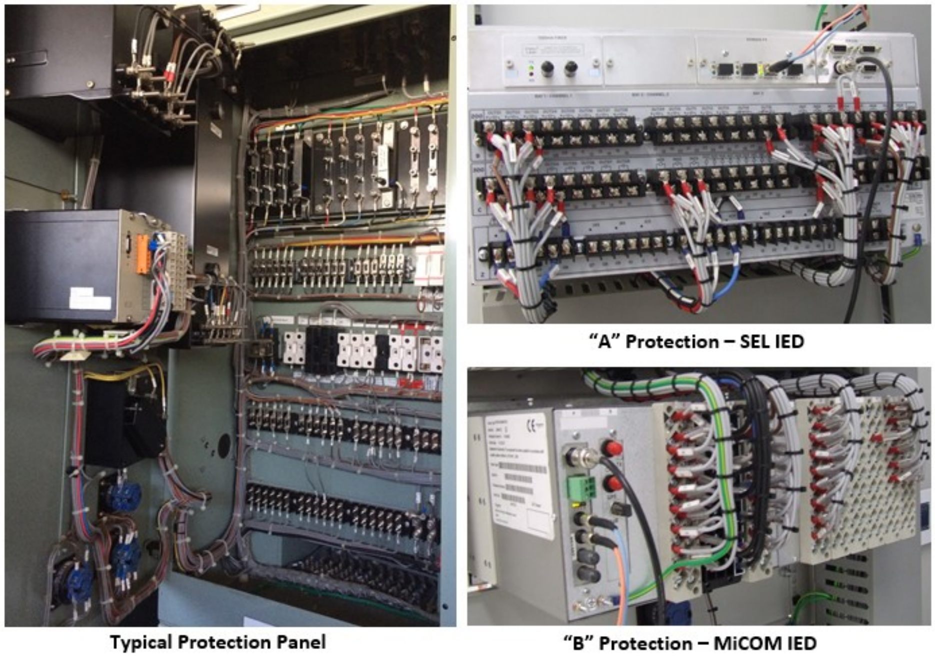
7.12 Reduced Wiring Terminations

The installation and commissioning of the IEDs, hardware and individual protection schemes took much less time compared to conventional systems in place. This in large, is due to the minimal wiring terminations needed to be made as the majority of data is transferred via Ethernet.

The only wiring terminations actually required in the test facility have proven to be:

- Circuit Breaker tripping circuits,
- Circuit Breaker Status,
- Voltage and Current Inputs.

Figure 7-8 shows a comparison between a typical in-service protection panel and what has been installed as part of the test facility.



Source: (Hogan, 2014)

Figure 7-8 – Comparison between In-Service and Test Facility Protection Panels

Reviewing the data collected showed that by implementing an IEC 61850 system, it showed that the amount of labour this process usually takes for the installation of a typical 11kV feeder panel could be completed by one installation technician over two and in approximately half the time.

The time it takes to commission the substation will also take less time due to in large too much of the pre-commissioning works able to be carried out in the test facility. The IED settings and associated test plans can also be pre-configured for quick and easy onsite loading of each device. This can be easily modified to cater for slight variations in the substation arrangement. With the figures at hand from the evaluation of the test facility, it is estimated that up to 60% of wiring terminations throughout a typical two transformer, 132/11kV zone substation can be replaced with the utilisation of virtual outputs inside the IED and Ethernet cabling providing the data transfer.

Figure 7-9 provides an indication of the typical wiring savings that are achievable with an IEC 61850 substation automation system design. Note that the multicore cabling removed from the cable trench is replaced with a 6 core multimode fibre optic cable.

Source: (Dolezilek, et al., 2010)

Figure 7-9 – Typical Wiring Savings with an IEC 61850 SAS

7.13 Performance Evaluation Summary

Following the performance evaluation carried out on the test facility, all results were passed onto the key stakeholders within ActewAGL Distribution, who ultimately make the final decision as to whether this new substation automation design will be implemented in the future, to both new and existing substations.

The findings of this test facility were accepted and approved in August 2014 for its implementation into ActewAGL Distributions new 132/11 kV Molonglo Zone Substation. This new substation is due to be constructed sometime over 2015 – 2016.

CHAPTER 8 – COST EVALUATION

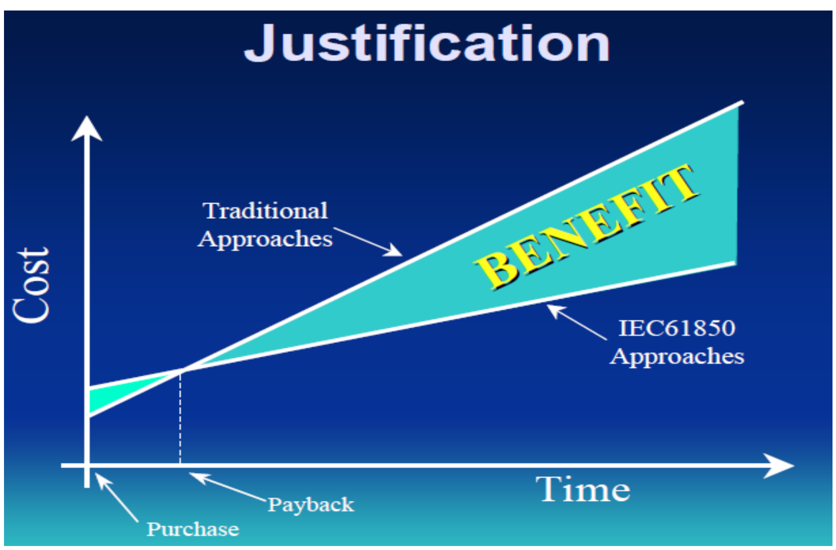
8.1 Chapter Overview

This chapter details the cost comparisons of an IEC 61850 substation automation system, as opposed to a typical hardwired substation automation system that is currently implemented within ActewAGL Distributions network. This comparison has been assessed on a typical two transformer 132/11kV zone substation.

8.2 Key to a Successful Cost Comparison

"The tragedy of substation automation systems is that there are no benefits without some costs," (Gauci, 2013). In order out carry out a successful cost comparison with regards to an IEC 61850 vs. the current in-service substation automation systems within ActewAGL Distribution's network. The advantages and disadvantages of either system cannot be simply justified by examining only the price of the system, a true cost justification requires a longer time frame to be assessed over a range of variables that take into account the full life cycle of the system.

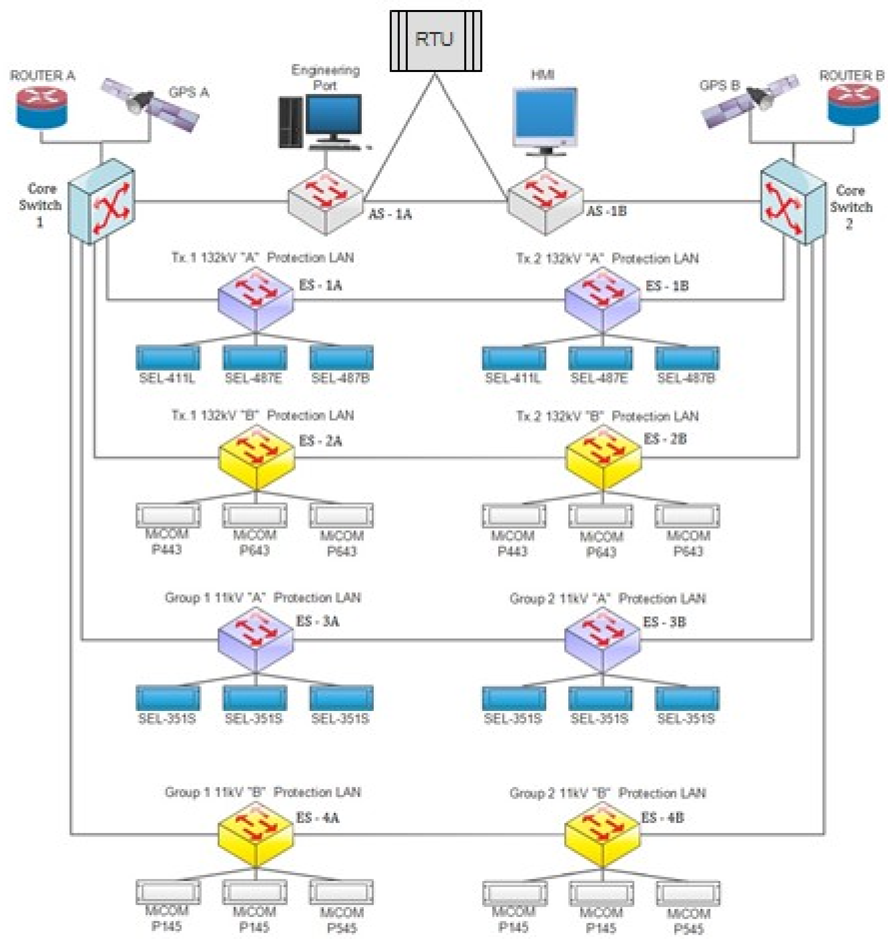
Figure 8-1 shows a graph for cost justification of traditional vs. IEC 61850 approaches.



Source: (Mackiewicz, 2006)

Figure 8-1 – IEC 61850 vs. Legacy Protocol Cost Justification

For the purpose of this cost evaluation, only the secondary equipment within a typical 132/11kV two transformer zone substation have been considered, as shown in the final IEC 61850 substation automation system design that is due for implementation, in figure 8-2. This means that no primary equipment or secondary switchboards have been factored due to the limited costing information of existing systems able to be obtained.



Source: (Hogan, 2014)

Figure 8-2 – IEC 61850 Substation Automation System Network Design

The items that this costing evaluation will focus on are:

- Equipment – *cost per unit*
- Installation – *cost per panel*
- Engineering – *cost of configuration*
- Commissioning – *cost of time and labor*

The data that has been obtained for the current substation automation systems in place have been averaged over the cost data of ten of ActewAGL Distributions 132kV zone substations because of the time between constructions of the in-service zone substations.

The data for the IEC 61850 equipment has been based upon the individual prices that were quoted by the selected vendors that were installed in the test facility as part of this research project.

An overview of each focus areas costing is provided in this chapter with a full account of the costing evaluation is given in Appendix G.

8.3 Equipment Costing

Mackiewicz, 2006, states that "You can't justify an IEC 61850 system by examining only the price of the equipment".

The IEC 61850 substation automation system developed with the use of the test facility has a much higher level of complexity to any existing automation system currently implemented in ActewAGL Distribution's electrical network.

Because of this, the initial cost outlay for the equipment, is higher than any current substation automation system currently implemented within its electrical network. This is because the devices required for an IEC 61850 substation automation system are powerful micro-processor based devices, while the current systems use primarily electromechanical relays with some first generation numerical relays installed as backup schemes.

Table 8-1 gives an overview of the total equipment costs of both substation automation systems.

Table 8-1 – Equipment Costing

	Current Protocols	**IEC 61850 Standard**
TOTAL	$108,100.00	$186,610.00

8.4 Installation Costing

As has been previously stated in this report, the IEC 61850 systems is considerably cheaper to install due to the reduction of equipment, time and labour when compared to the current substations and their associated automation systems installed in ActewAGL Distributions electrical network.

For this costing, the installation of both the current systems and the IEC 61850 substation automation system has been assessed on an average electrical installation technician's hourly wage of $40 per hour working an eight hour shift. A typical time frame allowed for the installation work on previous ActewAGL Distribution zone substations secondary equipment ranged from two to three months.

Although the test facility was a simplified version of an actual zone substation, this only took less than three weeks to construct and commission.

The considerable cost savings that are present at the installation stage of the substation automation system when an IEC 61850 system is implemented are shown in table 8-2.

Table 8-2 – Installation Costing

	Current Protocols	IEC 61850 Standard
TOTAL	$162,000.00	$20,638.00

8.5 Engineering Costing

The engineering costing for a 132/11kV zone substation has been conducted for both substation automation systems at a zone substation design engineer's hourly rate of $80 per hour over a standard eight hour day.

Due to the reduced configuration costs because of the common naming conventions and automatic point configuration and retrieval schemes that the IEC 61850 standard employs, the time it takes to engineer protective devices has dropped significantly.

Much of the engineering time with the current automation systems is the mapping of data to multiple stacks at both the individual device and SCADA levels. The time ActewAGL

Distribution design engineers allowed for a relay to be configured with the DNP3.0 protocol was typically eight hours per relay, with up to six individual relays per protection panel. With the IEC 61850 standard, the engineering time has been bought down to two hours per device and only two devices are installed per protection panel due to their greater capability.

Table 8-3 gives an overview of the engineering costing for both substation automation systems.

Table 8-3 – Engineering Costing

	Current Protocols	IEC 61850 Standard
TOTAL	$67,200.00	$8,000.00

8.6 Commissioning Costing

The commissioning of a 132/11kV zone substation, has in the past, been the highest cost associated with the substation automation system. Depending on the complexity of the substation, the amount of time needed to commission an existing substation could take months. Much of the work in commissioning existing substations is confirming wiring terminations for every scheme and in the case at ActewAGL Distribution, having to manually set and calibrate every relay, which in itself is a very time consuming effort.

The IEC 61850 standard devices are software based which means a setting file can be loaded into a device in a matter of seconds, then fully tested to confirm these settings in less time than it would take to set one individual relay in the current systems.

Commissioning these new systems can become a highly automated process as the use of a test facility, like the one presented in this research project, is vital in eliminating much of this onsite commissioning time as logic can be checked prior to going onsite, the automated testing plans can be developed and validated and any miscellaneous problems can be resolved. Table 8-4 gives an overview of the commissioning costing for both substation automation systems.

Table 8-4 – Commissioning Costing

	Current Protocols	IEC 61850 Standard
TOTAL	$176,400.00	$28,000.00

8.7 Costing Summary

The costing overviews provided in this chapter along with the detailed costings provided in Appendix G show that the IEC 61850 standard is cheaper to design and implement that the current systems installed within ActewAGL Distribution. The figures provided here as part of this costing are true and correct as of October 2014.

Although the equipment costs are greater with the IEC 61850 standard, the savings are apparent when the other life cycle costs of engineering, commissioning and maintenance are factored in. In total, this research project has identified a total saving of approximately $270,452.00 for a typical two 132/11kV transformer zone substation installed in ActewAGL Distributions electrical network.

It must also be remembered, that this figure is only for the secondary equipment within the substation environment. There are more savings that would present themselves with a full review of the primary equipment taken into account.

CHAPTER 9 – CONCLUSIONS

This dissertation had two main aims. The first was to develop a test facility that can be used to assess the IEC 61850 – Communication Networks and Systems in Substations Standard. The second was to use the test facility to evaluate the newly developed substation automation system designs for implementation into the existing and proposed 132/11kV zone substations within ActewAGL Distribution's electrical network. The project has successfully achieved both of these aims using multi-vendor devices and engineering tools.

A literature review was carried out which provided the foundation knowledge of the IEC 61850 standard, how it should be implemented within the substation environment and described how major vendors, power utilities and universities have developed test facilities in order to conduct research and enhance their learning on the IEC 61850 standard and associated devices.

This report has presented all of the features of the individual components that have been installed in the test facility from the initial design and construction stages, through to the performance and evaluation of the developed IEC 61850 substation automation system designs.

The test facility has proven itself as an important tool in the design and implementation of an IEC 61850 compliant substation automation system for ActewAGL Distribution. The advantages of using the IEC 61850 standard over legacy protocols are numerous as they help in achieving a superior substation automation system functionality at considerably lower costs.

As a result of the performance and cost evaluations carried out on the developed substation automation system designs with the use of the test facility, it is recommended that this IEC 61850 compliant design be approved for implementation within ActewAGL Distributions 132/11kV zone substation network in the near future.

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Appendix A – Project Specification

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR: **Matthew Julian HOGAN**

TOPIC: A TEST FACILITY FOR ASSESSING THE PERFORMANCE OF IEC 61850 BASED SUBSTATION AUTOMATION DESIGNS

SUPERVISORS: Dr. Tony Ahfock

ENROLMENT: ENG 4111 – S1, 2014 EXT
ENG 4112 – S2, 2014 EXT

PROJECT AIM: This project aims to design and construct a test facility to be used to assess the "IEC 61850 – Communication Networks and Systems in Substations" standard for substation automation schemes for ActewAGL's electricity network.

SPONSORSHIP: ActewAGL

PROGRAMME: **Issue A, 15th November 2013**

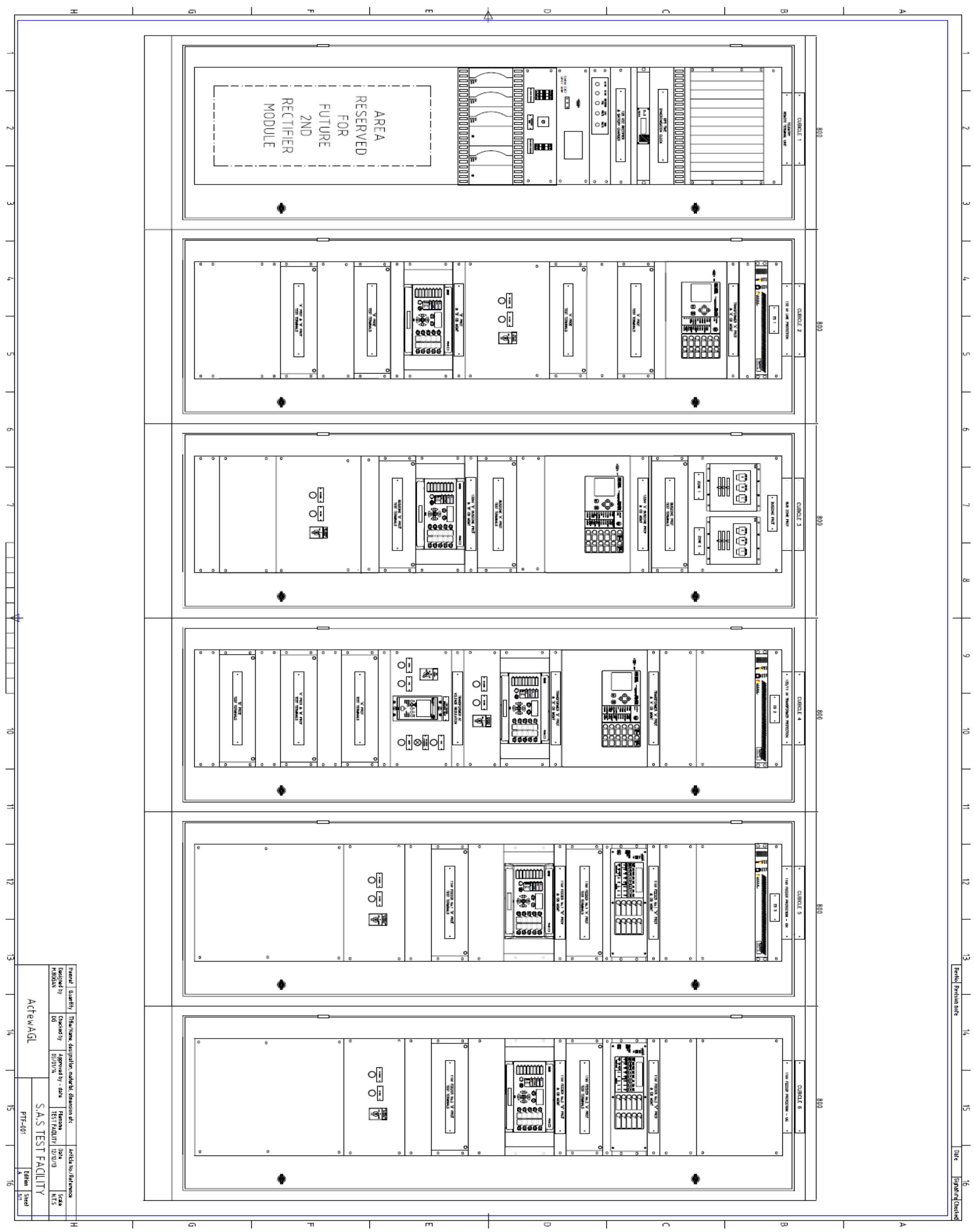
1. Research background information of the "IEC 61850 Communication Networks and Systems in Substations" standard for use in substation automation.
2. Selection of hardware for a suitable test facility for testing of protection and metering systems that use IEC 61850 compliant intelligent electronic devices.
3. To demonstrate the usage of the test facility.
4. Undertake a preliminary design of an IEC 61850 compliant substation automation system for a typical ActewAGL 132/11 kV zone substation.
5. Carry out cost and performance comparisons that would justify the use of IEC 61850 compliant designs for ActewAGL's 132/11 kV zone substations.
(Critical performance data to be obtained using the above test facility)

AGREED: ________________(Student) ___________________(Supervisor)

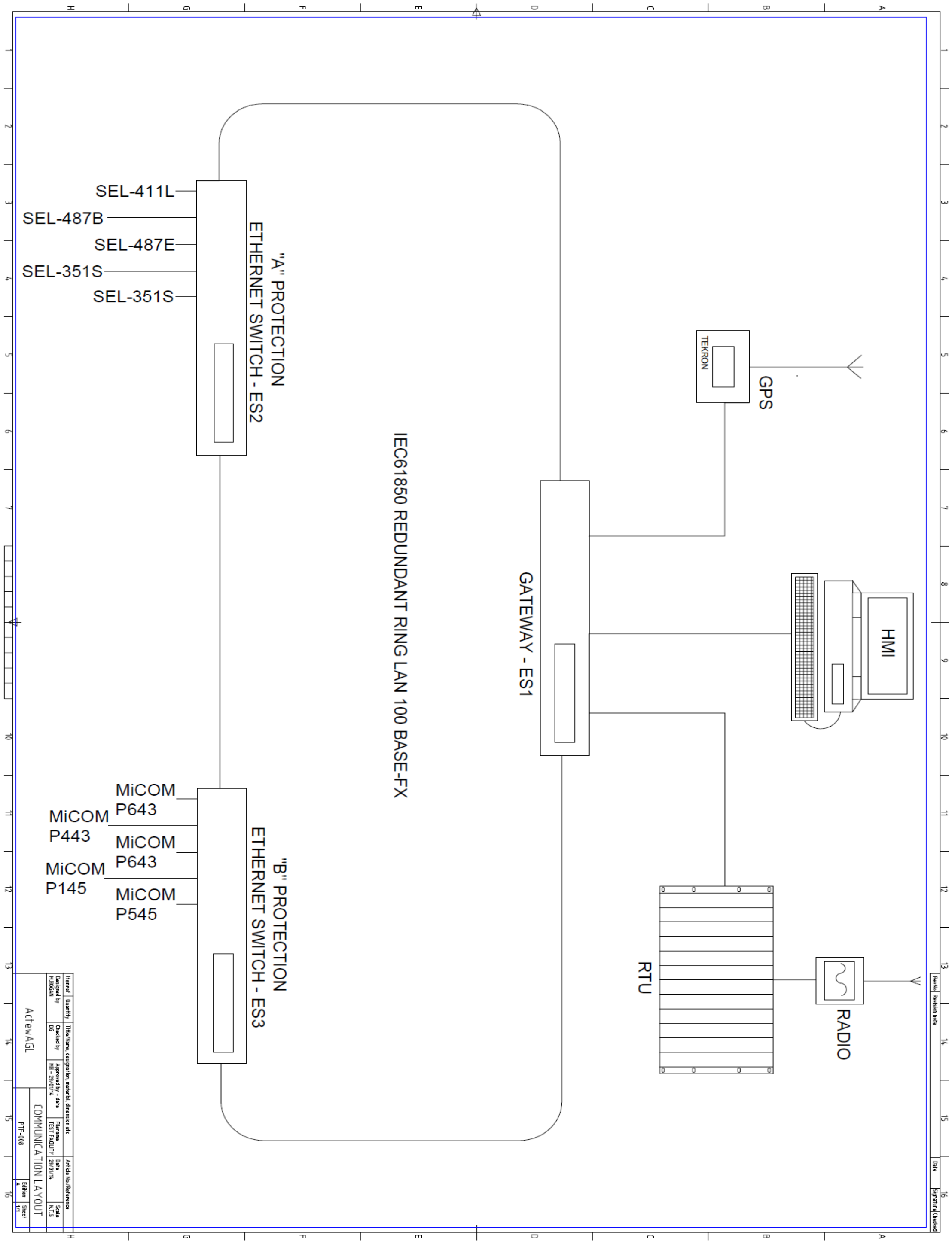
Date: 11 / April / 2014 Date: 11 / April / 2014

Appendix B – Test Facility Drawings

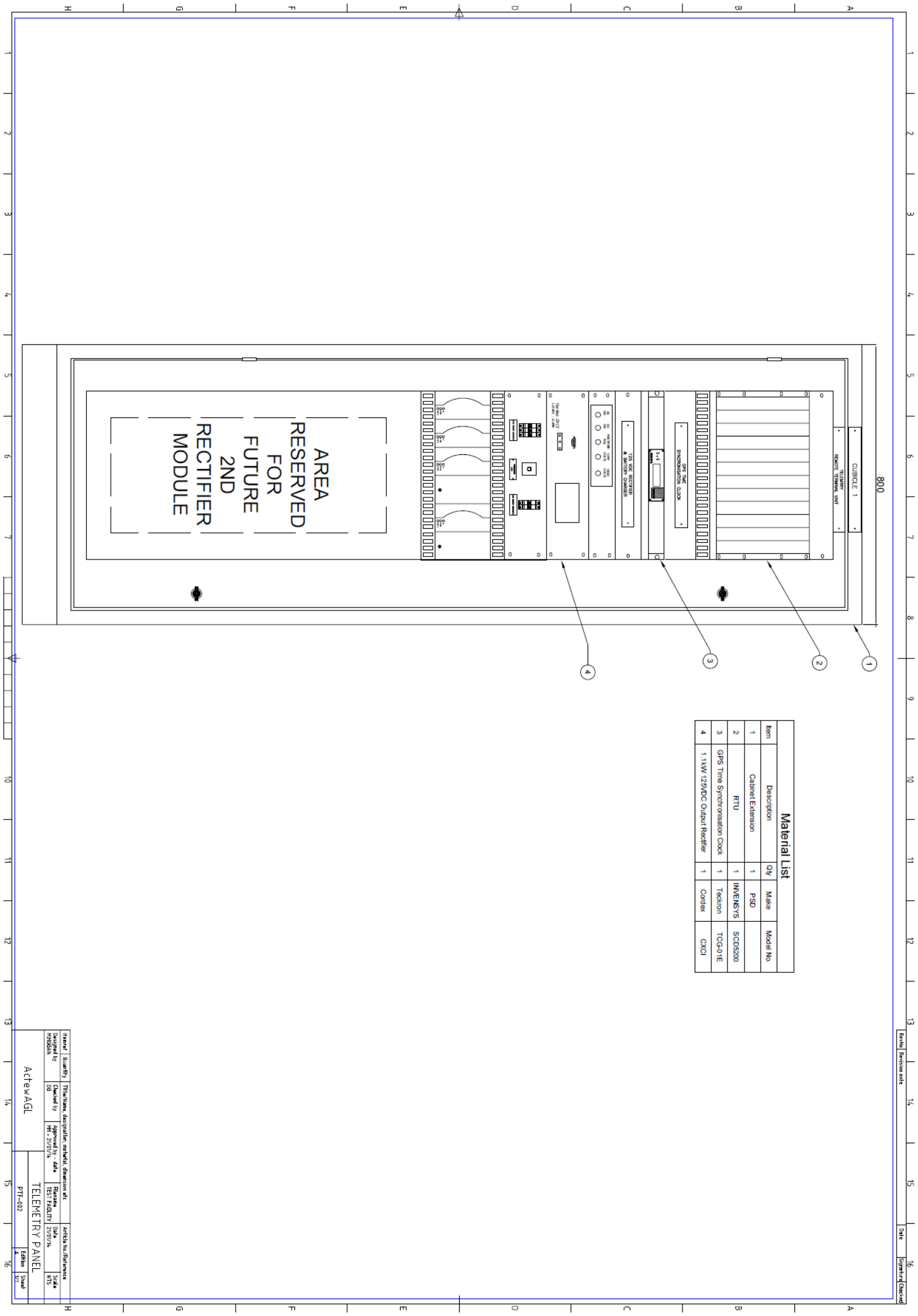
B1 – Substation Automation System Test Facility Layout



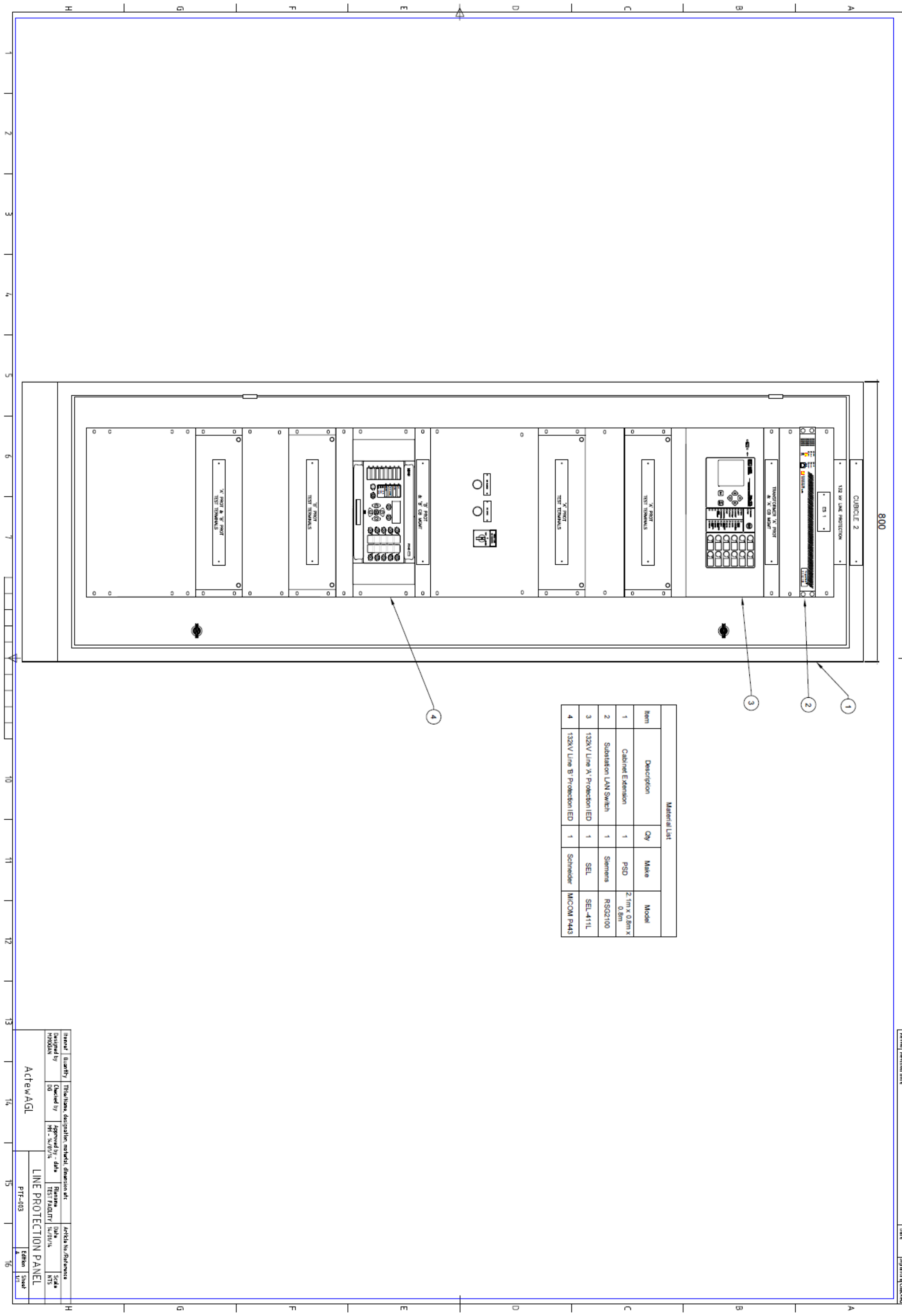
B2 – Communication Layout



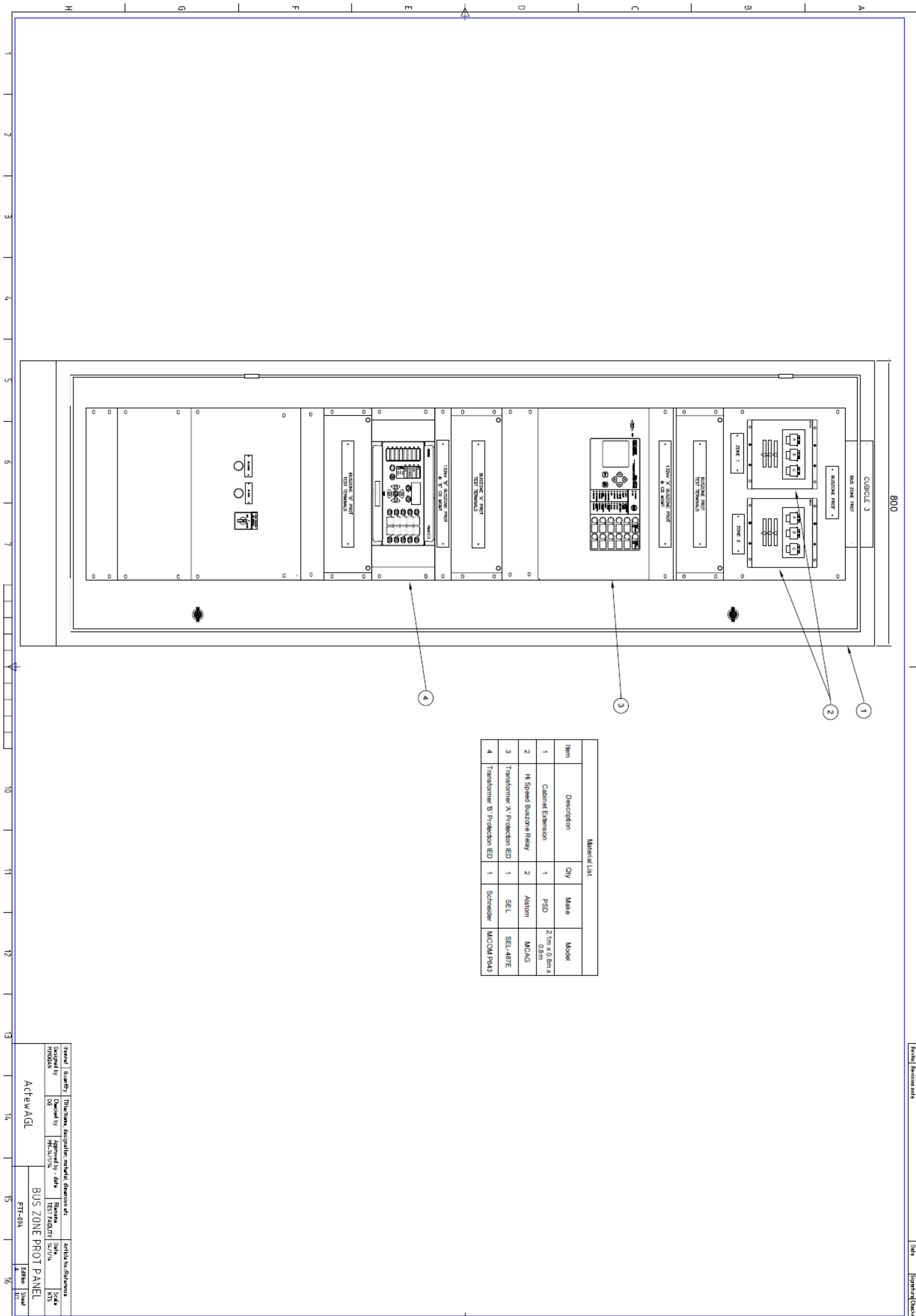
B3 – RTU and Power Supply Panel



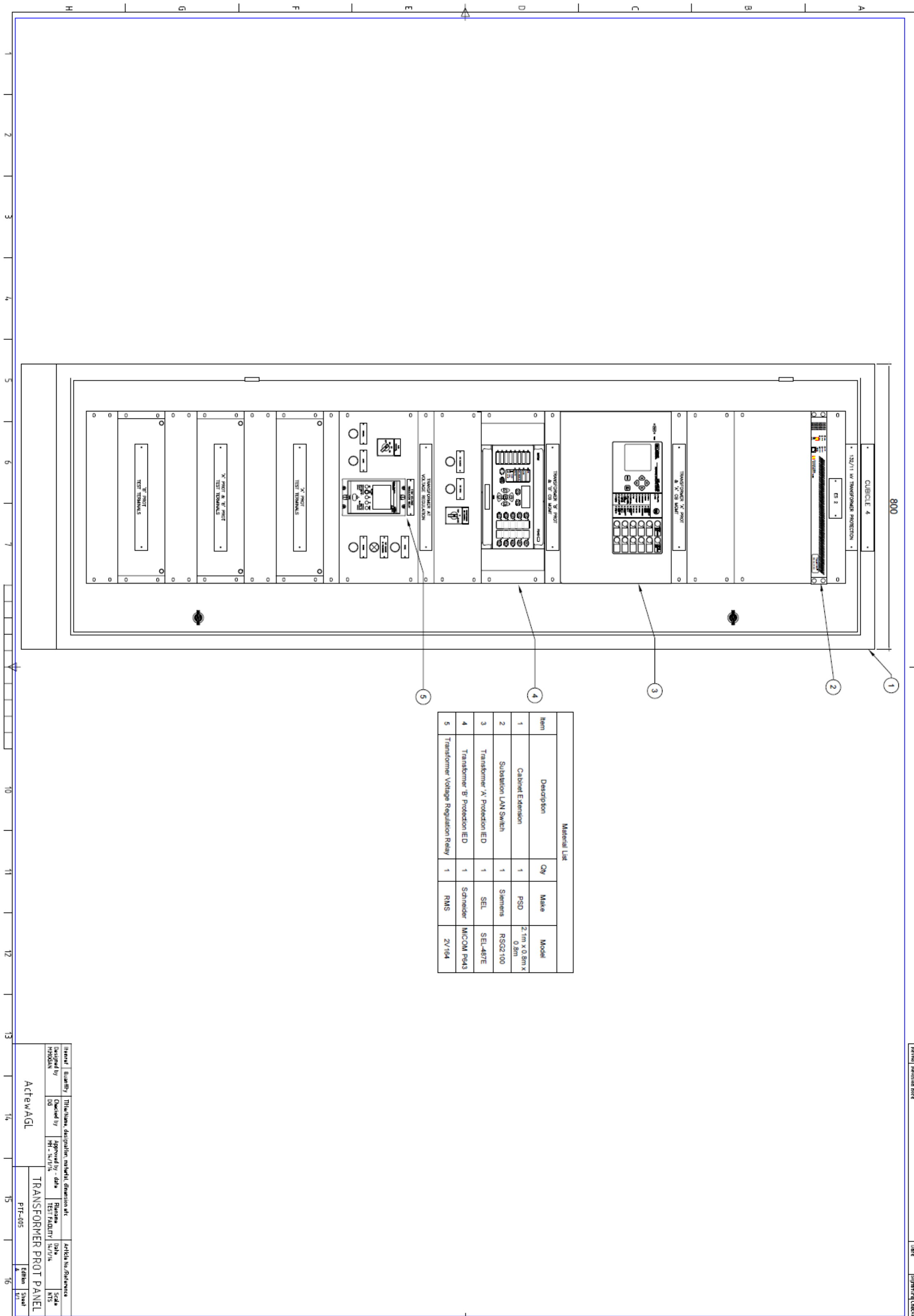
B4 – Line Distance Protection Panel



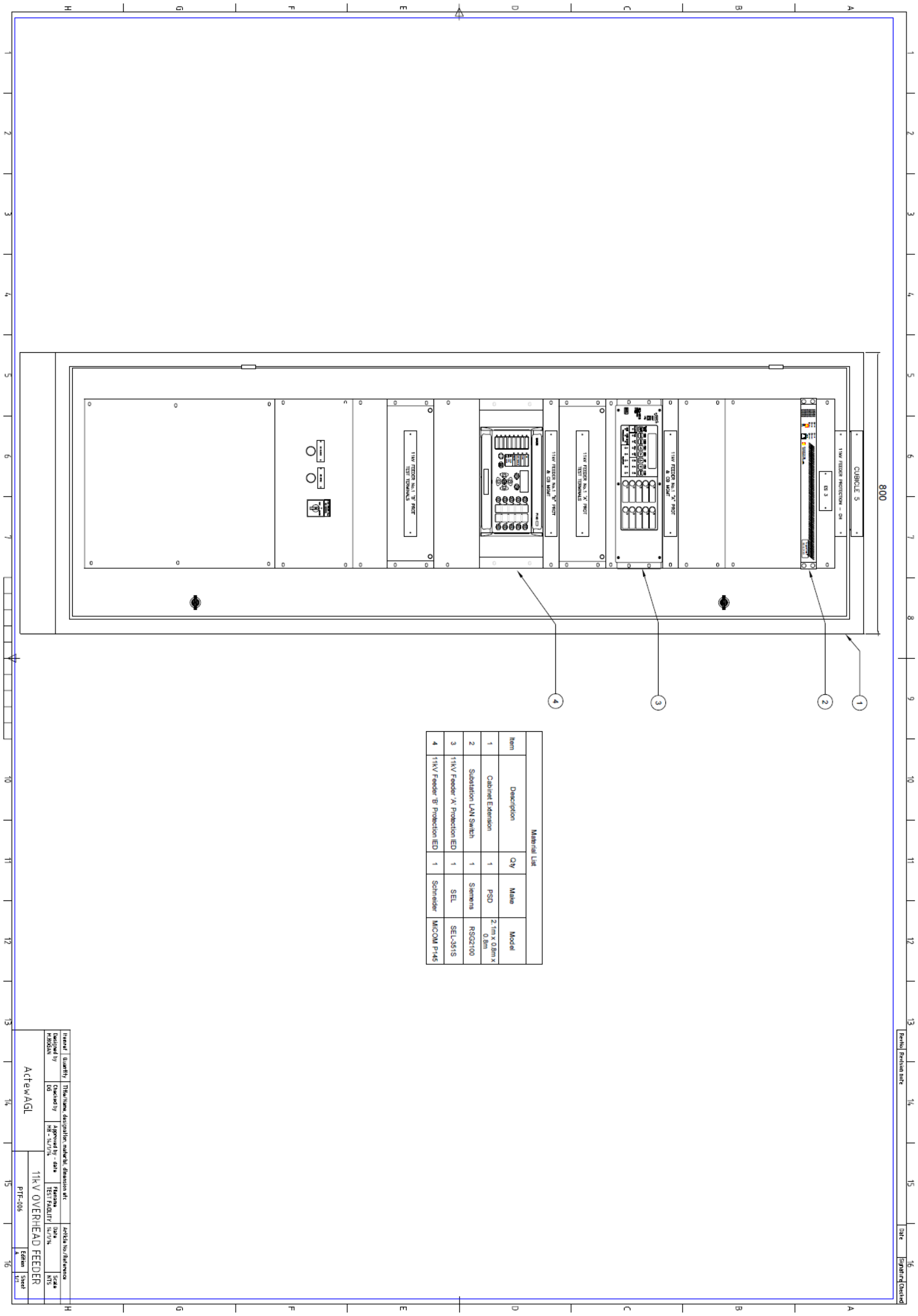
B5 – Bus Zone Protection Panel



B6 – Transformer Protection Panel



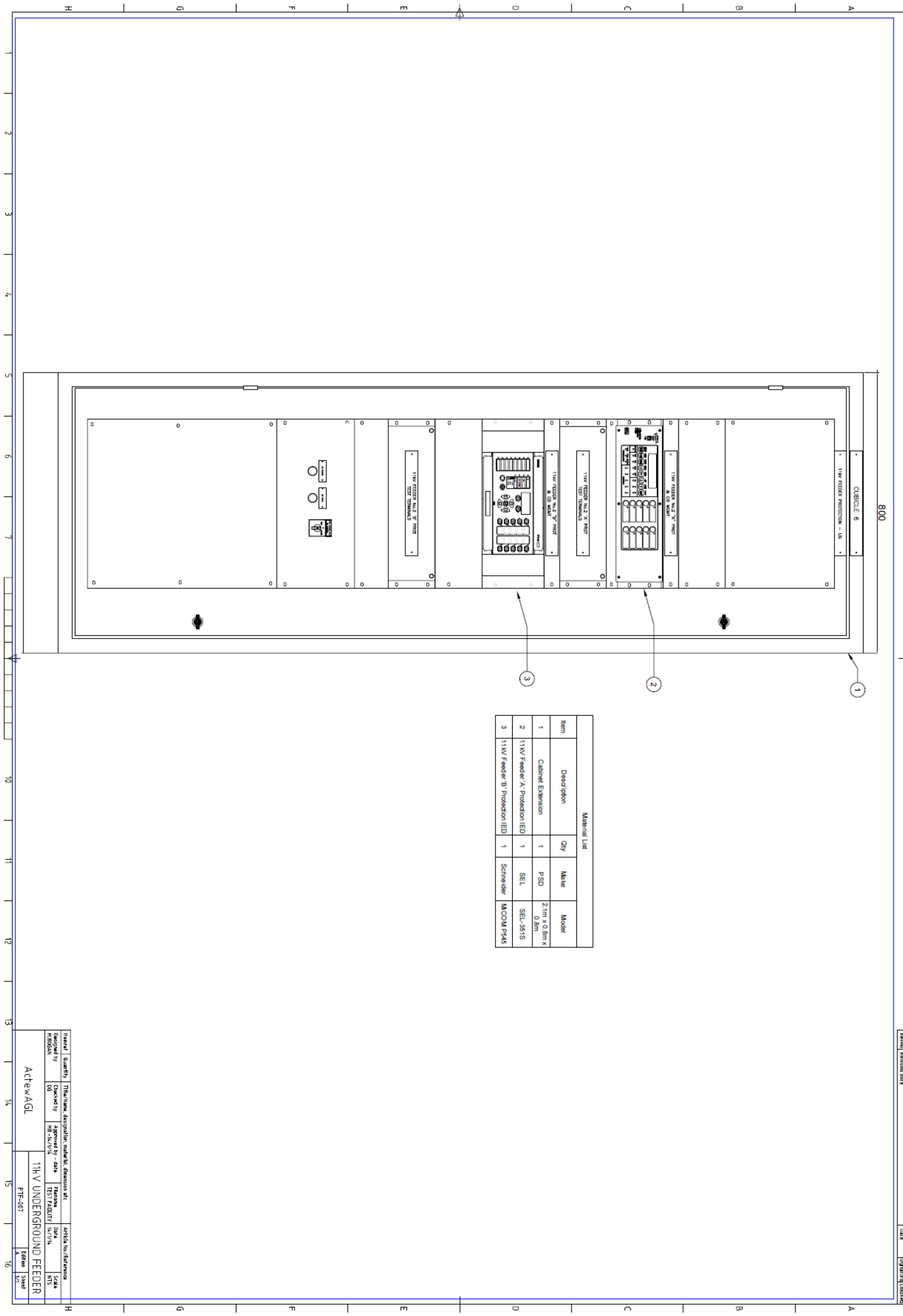
B7 – 11kV Overhead Protection Panel



Material List

Item	Description	Qty	Make	Model
1	Cabinet Extension	1	PSD	2.1m x 0.8m x 0.8m
2	Substation LAN Switch	1	Siemens	RSG2100
3	11kV Feeder 'A' Protection IED	1	SEL	SEL-351S
4	11kV Feeder 'B' Protection IED	1	Schneider	MiCOM P145

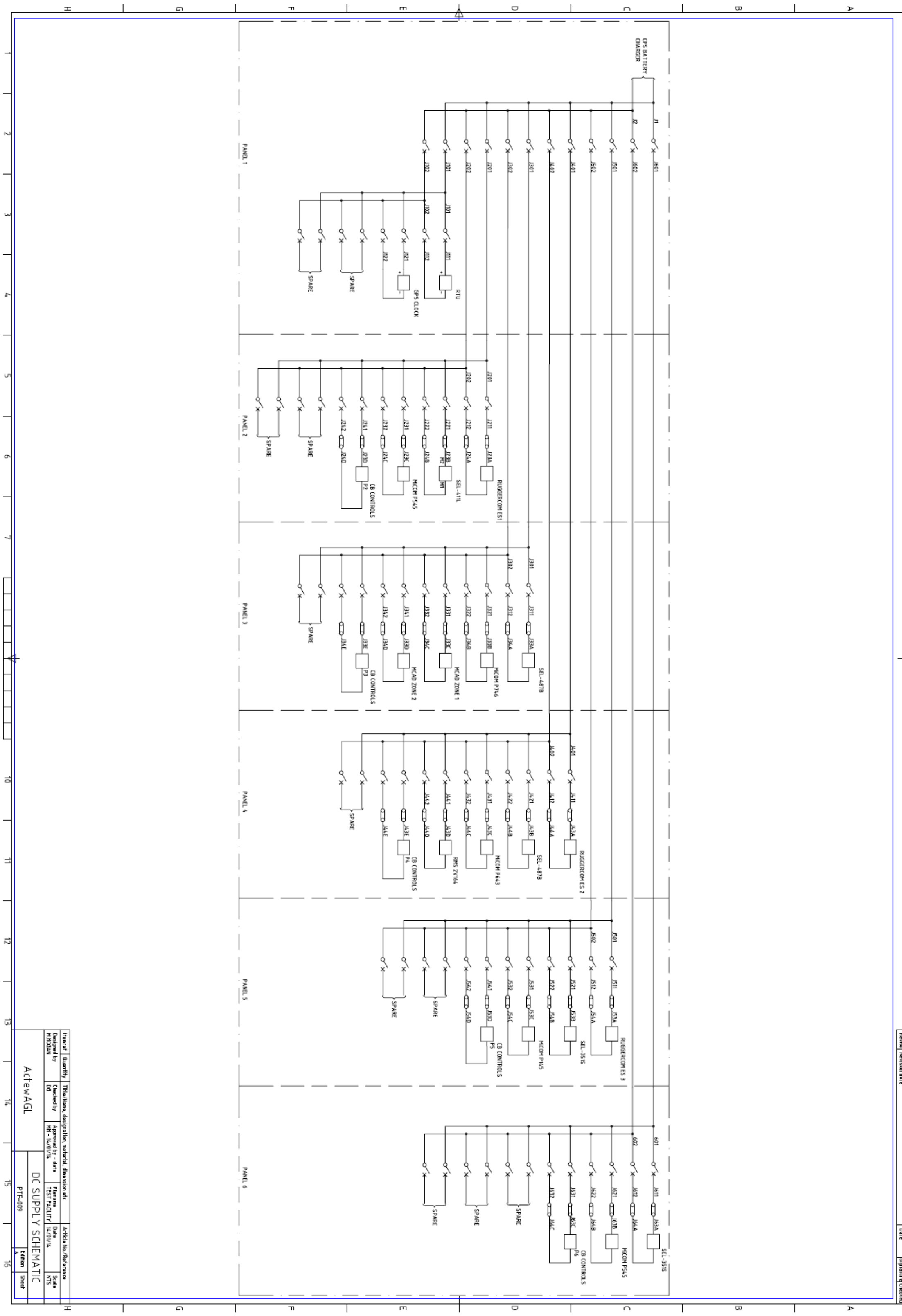
B8 – 11kV Underground Protection Panel



Material List

Item	Description	Qty	Make	Model
1	Cabinet Extension	1	PSD	2.1m x 0.8m x 0.8m
2	11kV Feeder 'A' Protection IED	1	SEL	SEL-351S
3	11kV Feeder 'B' Protection IED	1	Schneider	MiCOM P545

B9– DC Supply Schematic



Appendix C – Project Gantt Charts

C1 – ENG4111 Research Project Part 1 Gantt Chart

ENG4111 - Research Project Part 1

Project Name: A Test Facility for Assessing the Performance of IEC61850 based Substation Automation Designs

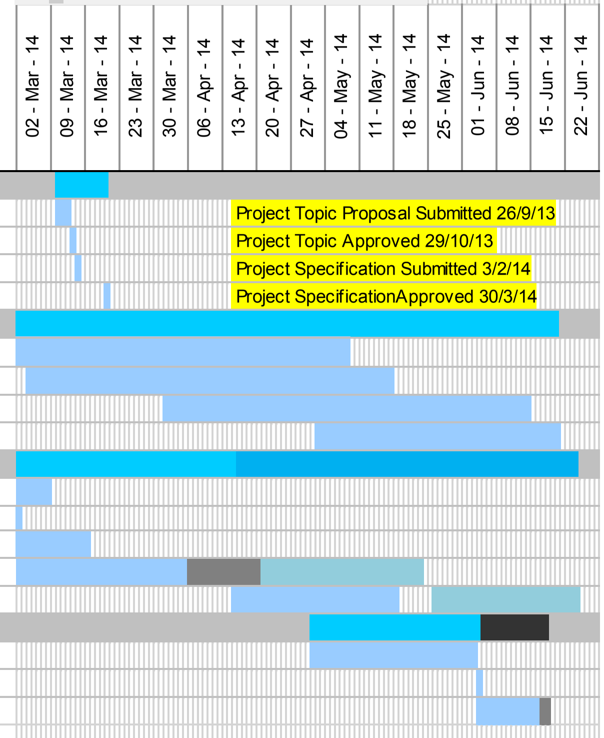
Today's Date: 06-10-14 Monday

Project Lead: Matthew HOGAN

Start Date: 06-03-14 Thursday

First Day of Week (Sun=1): 1

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	**Project Selection**	MH	10-3-14	20-3-14	11	100%	9	11	0
1.1	Prepare Project Topic Proposal		10-03-14	12-03-14	2	100%	3	3	0
1.2	Project Topic Approved		13-03-14	13-03-14	1	100%	1	1	0
1.3	Prepare Project Specification		14-03-14	19-03-14	1	100%	4	1	0
1.4	Project Specification Approved		20-03-14	20-03-14	1	100%	1	1	0
2	**Preliminary Works**	MH	23-02-14	20-06-14	118	100%	85	118	0
2.1	Research IEC61850 Background/Theory		23-02-14	8-05-14	75	100%	54	75	0
2.2	Review Peer Journals/Papers		4-03-14	31-03-14	75	100%	20	75	0
2.3	Conduct Literature Review		1-04-14	14-06-14	75	100%	54	75	0
2.4	Prepare Project Methodology		2-05-14	20-06-14	50	100%	36	50	0
3	**Test Facility Design & Construction**	MH	1-02-14	18-05-14	74	100%	75	74	0
3.1	Procure Test Facility Panels		23-02-14	28-02-14	6	100%	5	6	0
3.2	Select Test Facility Hardware/Equipment		1-02-14	2-03-14	30	100%	20	30	0
3.3	Develop Test Facility Drawings		2-03-14	14-03-14	15	100%	10	15	0
3.4	Construct Test Facility		20-02-14	15-04-14	60	100%	45	45	0
3.5	Commission Test Facility		15-04-14	18-05-14	34	100%	24	34	0
4	**Preliminary Report**	MH	1-05-14	18-06-14	49	100%	35	35	0
4.1	Prepare Preliminary Report		1-05-14	3-06-14	34	100%	24	34	0
4.2	Submit Preliminary Report		4-06-14	4-06-14	1	100%	1	1	0
4.3	Preliminary Report Review		4-06-14	18-06-14	15	100%	13	13	0



C2 – ENG4112 Research Project Part 2 Gantt Chart

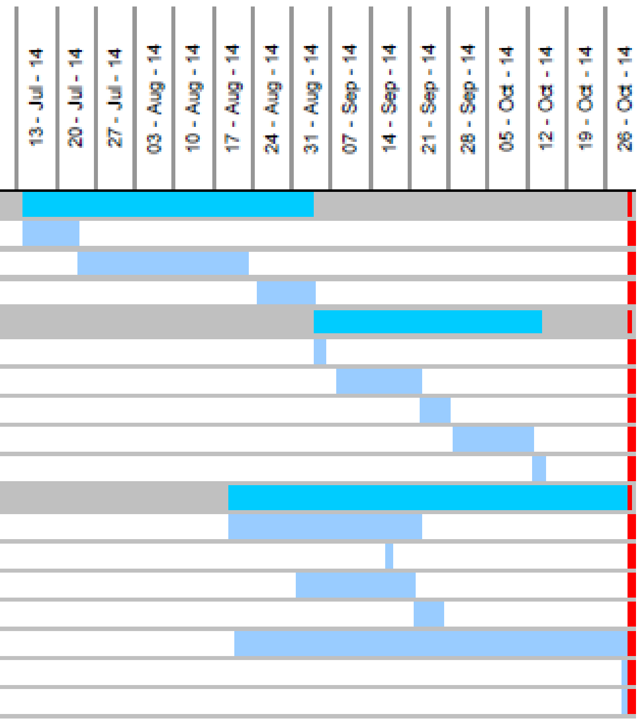
ENG4112 - Research Project Part 2

Today's Date: 30-10-14 Thursday
(vertical red line)

Project Lead: Matthew HOGAN
Start Date: 14-07-14 Monday

First Day of Week (Sun=1): 1

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	**Test Facility Performance**	MH	14-07-14	3-09-14	52	100%	38	52	0
1.1	Configure Test Facity Settings		14-07-14	23-07-14	10	100%	8	10	0
1.2	Carry Out Test Facility Evaluation		24-07-14	22-08-14	30	100%	22	30	0
1.3	Performance Comparison with DNP3		25-08-14	3-09-14	10	100%	8	10	0
2	**IEC61850 Substation Design**	MH	4-09-14	14-10-14	41	100%	29	41	0
2.1	Selection of Zone Substation for Design		4-09-14	5-09-14	2	100%	2	2	0
2.2	Carry out Initial IEC61850 Design		8-09-14	22-09-14	15	100%	11	15	0
2.3	Review Design		23-09-14	27-09-14	5	100%	4	5	0
2.4	Ammend Design (if required)		29-09-14	12-10-14	14	100%	10	14	0
3.5	Final Design		13-10-14	14-10-14	2	100%	2	2	0
4	**Final Report**	MH	20-08-14	30-10-14	72	100%	52	72	0
4.1	Prepare Draft Dissertation		20-08-14	16-09-14	34	100%	20	34	0
4.2	Submit Draft Dissertation		17-09-14	17-09-14	1	100%	1	1	0
4.3	Prepare Residential School Presentation		1-09-14	21-09-14	21	100%	15	21	0
4.4	Resdential School		22-09-14	26-09-14	5	100%	5	5	0
5.2	Prepare Final Dissertation		20-08-14	29-10-14	71	100%	51	71	0
5.3	Submit Final Dissertation		30-10-14	30-10-14	1	100%	1	1	0
5.4	Project Complete		30-10-14	30-10-14	1	100%	1	1	0



Appendix D – Risk Assessment

D1 – Hazard and Risk Assessment Form

Job risk assessment

08130

ActewAGL

Date: 12/5/14	Name of person in control of job site (PIC):	MATTHEW HOGAN	1. Commence by discussing what the job is going to involve.
Job location/s:	ACTEWAGL SAS TEST FACILITY – GREENWAY DEPOT.		2. Evaluate the site to identify any source of potential harm/damage that may impact the job.
Job description:	TEST FACILITY CONSTRUCTION/COMMISSIONING		3. Set up site, put controls in place and ensure the controls are monitored. Barricade/delineate the work site.

What generic work method statement (**GWMS**) and/or procedure/s are you following to do this job? Identify below by name and ID.

1 SWMS 05 001	2 SWMS 02 001	3 NTS 8.01 P39 W15
4 SWMS 05 006	5 EN 4.09 P65	6

Does the generic work method statement (**GWMS**) and/or procedure cover all steps to complete the job safely? ☑ **YES** ☐ **NO** If 'No', complete a specific work method statement (**SWMS**) using 7.5 P25 F02

What aspects of the site or hazards at the site could impact the job and cause potential harm or damage?

Hazard (Source of potential harm/damage)	**Present** Yes / No / N/A	**Controls** *(How we will deal with the source of potential harm/damage)*	Workers/work crews Stop / Check / Start	PIC Stop / Check / Start
Energised electrical services (HV)	NO	N/A	—	—
Energised electrical services (LV)	YES	ALL LIVE AREAS DANGER TAGGED + BARRIERS IN PLACE	START	START
Asbestos	NO	N/A	—	—
Energy source (non electrical) not isolated	NO	N/A	—	—
Hitting object and causing release e.g. gas	NO	N/A	—	—
Working in a confined space	NO	N/A	—	—
Fatigue/working long hours	NO	N/A	—	—
Noise	YES	HEARING PROTECTION TO BE WORN	START	START
Falling in/from/on/off i.e. height, trench	YES	PLATFORM LADDERS, HEIGHT AWARENESS TRAINING	START	START
Objects falling/moving/striking or hitting	YES	TOOLS SECURED AT ALL TIMES, HARD HATS TO BE WORN	START	START
Being stuck/caught in, on, between	NO	N/A	—	—
Sharp objects – cutting	YES	CARE TO BE TAKEN WHEN TERMINATING CONNECTIONS	START	START
Vibration	NO	N/A	—	—

ActewAGL Distribution ABN 76 670 568 688 a partnership of ACTEW Distribution Limited ABN 83 073 025 224 and Jemena Networks (ACT) Pty Ltd ABN 24 008 552 663.

7.5 P25 F01, Revision 1, November 2013

D2 – Hazard and Risk Assessment Matrix

HAZARD AND RISK ASSESSMENT MATRIX

CONSEQUENCE	**Environment**	Minor Impact	Moderate Impact	Major Impact
	Quality	Damage or Rework < 20k	Damage or Rework20k - 100k	Damage or Rework > 100k
	Safety	First Aid	Medical Treatment	Permanent Injury or Fatality
LIKELIHOOD	**ALOMOST CERTAIN**	**CHECK**	**STOP**	**STOP**
	POSSIBLE	**START**	**CHECK**	**STOP**
	UNLIKELY	**START**	**START**	**CHECK**

MATRIX DESCRIPTION

STOP	The task **CANNOT** proceed until the Works Coordinator/relevant manager has agreed to the controls that must be applied
CHECK	The Person In Control (PIC) of the task must review the controls with the crew/team and decide if they are suitable for the task to start or if it must stop.
START	The task **CAN** start as all controls are suitable and in place.

Appendix E – Selected Protection IEDs

SEL IEDs

Line Distance Protection

SEL-411L

Bus Zone Protection

SEL-487B

Transformer Protection

SEL-487E

11kV Feeder Protection

SEL-351S

Schneider MiCOM IEDs

All Schneider MiCOM IEDs have the same body and shell size. It is only the I/O modules and CPU that differ.

MiCOM P1XX Series

Appendix F – Test Facility Commissioning Sheet

Pre-Commissioning Check Sheet

Substation:	SAS Test Facility Greenway Depot.
Date:	16 -18 / 4 /2014
Commissioned by:	MH PB RH
Equipment Used:	A24 A44 E19 E21 I15

TEST	RESULT	PASS/FAIL	COMMENT
DC WIRING			
RTU SUPPLY	20 MΩ	PASS	**each circuit tested to all other circuits & earth*
COMMS SUPPLY	500 MΩ	PASS	**pass mark value is 2MΩ at 1000VDC*
"A" PROTECTION SUPPLY	100 MΩ	PASS	
"B" PROTECTION SUPPLY	120 MΩ	PASS	
TRIP CIRCUITS	500 MΩ	PASS	
AC WIRING			
MAIN SUPPLY	500 MΩ	PASS	** all AC wiring tested by meggering, polarity*
CABINENT LIGHT SUPPLY	500 MΩ	PASS	*and insulation resistance*
CT CIRCUIT WIRING	100 MΩ	PASS	**pass mark value is 2MΩ at 1000VDC*
VT CIRCUIT WIRING	110 MΩ	PASS	
OPTIC FIBRE			
LIGHT SOURCE TEST			**tested for continuity and loss*
ES1 - ES2	< 3dB	PASS	*with optical fibre power meter*
ES2 - ES3	< 3dB	PASS	**pass mark is less than 3dB of loss*
ES3 - ES1	< 3dB	PASS	
ES2 -SEL IEDS	< 3dB	PASS	
ES3 - MiCOM IEDS	< 3dB	PASS	
CONTINUITY			
EARTHING	< 1.5 Ω	PASS	** all multicore cabling and earth proved continuous*
DC POINT TO POINT	< 1.5 Ω	PASS	
AC POINT TO POINT	< 1.5 Ω	PASS	
NUMBERING			
DC WIRING	N/A	PASS	**all cabling, fibres and panel layout are as per drawing*
AC WIRING	N/A	PASS	**multicore numbers and core ferrull numbers are correct*
OPTIC FIBRE	N/A	PASS	
PANEL LAYOUT	N/A	PASS	
IEDs			
SEL	N/A	PASS	**passed as per ActewAGL procedures*
MiCOM	N/A	PASS	

Appendix G – Cost Evaluation Data

COST EVALUATION - IEC 61850 vs. CURRENT SYSTEMS				
EQUIPMENT COST				
CURRENT SYSTEMS	**UOM**	**NUMBER REQUIRED**	**PRICE PER UNIT**	**TOTAL COST**
ABB - SPAJ Three Phase & Earth Fault Relay	1	20	$1,750.00	$35,000.00
ABB - RAZFE Line Protection Relay	1	2	$6,000.00	$12,000.00
ASEA - Transformer Differential Relay	1	2	$1,400.00	$2,800.00
EMAIL - Busbar Selection Relay	1	20	$200.00	$4,000.00
EMAIL - Sensitive Earth Fault Relay	1	20	$500.00	$10,000.00
GE - Earth Fault Overcurrent Relay	1	20	$600.00	$12,000.00
GE - Three Phase Overcurrent Relay	1	20	$1,450.00	$29,000.00
REYROLE - Busbar Protection Relay	1	1	$800.00	$800.00
INVENSYS - Remote Terminal Unit	1	1	$2,500.00	$2,500.00
TOTAL				$108,100.00
IEC 61850 SYSTEM	**UOM**	**NUMBER REQUIRED**	**PRICE PER UNIT**	**TOTAL COST**
Schweitzer Engineering Laboratories				
SEL-411L - Line Protection IED	1	2	$8,515.00	$17,030.00
SEL-487B - Busbar Protection IED	1	1	$6,830.00	$6,830.00
SEL-487E - Transformer Protection IED	1	2	$6,750.00	$13,500.00
SEL-351S - Feeder Management IED	1	20	$2,550.00	$51,000.00
Schneider MiCOM				
MiCOM P443 - Line Protection IED	1	2	$8,900.00	$17,800.00
MiCOM P643 - Busbar Protection IED	1	1	$6,650.00	$6,650.00
MiCOM P643 - Transformer Protection IED	1	2	$6,650.00	$13,300.00
MiCOM P145 - Feeder Management IED	1	20	$2,300.00	$46,000.00
Other Equipment				
Tekron - TCG 0.2-E GPS Time Clock	1	1	$800.00	$800.00
ABB - RTU560 Remote Terminal Unit	1	1	$2,000.00	$2,000.00
Siemens - RS400 Ethernet Switch	1	6	$1,950.00	$11,700.00
TOTAL				$186,610.00

INSTALLATION COST				
CURRENT SYSTEMS	**UOM**	**NUMBER REQUIRED**	**PRICE PER UNIT**	**TOTAL COST**
Electrical Installation Technician Hourly Wage	1	NA	$40.00	NA
Installation Time Required Per Relay	HOUR	2	$40.00	$80.00
Installation Time Required Per Protection Panel	HOUR	20	$40.00	$800.00
Number of Protection Relays	1	105	NA	105
2.5mm^2 12 Core + Earth Multicore Cable	metre	12,000	$6.50	$78,000.00
TOTAL				$162,000.00

IEC 61850 SYSTEM	**UOM**	**NUMBER REQUIRED**	**PRICE PER UNIT**	**TOTAL COST**
Electrical Installation Technician Hourly Wage	1	NA	$40.00	NA
Installation Time Required Per Device	HOUR	2	$40.00	$80.00
Installation Time Required Per Protection Panel	HOUR	4	$40.00	$160.00
Number of Protection Relays	1	50	NA	50
2.5mm^2 12 Core + Earth Multicore Cable	metre	1000	$6.50	$6,500.00
Dual Core MM Optic Fibre Cable	metre	2232	$2.75	$6,138.00
TOTAL				$20,638.00

COMMISSIONING COST				
CURRENT SYSTEMS	**UOM**	**NUMBER REQUIRED**	**PRICE PER UNIT**	**TOTAL COST**
Electrical Commissioning Technician Hourly Wage	1	NA	$40.00	NA
Commissioning Time Required Per Relay	HOUR	3	$40.00	$120.00
Commissioning Time Required Per Panel	HOUR	18	$40.00	$720.00
Number of Relays Per Substation	1	105	NA	105
Automated Test Plan Set Up	HOUR	4	$40.00	$960.00
TOTAL				$176,400.00

IEC 61850 SYSTEM	**UOM**	**NUMBER REQUIRED**	**PRICE PER UNIT**	**TOTAL COST**
Electrical Installation Technician Hourly Wage	1	NA	$40.00	NA
Commissioning Time Required Per IED	HOUR	1	$40.00	$40.00
Commissioning Time Required Per Panel	HOUR	2	$40.00	$80.00
Number of Relays Per Substation	1	50	NA	50
Automated Test Plan Set Up	HOUR	2	$40.00	$480.00
TOTAL				$28,000.00

ENGINEERING COST				
CURRENT SYSTEMS	**UOM**	**NUMBER REQUIRED**	**PRICE PER UNIT**	**TOTAL COST**
Design Engineer Hourly Wage	1	NA	$80.00	NA
Engineering Time Required Per Relay	1	8	$80.00	$640.00
Number of Relays Per Protection Panel	1	6	NA	$3,840.00
Number of Relays Per Substation	1	105	NA	105
TOTAL				$67,200.00
IEC 61850 SYSTEM	**UOM**	**NUMBER REQUIRED**	**PRICE PER UNIT**	**TOTAL COST**
Design Engineer Hourly Wage	1	NA	$80.00	NA
Engineering Time Required Per IED	1	2	$80.00	$160.00
Number of IEDs Per Protection Panel	1	2	NA	$320.00
Number of IEDs Per Substation	1	50	NA	50
TOTAL				$8,000.00