University of Southern Queensland

Faculty of Health, Engineering and Sciences

An Investigation into the Testing and Commissioning Requirements of IEC 61850 Station Bus Substations

A dissertation submitted by

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Abstract

The emergence of the new IEC 61850 standard generates a potential to deliver a safe, reliable and effective cost reduction in the way substations are designed and constructed. The IEC 61850 Station Bus systems architecture for a substation protection and automation system is based on a horizontal communication concept replicating what conventional copper wiring performed between Intelligent Electronic Devices (IED's). The protection and control signals that are traditionally sent and received across a network of copper cables within the substation are now communicated over Ethernet based Local Area Networks (LAN) utilising Generic Object Oriented Substation Event (GOOSE) messages.

Implementing a station bus system generates a substantial change to existing design and construction practices. With this significant change, it is critical to develop a methodology for testing and commissioning of protection systems using GOOSE messaging. Analysing current design standards and philosophies established a connection between current conventional practices and future practices using GOOSE messaging at a station bus level. A potential design of the GOOSE messaging protection functions was implemented using the new technology hardware and software. Identification of potential deviations from the design intent, examination of their possible causes and assessment of their consequences was achieved using a Hazard and Operability study (HAZOP). This assessment identified the parts of the intended design that required validating or verifying through the testing and commissioning process. The introduction of a test coverage matrix was developed to identify and optimise the relevant elements, settings, parameters, functions, systems and characteristics that will require validating or verifying through inspection, testing, measurement or simulations during the testing and commissioning process. Research conducted identified hardware and software that would be utilised to validate or verify the IEC 61850 system through inspection, testing, measurement or simulations.

The Hazard and Operability study (HAZOP) has been identified as an effective, structured and systematic analysing process that will help identify what hardware, configurations, and functions that require testing and commissioning prior to placing a substation using IEC 61850 Station bus GOOSE messaging into service. This process enables power utilities to understand new challenges and develop testing and commissioning philosophies and quality assurance processes, while providing confidence that the IEC 61850 system will operate in a reliable, effective and secure manner.

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Date

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Robert Peter Accendere

University of Southern Queensland

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

ACSI	Abstract Communication Service Interface
A/D	Analogue to Digital Converter
CB	Circuit Breaker
CBF	Circuit Breaker Fail
CID	Configured IED Description
CT	Current Transformer
CDC	CDC Common Data Class
CIM	Common Information Model
DT	Definite Time
DTRMP	Daily Task Risk Assessment Plan
FMEA	Failure Mode and Effects Analysis
GSE	Generic Substation Event (communication model)
GSSE	Generic Substation State Event (communication model)
GOOSE	Generic Object Oriented System Event (communication model)
HAZOP	Hazard and Operability Studies
HMI	Human Machine Interface
IEC	International Electrotechnical Commission
I/O	Input/Output
ICD	IED Capability Description
IED	Intelligent Electronic Device
LAN	Local Area Networks
LN	Logical Node
LPHD	Logical node “physical device”
LD	LD Logical Device
MAC	Media Access Control
NIT	Network Interface Card
PC	Personal Computer
PD	Physical Device
PED	Programmed Electronic Device
PES	Programmed Electronic System
PSL	Programmable Scheme Logic
RTU	Remote Terminal Unit

SAS	Substation Automation System
SEF	Sensitive Earth Fault
SCL	System Configuration description Language
SCSM	Specific Communication Service Mapping
SSD	System Specification Description
SCD	Substation Configuration Description
VT	Voltage Transformer
VLAN	Virtual Local Area Network
XML	eXtensible Markup Language

List of Standards

Standard	Title
IEC 61850	Communication networks and systems for power utility automation –
IEC 61850-1	Part 1: Introduction and overview
IEC 61850-3	Part 3: General requirements
IEC 61850-4	Part 4: System and project management
IEC 61850-5	Part 5: Communication requirements for functions and device models
IEC 61850-6	Part 6: Configuration description language for communication in electrical substations related to IEDs
IEC 61850-7-1	Part 7-1: Basic communication structure – Principles and models
IEC 61850-7-2	Part 7-2: Basic information and communication structure – Abstract communication service interface (ACSI)
IEC 61850-7-3	Part 7-3: Basic communication structure – Common data classes
IEC 61850-7-4	Part 7-4: Basic communication structure – Compatible logical node classes and data object classes
IEC 61850-8-1	Part 8-1: Specific communication service mapping (SCSM) – Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3
IEC 61850-10	Part 10: Conformance testing
IEC 61850-90-4	Part 90-4: Network engineering guidelines
IEC 62439	Industrial communication networks – High availability automation networks –
IEC 62439-1	Part 1: General concepts and calculation methods
IEC 62439-3	Part 3: Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR)
AS 2067	Substations and high voltage installations exceeding 1 kV a.c.
AS/IEC 61882	Hazard and operability studies (HAZOP studies)—Application guide
AS/IEC 14763.3	Telecommunications installations — Implementation and operation of customer premises cabling. Part 3: Testing of optical fibre cabling
C37.119	IEEE Guide for Breaker Failure Protection of Power Circuit Breakers
C37.233	IEEE Guide for Power System Protection Testing

Chapter 1

Introduction

1.1 Ergon Energy

Ergon Energy supplies electricity across a service area of more than one million square kilometres, which is equal to 97% of the state of Queensland. With a large geographical area comes a large operational and capital cost. The electrical supply industry is under increasing pressure from customers and stakeholders to proactively reduce these costs while providing a safe, reliable and efficient service. Substations play an integral part of the Ergon Energy network and are vital for the distribution of electricity. Substations are essential in providing a connection between power stations, transmission networks, distribution networks and high voltage customers. Substations have two categories of plant, primary plant and secondary systems. Primary plant is equipment that is connected directly to the high voltage network such as high voltage switchgear, power transformer, circuit breakers, and voltage and current transformers. Secondary systems are equipment used to protect, control and monitor the primary plant and high voltage feeders leaving or entering the substation. These are typically protection relays, control and SCADA systems, metering schemes and power quality systems. One of Ergon Energy's strategies is focusing on technological innovation to reduce the operational and capital expenditure for substation infrastructure. Any technology change that can potentially deliver a safe, reliable and effective cost reduction in the way substations are designed, constructed, tested, commissioned and during its operation life warrants further investigation.

1.2 Background

Protection relay and protection schemes play an integral part of Ergon Energy's secondary systems. The protection relay function is to detect faults or abnormal operating states on the power system and to disconnect the faulted equipment and loads in a reliable and timely manner. The consequences of inadequate protection at any level of the power system can result in major damage, injury or loss of life, and disruptions to the security and reliability of supply of the network. There have been enormous changes in protection relay technology over the last fifty years. Electromechanical relays were the first type of protection relays that operated on the principle of a mechanical force causing operation of a relay contact in response to a stimulus. The mechanical forces are generated through current flow in one or more windings on a magnetic core (Alstom Grid, 2011). All of the protection tripping and backup functions of the protection scheme were performed by additional auxiliary relays and circuitry. Figure 1 illustrates an electromechanical distance relay.

Figure 1: Electromechanical Distance Relay (Brown Boveri LZ32)

In the early 1960's electromechanical relays were eventually replaced with static relays which eliminated the use of moving parts and their design was based on the use of analogue electronic devices and discrete devices such as transistors and diodes in conjunction with resistors, capacitors, inductors. In the 1980's digital protection relays were developed and the change in technology introduced microprocessors, microcontrollers and A/D conversion for all measured analogue magnitudes and to implement and perform protection algorithms and digital logic. Manufacturers of these relays introduced proprietary communication protocols used to communicate between the protection relays and the manufacturers controls systems. With the introduction of this additional technology, introduced challenges with designing of substations, where only proprietary manufacturer's hardware could be used or additional media converters were required. In the early 1990's numerical protection relays were developed due to advances in digital signal processor (DSP) technology and specialised microprocessors that enabled functions and mathematical algorithms to be processed at optimum speeds. With each change in the relay technology brought a reduction in the size of the protection relay and an improvement in functionality and reliability due to their superior microprocessors and self-monitoring functions. This enabled designers to reduce the required auxiliary relays and circuitry within the protection schemes and allowed these functions to be engineered within the protection relay. During these significant technological advances in protection relaying all of the analogue signals from the current and voltage transformers and binary input and output signals used to connect the substation protection schemes were achieved by the use of copper wiring. Figure 2 illustrates typical protection and control IED's

Figure 2: Protection & Control IEDs

Testing and commissioning plays a significant role in the safe and reliable operation of a substation. The testing and commissioning process are designed to ensure plant or secondary systems operate in accordance with its design specifications prior to operation. This process allows confirmation that plant or equipment have been constructed and installed correctly, configurations of electronic devices are as intended and systems operate as an integrated system. The testing and commissioning philosophies and practices for protection relays and their associated schemes have not greatly changed over the last 50 years. Initial protection relay testing for electromechanical or static relays were aimed at detecting incorrect ratings and setting(s), inaccurate performance or failure in a protection element. This detection was achievied by injecting secondary voltages and currents into the protection relay and confirming its contact outputs operated as per the design intent. This was a reflection of the relay's use of analogue signals, its variability or failure on a single phase basis and its rudimentary self-supervision functions (Stevens, 2009). The introduction of digital and numerical relays brought flexibility and expansion in the way the protection relay could be configured. The configuration of flexible logic and increase in protection functions developed an increase in the number of test performed on the protection relays. A similar process was applied by injecting secondary voltages and currents into the protection relay and confirming its logic and settings and it associated I/O operated as per the design. The use of automated test equipment with smart configurations allowed testing and commissioning personnel to perform advance simulations on the protection relays. Even to the extent of proving the mathematical algorithms used to imitate the protection characteristics. All of the copper wiring between the secondary systems was point to point tested and testing of the integrated protection system was completed prior to placing the plant into service.

1.3 Emergence of a New Technology

1.3.1 Background of the IEC 61850 Standard

In 1986, the Electrical Power Research Institute (EPRI) launched the Utility Communication Architecture (UCA) project. The objective of this project was to decrease the expenditure in substation automation systems (SAS) and the integration of an open architecture and a selection of standard protocols that will meet the engineering requirements of power utilities and accepted by substation automation systems (SAS) manufacturers. In 1995, the International Electrotechnical Commission's (IEC) initiated a project called 61850. This project was designed to define the next generation of standardized high-speed substation control and protection communications. The main objective of this project was to develop a standard for communications infrastructure for substation control, monitoring and protection with input from both substation automation systems (SAS) manufacturers and power utilities. In 1996, both EPRI and the IEC 61850 develop groups were independently developing their individual standards to address the interoperability of different manufacturers IED's in substation protection and automation systems. In 1997, the ERPI joined forces with the International Electrotechnical Commission's (IEC) Technical Committee 57 (TC57) to build a single worldwide accepted standard. The objectives of the standard are:

- Provide interoperability between IED's from different manufacturers
- IED's self-description capabilities and communication parameters
- High speed communication for the required applications
- Reduction in conventional wiring in the substation.
- Conformance testing requirements for IEC 61850 IED's

1.3.2 IEC 61850 Standard Systems Architecture

The IEC 61850 standard defines the required systems architecture for a substation protection and automation system. The standard defines three levels for representation of functions and communication interfaces within the substation and between substations. This is illustrated in Figure 3.

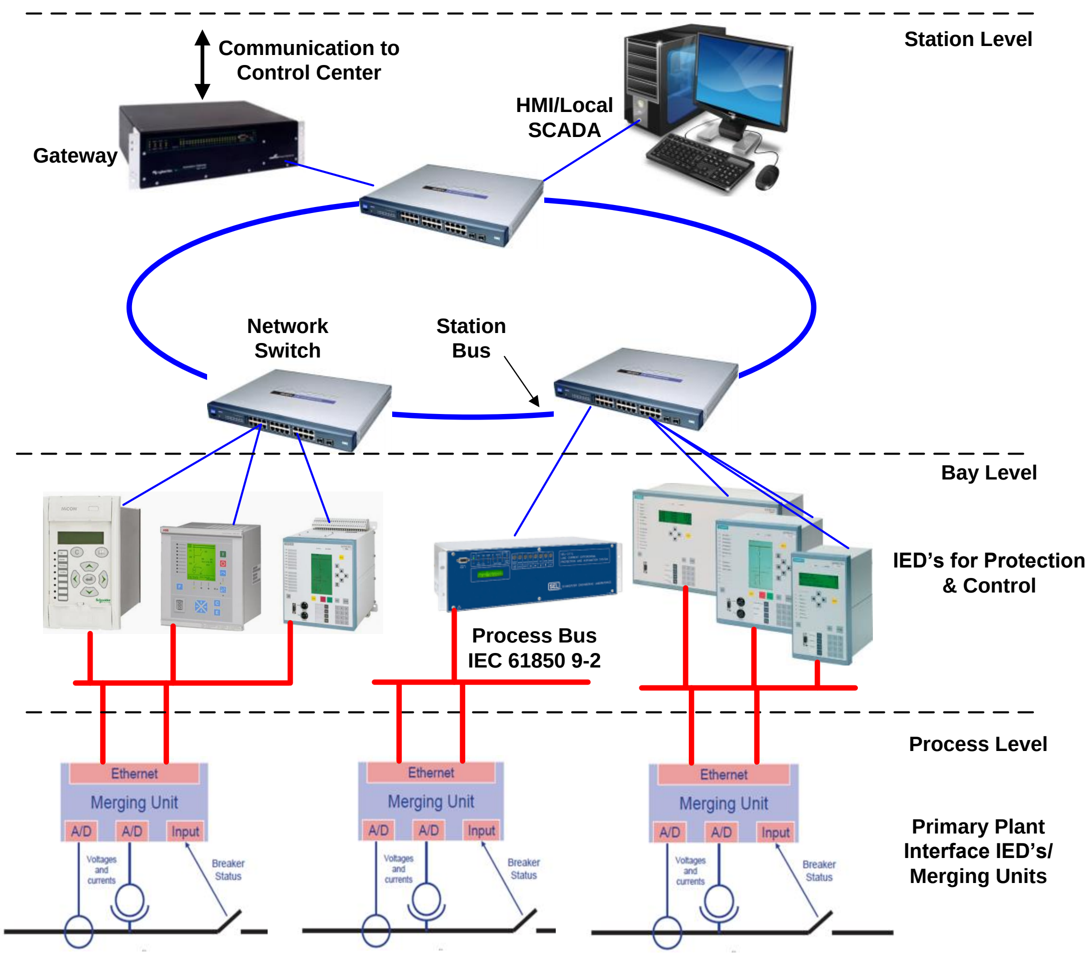

Figure 3: Architecture of an IEC 61850 System

The Station Level devices consist of the substations remote gateway, Human Machine Interface (HMI) and remote interrogation station. Within the substation control status, process and supervisory control data and monitoring data is exchanged between the Bay/Unit Level and Station Level. The Station Level communications and exchanges control, status and monitoring data between the substation and control centre.

The Bay Level devices consist of protection, control and monitoring IED's. These devices are connected to the Station Level (via the station bus) and Process Level (via the process bus) using Ethernet based Local Area Networks (LAN) and Ethernet switches. The station bus exchanges data within the bay level that can be used for protection, control status, process and supervisory control data and monitoring data. The station bus can also be used to interface between substations for exchange of protection and control data. GOOSE messaging can be utilised on the station bus for fast reliable control and time critical protection applications between bay level IED's.

The Process Level devices consist of remote I/O's, non-conventional instrument transformers and intelligent sensors and control units from switchgear, transformers and monitoring devices. These devices are connected to the bay level via the process bus. The voltage transformers (VT) and current transformers (CT) that are connected to the process bus are connected via an IED called a “Merging Unit”. This is illustrated in Figure 4. The Merging Units samples the conventional CT and VT analogue outputs and converts the values to a digital signal referred to as “Sample Values”. The Merging Unit digital output is defined in IEC 61850-9-2.

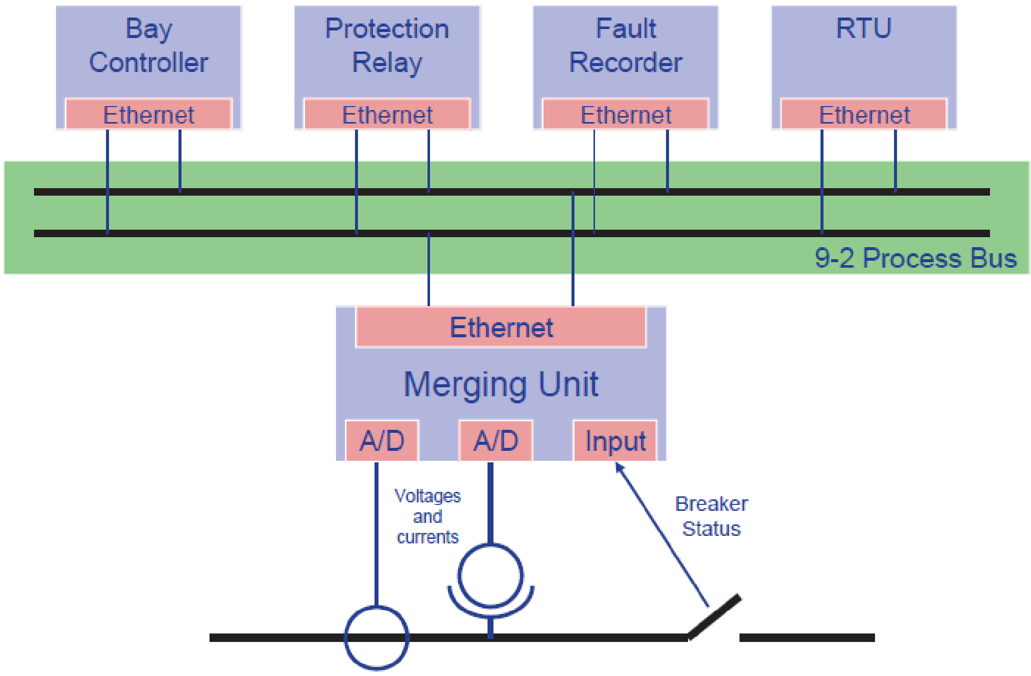

Figure 4: Typical IEC 61850 Process Level System (Tournier & Werner, 2010)

1.3.3 Advantages & Disadvantages of IEC 61850 Standard

There are a number of advantages and disadvantage of using the IEC 61850 standard in substation protection and automation systems. The advantages of using such systems have been highly publicised by IED manufactures, while the disadvantages can only be compared with current substation protection and automation systems. Table 1 provides an overview of the advantages and disadvantages of using IEC 61850.

ADVANTAGES
A reduction of copper cabling and wiring between the substation primary plant and secondary systems
An increase in functionality in a single IED and a reduction in auxiliary relays.
A reduction in relays and wiring allows for additional space inside of the substation
Interoperability between IED’s from different manufactures
A reduction in the substation footprint with the use of fibre optic sensors (NCIT) instead of conventional measuring transformers
A decrease in electrical interference of signal using fibre optic cables
GOOSE signals are supervised, where equivalent hard wired signals between IED's provide no or limited supervision of connection. The subscribing IED's monitor the GOOSE message from the publishing IED. An IED failure or network failure will result in the subscribing IEDs enabling a GOOSE failure alarm.
An increase in safety since there will be no risk of inadvertent opening of current transformer secondary circuits while they are in service.
Simplified engineering process with the use of the substation configuration language and standard system configuration tools and decrease in manual configurations. A decrease in circuitry design.
DISADVANTAGES
Initial increase in cost to develop new substation design and protection standards for the company.
An increase in Cyber security threats due to the increase use of communication networks
A loss of communication or data on the process or station bus may delay or prevent the operation of protection function.
A huge change in the skill sets on personnel that design, construct and test substation protection and automation systems

Table 1: Advantages and Disadvantages of using IEC 61850

1.4 Project Justification

Majority of the time new technology is introduced into the system with the concept of increasing safety and reliability while reducing operational and capital expenditure. The emergence of the new IEC 61850 standards brings this potential saving in the design and construction of a substation. On site testing and commissioning plays, a critical role in ensuring that the substation protection schemes meet their intended design and the systems operate as an integrated system prior to operation. Due to the significant change in the way an IEC 61850 substation and automation system is designed and constructed with the potential of having no copper wiring between the primary and secondary systems, current testing and commissioning philosophies and practices need to be reviewed. A full understanding of the new SAS systems hardware, configurations, functions and the requirements, if any to validate or verify the intended design through inspection, testing, measurement or simulations during the testing and commissioning process is essential. This is more relevant than ever before since the protection systems have changed from an electromechanical relay to a digital relay with conventional analogue inputs and binary I/O using copper wiring to digital software based and communication network orientated protection schemes. Only a structured and systematic analysing process will help identify what hardware, configurations, and functions that require testing prior to commissioning a substation using IEC 61850 Station bus GOOSE messaging.

1.5 Project Objectives

The aim of this project is to investigate and provide a better understanding of the methods and technical requirements to safety, reliably and efficiently test and commission and place in service a substation using IEC 61850 Station bus GOOSE messaging. This will provide a future reference and reasoning on what and why certain functions and components of a protection system using GOOSE messaging are tested and commissioned.

The key objectives of this research project are as follows:

1. To carry out a literature review relating to the IEC 61850 and IEC 62439 standards, Current Safety Legislations and National Electricity Rules regarding testing, commissioning and operating a substation, Current standards and technical papers and case studies written regarding the testing and commissioning of an IEC 61850 station bus substations. A literature review on risk assessment methodology of highly dependable software based systems and programmed electronic systems to identify potential systems that could be used to analyse the IEC 61850 station bus system validation and verification requirements.

2. Identify the configuration tools, test equipment and software used for the design, testing and commissioning of an IEC 61850 station bus substation using GOOSE messaging.
3. Analyse the protection functions that could potentially be used in the implementation of an IEC 61850 station bus substation and the test required for verifying associated IED's logic/protection functions that uses the GOOSE messaging.
4. Analyse the site integration test required for verifying the station bus network, protection inter-tripping schemes. Investigate the protection isolation requirements for an operational IEC 61850 station bus substation using GOOSE messaging.
5. Analyse IED's logic/protection functions that uses the GOOSE messaging within an IEC 61850 station bus substation against conventional protection relay logic/protection functions.
6. Develop a substation utilising IEC 61850 station bus GOOSE messaging and examine the methods, practices and technical requirements for testing an IEC 61850 station bus substation.

1.5.1 Resource Requirements

There are a number of resources required to complete this project. Majority of the resources will be essential for the testing of the IED's and the station bus network. Due to the expense of the IEC 61850 hardware and software, only a small network with limited IED's will be setup. The hardware (IED's & Ethernet Switches) for the project have been provided by Ergon Energy substation standards group and IED manufacturer Schneider. The system and IED configuration tool used for the development of the IED Files (SSD, ICD, SCD, CID) will be provided by Schneider. This tool is currently a BETA version of their SET system configuration tool. The IEC 61850 compatible secondary injection test set, test leads and interface software will be provided by Ergon Energy's test section. Ergon Energy's protection group will provide the manufacturer IED configuration tools. Ergon Energy's Substations standards group will provide the network analysing software and tools for examining the station bus GOOSE traffic. Below is a breakdown of the required hardware and software.

Required Hardware:

- IED's. (2 x Micom P142, 1 x Micom P642, 1 x P746, 1 x P140)
- 2 x 2520 CISCO Communication Switches
- Fibre Optic Cable for connection between IED's and Switches
- Doble Test Set & Test Leads
- Laptop and required serial leads for communication to IED's

Required Software:

- Schneider's System Configuration Tool SET (BETA Version)
- Micom S1 studio
- Doble Protection Suite & IEC61850 GSE 3.2 Configurator Tool
- Wireshark software

Chapter 2

Literature Review

This chapter will provide the findings of a Literature Review that is aimed to increase the knowledge and understanding in the following areas.

- Current Safety Legislations and National Electricity Rules that Network Service Provider and/or electricity entities need to follow for testing, commissioning and operating a substation.
- Relevant parts of the IEC 61850 standard regarding the communication principles, communication structure (functions and models), GOOSE messaging, and Substation Configuration Language.
- Communication technologies and topologies used in an IEC 61850 protection and automation system and IEC 62439 *Industrial communication networks – High availability automation networks,* in particular part 3 of the standard that defines the implementation of redundancy protocols for critical network systems.
- Current standards and technical papers and case studies written regarding the testing and commissioning of an IEC 61850 protection and automation system using station bus.
- Risk assessment methodology of highly dependable software based systems and programmed electronic systems.

2.1 Safety Legislations and Rules

The following Queensland legislations and National Electricity Rules were reviewed to determine the requirements by law on the requirements in testing and commissioning of a substation protection and control system and during its operational life.

- Queensland Electrical Safety Act 2002
- Queensland Electrical Safety Regulation 2013
- Electrical Safety Code of Practice 2013
- Queensland Work Health and Safety Act 2011
- Queensland Work, Health and Safety Regulation 2011
- National Electricity Rules version 61
- AS 2067 Substations and High Voltage Installations exceeding 1 kV A.C

The review identified that the National Electricity Rules states that a Network Service Provider like Ergon Energy must institute and maintain a compliance program to ensure the proper operation of protection systems and control systems that may affect power system security and the safe and reliable operation of equipment (AEMO, 2015). The Queensland Electrical Safety Act 2011 states that electricity entity like Ergon Energy has a duty to ensure that its works are electrically safe and operate in a way that is electrically safe. These duties include the requirement that the electricity entity inspect, test and maintain these works (Electical Safety Act, 2002).

The current revision of AS 2067-2008 section 9 provides the minimum requirements for the inspection and testing of Substations and High Voltage Installations exceeding 1 kV A.C. The standard recommends that verification should be achieved utilising visual inspection, functional tests and measuring. The standard does not provide any specific details or recommendations on testing and commissioning of protection schemes utilising IEC 61850. The standard recommends that functional test, verification of settings and circuitry and programming, verification of operation and configuration by measurement or testing of protective, monitoring, measuring and control devices should be carried out prior to service (Australian Standard - AS 2067, 2008).

2.2 IEC 61850 Standard

2.2.1 IEC 61850 Communication Structure – Functions and Models

The IEC 61850 standard defines information models and the modelling methods to ensure the open exchange of information between any of the substation IED's. The IEC 61850 information model is based on two levels of modelling. The first is the breakdown of a physical device (IED) into a logical device (LD), second is the breakdown of the logical device into logical nodes (LN), data objects, and attributes. The logical devices provide information about the physical devices they use as host. The physical device (IED) is connected to the network by a network address. The IED's hardware health and communication problems are modelled at the physical device level. The logical device represents a group of typical protection and automation functions within the IED. To achieve interoperability amongst IED's, common functions in a power utility automation system have been identified and have been split into sub-functions known as logical nodes. The IEC 61850-7 series defines a collection of standard logical nodes, object classes and attributes used for protection, control, monitoring, measurement and power quality systems. Figure 5 shows an example of the IEC 61850 data model. In this example the logical device has two logical nodes. Logic node MMXU1 is defined in IEC 61850-5 as a 3 phase measurement logical node used for calculation of currents, voltages, powers and impedances in a three phase system. The data object (TotW) for the LN is modelled in IEC 61850-7-4 as a measured and metered total active power value. Logic node XCBR1 is defined in IEC 61850-7-4 as a switch with short circuit breaking capability. The data object (Pos) for the LN is used to indicate the circuit breaker position. The data attribute indicates Boolean status of the circuit breaker and quality and time stamp of the bit.

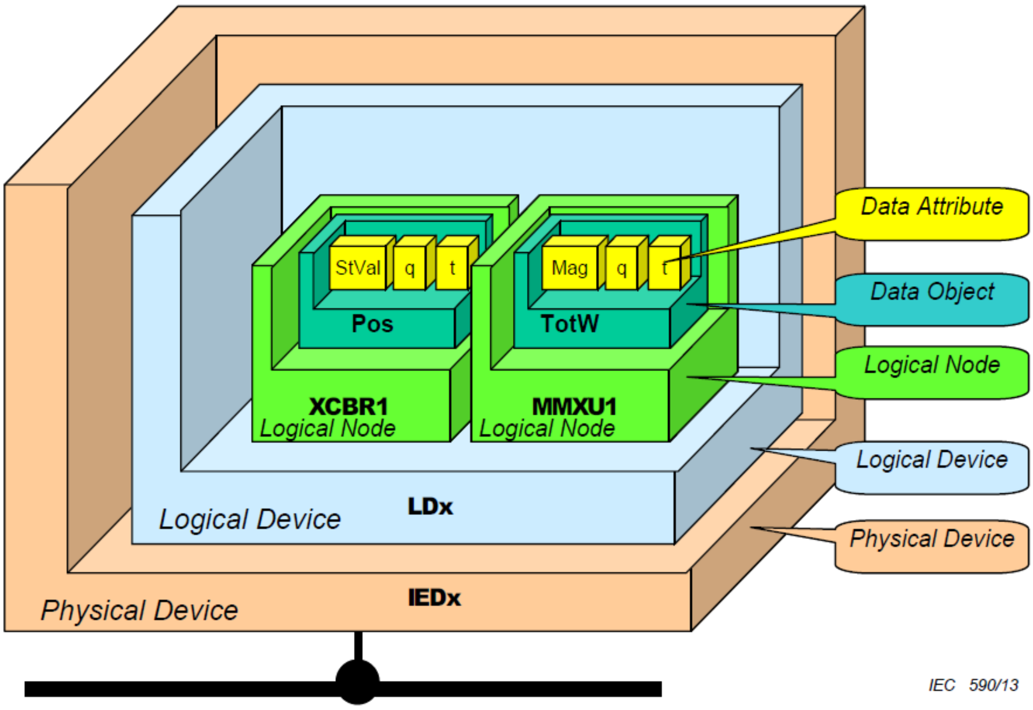

Figure 5: IEC 61850 Data Modelling (International Electrotechnical Commission, 2013)

IEC 61850-5 defines two special logic node modelled under LPHD and LLN0. Logical node “physical device” (LPHD) is a logical node that does not refer to any function but to the IED. LPHD is used to model common features of the IED, which include the IED physical name plate and device health. Logical node LLN0 describes common functionality of the logic device such as data sets, report control blocks, GOOSE control blocks and setting group control blocks.

2.2.2 IEC 61850 Communication Principles

The IEC 61850 standard communication stack and model mapping provides an important role in achieving interoperability between IED’s from different manufactures. The standard is built on services that are mapped to concrete communication protocols. There are three types of communication models used in the IEC 61850 standard. The Client/Server type communication services model are used for exchanging non-time critical real time data such as monitoring and control services between IED’s in substation automation systems (SAS). The publisher-subscriber model is the second model, which is used for critical fast and reliable system-wide distribution of data. The GOOSE control class is defined in this model and is used for fast protection tripping between IED's. The third model is Sample Values (SMV) model for multicast measurement values. This model is used for exchanging time critical voltage and current data on to the process bus. Figure 6 illustrates the IEC 61850 communication model and communication stack according to the ISO/OSI model. The Client/Server type communication service uses MMS (Manufacturing Message Specification) at the Application (layer 7), Presentation (layer 6) and Session (layer 5) layers. The Transport (layer 4) and Network (layer 3) layers use TCP/IP while the Link (layer 2) and Physical (layer 1) layers uses Ethernet. The GOOSE and Sample Values (SMV) model are mapped directly to the Link (layer 2) and Physical (layer 1) layers using Ethernet to enable time critical data transfer.

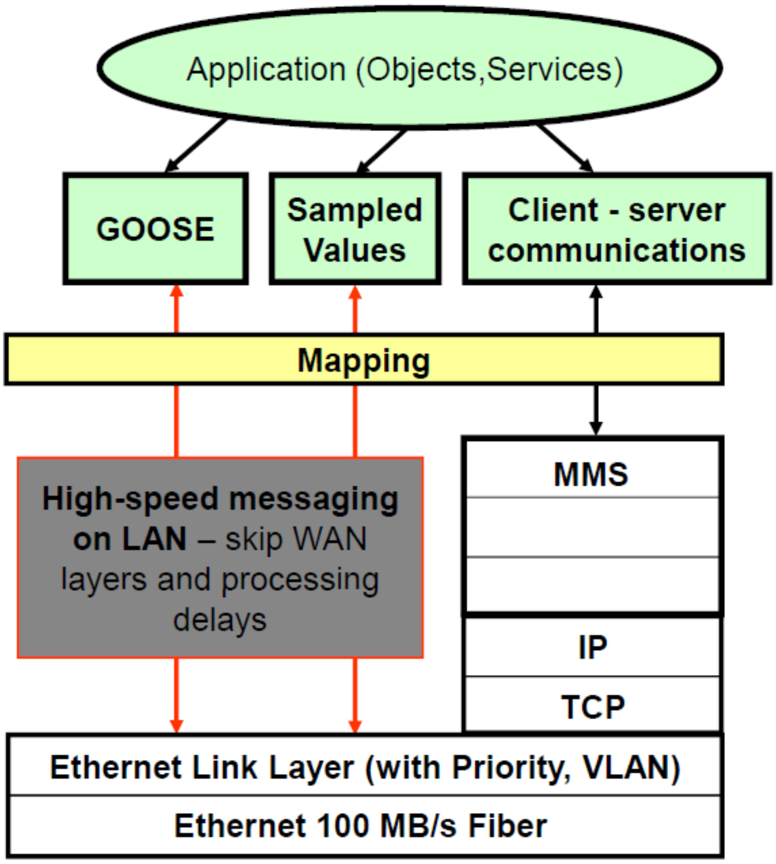

Figure 6: IEC 61850 Communication model and communication stack (Midence & Iadonis, 2009)

The IEC 61850-7-2 standard defines a set of abstract communication services (Abstract Communication Service Interface services – ACSI) which details the required actions on the receiving and sending of a service request. This allows for compatible exchange of information between IEDs on substation automation systems (SAS). Part 8 of the standard specifies the method for exchanging time critical and non-time critical data through LANs by mapping the ACSI to MMS (Manufacturing Message Specification) and ISO/IEC 8802-3 frames. Services and protocols of the TCP/IP T-Profile client/server are detailed in Part 8 of the standard. The direct mapping on Ethernet is detailed in Part 9-2 of the standard.

2.2.3 GOOSE Overview

2.2.3.1 What is GOOSE

Generic Object Oriented Substation Event (GOOSE) messages were develop as part of the standard for fast reliable control and protection applications. The GOOSE messaging is based on a publisher-subscriber model where the GOOSE message is broadcasted on a multicast Media Access Control (MAC) address by the publisher IED and the subscribing IED’s listen for messages that are of interest. The model was constructed under the concept of decentralized and autonomous distribution. This process would ensure any equipment, independently of its location can provide a GOOSE message delivery simultaneously to more than one host on a Local Area Network (LAN), using multicast (Oliveira, et al., n.d.). The GOOSE messaging is based on a horizontal communication concept replicating what conventional copper wiring performed between IED’s. The protection and control applications that were traditionally sent and received across a network of copper cables are now communicated over Ethernet based Local Area Networks (LAN). Time critical protection functions like protection inter-tripping, primary plant interlocking and status indications, auto-reclosing and trip signals can now be implemented and achieved using GOOSE messaging.

2.2.3.2 Generic Substation Event (GSE) Model

IEC 61850-7-2 defines the generic substation event (GSE) model, which provides the possibility for a fast and reliable system-wide distribution of input and output values to more than one physical device through the use of multicast/broadcast services (International Electrotechnical Commission, 2010). The GOOSE message uses the GSE model. The GOOSE messaging supports the exchange of common data organized by a dataset. GOOSE messages have the ability to support both binary and analogue data values. The abstract data classes and services of the GOOSE model are illustrated in Figure 7. If a substation event occurs in a publishing device the value of one or several Data-Attributes of a specific functional element in the Data-Set changes state, the transmission buffer of the publisher is updated through the local service “publish.req” and all values are transmitted with a GOOSE message (International Electrotechnical Commission, 2010). Specific mapping services of the communication network allow the subscriber’s buffers content to update automatically. When new values are received in the reception buffer they are forwarded to the relevant applications in the receiving device. The GOOSE message contains information that enables the subscribing device to know that a status has changed and the time of the last status change. This allows the subscribing device to set local timers relating to a given event. Due to the nature of the multicast scheme and the absence of the addressing layer for the straight mapping of the GOOSE message, there is no confirmation by the subscriber that the GOOSE message has been received successfully.

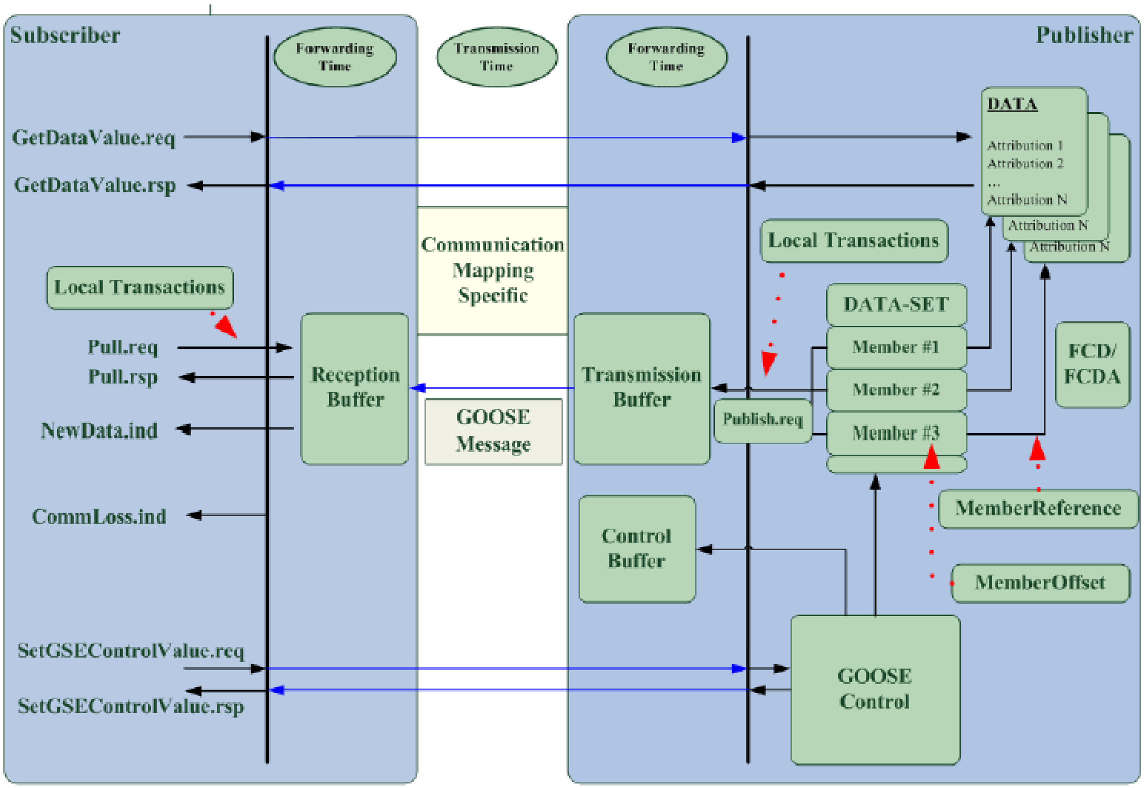

Figure 7: GOOSE Model (Zhang & Nair, 2008)

To improve the reliability of the GOOSE message, IEC 61850-8-1 defines the requirement for a scheme for retransmission of the GOOSE message. This is illustrated in Figure 8.

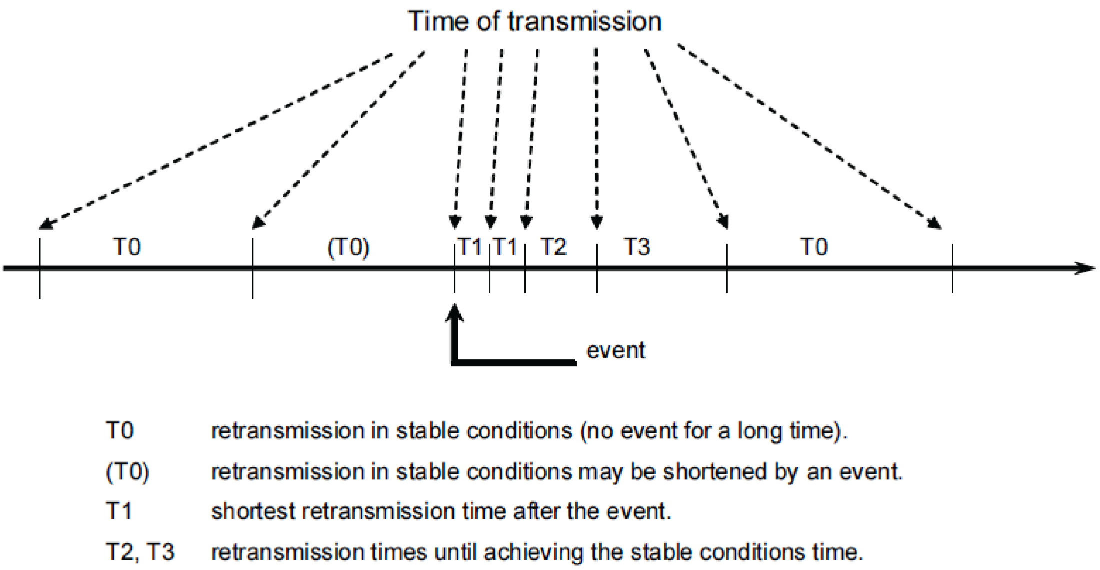

Figure 8: GOOSE Retransmission Scheme (International Electrotechnical Commission, 2011)

The retransmission scheme constantly resends the GOOSE message on to the network at the "time allowed to live" parameter time (T0). The "time allowed to live" parameter advises the receiving IED of the maximum time to wait for the next re-transmission. If the receiving IED does not receive the message in the retransmission time, the IED assumes that the message is lost. If an event occurs in a relay and there is a state change in the dataset, the stable condition retransmission time will be shortened ((t0)) and the “time allowed to live” time is shorted (T1). This allows for a rapid spray of GOOSE messages onto the network. After this short burst of messages, the retransmission time increases gradually until it reaches its configurable value (T0). Although this scheme enables an increase in reliability due to the increased frequency of the message during an event, the scheme does increase the amount of traffic on the network after a significant event (Oliveira, et al., n.d.).

2.2.3.3 GOOSE Message Frame

IEC 61850-8-1 defines the structure of the GOOSE message that allows for multicast messages across the substation LAN. Figure 9 illustrates the GOOSE message frame as per IEC 61850-8-1 Ed1.

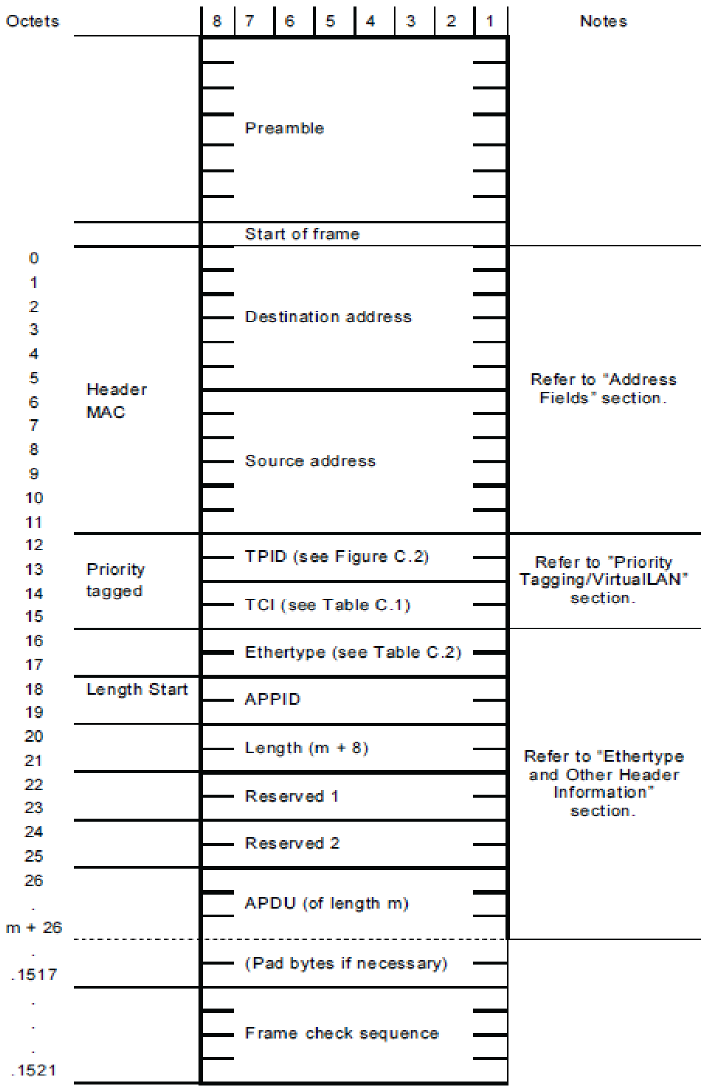

Figure 9: GOOSE message frame as per IEC 61850-8-1

The following details the GOOSE message frame and configurable IED dataset parameters that are used within the GOOSE message frame as per IEC 61850-8-1. The GOOSE message syntax found in the GOOSE APDU is defined in IEC 61850-7-2.

1. **Header MAC**

   The Destination Address is a Multicast MAC address that has to be configured for the transmission of GOOSE. This is defined in the standard as 01-0c-cd-xx-xx-xx.

   The Source address is the MAC address of the sending IED Ethernet card.

2. **Priority Tagging/Virtual LAN:** Priority tagging is used to separate time critical and high priority bus traffic for critical protection applications from low priority bus load (according to IEEE 802.1Q).

   TPID (Tag Protocol Identifier) Field: Is a 2-byte field identifies the frame as a tagged frame. For Ethernet, the value of this field is 0x8100.

   TCI (Tag Control Information) Fields: Is a 2 byte field used to carry priority information, the virtual LAN identifier (VID) and a canonical format indicator. The user priority information value shall be set by configuration to separate sampled values and time critical protection relevant GOOSE messages from low priority busload. If the priority is not configured, then the default values of 4 shall be used. The virtual LAN identifier is an optional configuration and is set to uniquely identifiers the VLAN to which the frame belongs. VID is set to zero if it is not set by the configuration. CFI (Canonical Format Indicator): BS1 [0]; a single bit flag value. For this standard the CGI bit value shall be reset (value = 0).

3. **Ethernet - PDU:**

   Ethertype is based on ISO/IEC 8802-3. The standard defines GOOSE shall be directly mapped to the reserved Ethertype(s) and the Ethertype PDU. The assigned value is 0x88B8.

   APPID: The application identifier is used to select ISO/IEC 8802-3 frames containing GOOSE messages and to distinguish the application association. The value of the APPID type for a GOOSE message is defined in the standard as the two most significant bits of the value. The assigned value for GOOSE is 00. The actual ID has configurable reserved value range for GOOSE, which is 0x0000 to 0x3FFF.

   Length: Number of octets including the Ethertype PDU header starting at APPID, and the length of the APDU (Application Protocol Data Unit). Therefore, the value of

Length shall be 8 + m, where m is the length of the APDU and m is less than 1492. Frames with inconsistent or invalid length field shall be discarded.

4. **GOOSE APDU:**

State Number (stNum): Is a counter that increments if a GOOSE message is generated as a result of an event change within a dataset.

Sequence Number (sqNum): Is a counter that increment if a GOOSE message has been sent.

Test/Simulation: This Boolean value is used for testing and simulation purposes. A true value indicates that the device is in test mode and the subscribing devices will not use the GOOSE message for operational purposes because the message has been published from a simulation unit.

Time Allowed to Live (TAL): This is the maximum time a packet remains alive on the network after transmission.

Needs Commissioning (NdsCom): This value is set to true if the GoCB requires further configurations and the GOOSE message is invalid.

Configuration Revision (confRev): This value represents a count on the number of times the Data-Set configuration has changed. The IED is responsible for incrementing this parameter and is an attribute of ConfRev of the GoCB.

Number of Data-Set Entries (numDatSetEntries): This value indicates the number of data present in the received GOOSE message.

GOOSE Control Block Reference (GoCBRef): This parameter details the name of the referenced GOOSE control block (GoCB).

Data-Set (DatSet): This parameter contains the object reference attributes (name) of GOOSE Data-Set identification in the publishing IED and the Logic Node (LN).

GOOSE ID (GoID): This parameter is a user definable identification of the GOOSE message.

Timestamp (t): This value contains the time at which a GOOSE message is generated as a result of an event change within a dataset.

GOOSE Data (GOOSEData): This parameter contains the information defined in the dataset members that will be sent by the GOOSE message.

2.2.3.4 GOOSE Transfer Times

IEC 61850-5 defines the transfer times, message type and performance classes for a GOOSE message. The GOOSE transfer time of a message is specified as the complete transmission time from one physical device transmission stack (coding and sending) to another physical device transmission stack (receiving and decoding). This overall transmission time consist of the individual times of the stack processing (t_a, t_c) and of the network transfer time (t_b). The network transfer time (t_b) includes waiting times and time delays caused by routers and other active communication devices being part of the complete communication path (International Electrotechnical Commission, 2013). The transfer time does not include the sending and receiving processing time of the functions (f_1 & f_2). Figure 10 illustrates the described GOOSE transfer times.

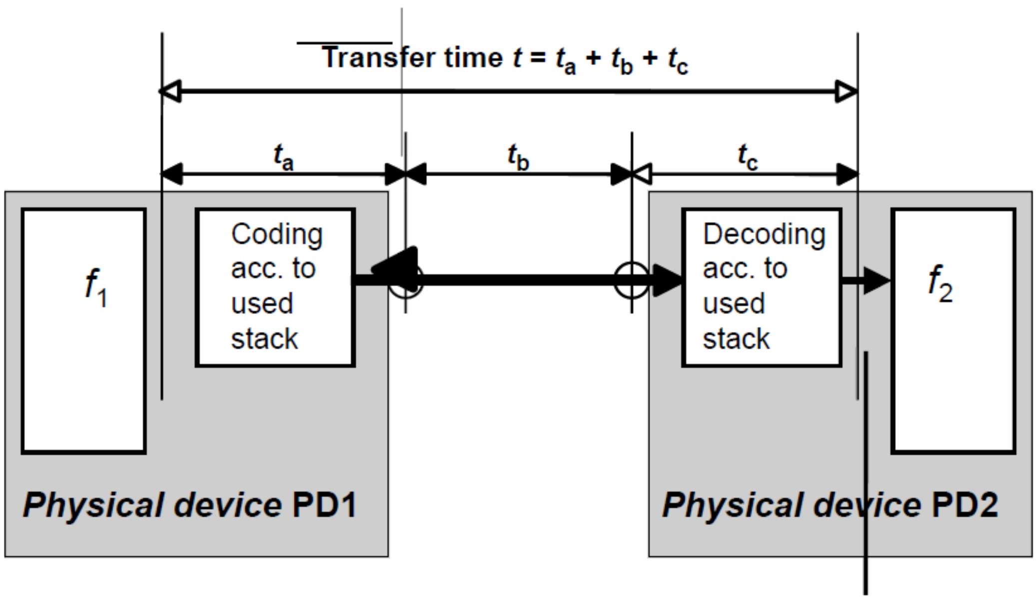

Figure 10: GOOSE Overall Transfer Time as defined in IEC 61850-5

IEC 61850-5 describes seven classes for transfer times. The GOOSE messages use the Type 1 – Fast messages performance class P1, P2 and P3. This type of message is used for time critical functions like protection. Type 1 messages contain simple messages such as “Trip”, “Block”, “Unblock”, and “Close”. The IED receiving the message will enable its related function to immediately operate, ensuring critical protection times are achieved on the network. The Type 1A “Trip” performance class P1 and P2 are used for protection trip messages in the substation. Type 1A messages are also used for interlocking, inter-trips and logic discrimination between protection functions. Table 2 details the Type 1A “Trip” message transfer times as per IEC 61850-5.

Performance Class	Requirement Description	Transfer Time	
		Class	ms
P1	The total transmission time shall be below the order of a quarter of a cycle (5ms for 50HZ)	TT6	≤ 3
P2	The total transmission time shall be below the order of a half of a cycle (10ms for 50HZ)	TT5	≤ 10

Table 2: "Trip" message transfer times as per IEC 61850-5.

2.2.4 Substation Configuration Language

To provide interoperability between IED's from different manufactures, a standardized support for system design and communication engineering was required. IEC 61850 part 6 specifies a file format for describing communication-related IED configurations and IED parameters, communication system configurations, switch yard (function) structures, and the relations between them (International Electrotechnical Commission, 2009). This file format enables the exchange of the IED capability descriptions and substation automation system (SAS) description between IED engineering tools and the system engineering tools. The language used to support the exchange of these capabilities and descriptions is called the System Configuration description Language (SCL). The SCL language is based on eXtensible Markup Language (XML) and the describing of the IED configurations and substation automation system (SAS) is achieved according to IEC 61850-5 and IEC 61850-7. There are four types of SCL files defined under the IEC 61850 and each SCL file contains the following part, which is, defined under IEC 61850-6 clause 9.

Clause 9.1: A header that is used to identify an SCL file and its version/revision history.

Clause 9.2: The substation description section in the SCL file is used to define the functional structure of a substation and to identify the primary device and their electrical connections.

Clause 9.3: The IED description section describes the pre-configuration of an IED. The description contains the IED communication services, access points, logical devices and logical nodes.

Clause 9.4: The communication system description section describes the communication connection between IED access points and common subnetwork or logical busses.

Clause 9.5: The Data type templates contains the instantiable template of the data of a logical node that is built from data object elements.

The four different SCL files (SSD, SCD, ICD, CID) and configurators defined under the IEC 61850-6 standard is implemented in different stages of the designing and configuration process of the substation automation system (SAS). This Engineering process is illustrated in Figure 11.

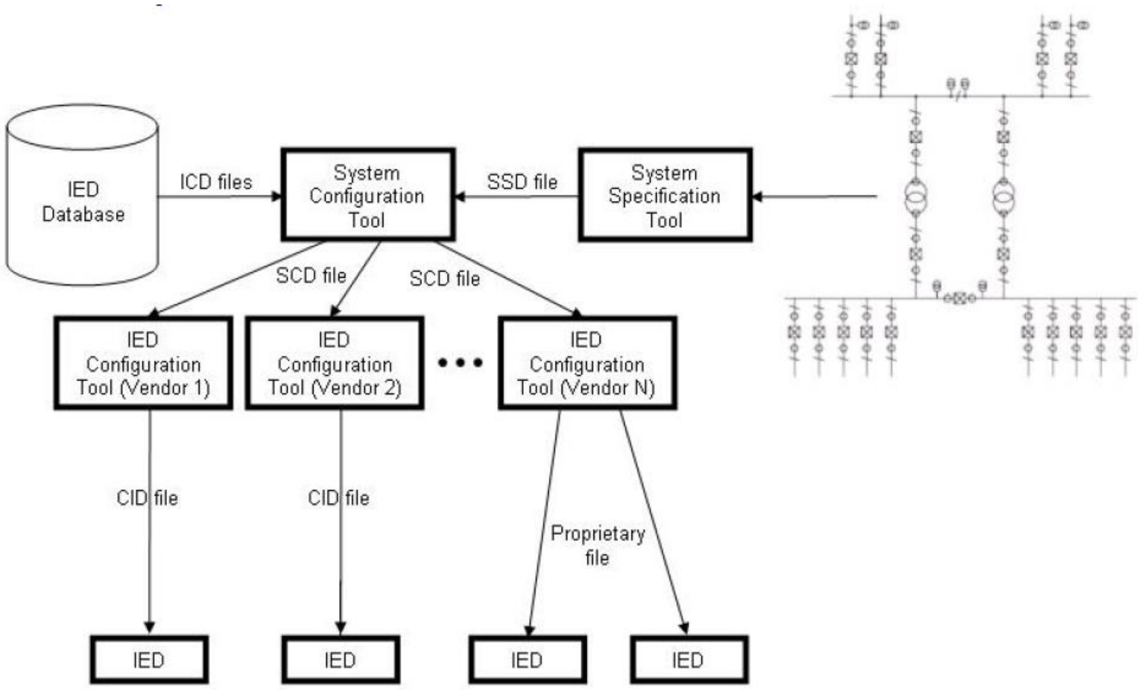

Figure 11: SCL Engineering Process (Apostolov, 2010)

The first step of the engineering process is the use of the system specification tools. This tool enables the user to describe the substation protection and automation system. This includes the substation single line diagram and the functional requirements represented by logical nodes (Apostolov, 2008). The SCL file created from the system specification tools is a system specification description, which has an .SSD file extension. The next step in the process is to create an IED Capability Description (ICD) file for each IED that will be connected to the substation protection and automation system. This is achieved using an IED configurator tool and is normally a manufacturer's proprietary software tool. The ICD file contains the default functionality of an IED and the information on the capabilities and data model of each individual IED. The IED description contains communication services related capabilities of the IED, the configurator related capabilities of an IED (Data sets or control blocks) and the functionality and data objects in terms of logic nodes and contain data objects (Wimmer & Wolfgang, 2005). The ICD file is imported to the system configuration tool. The system configuration tool is used to import or export configuration files defined by IEC 61850-6 and is used for the engineering of the communication system level. All of the substation IED's ICD files and the substation SSD file are imported into the system configuration tool. The system configurator is used to configure the data exchange between IED's and communication parameters for the substation protection and automation system. The system configurator is also used to configure the GOOSE messages by specifying the senders (publishers) and the receivers (subscribers) of messages (Aguilar & Ariza, 2010). The substation protection and automation system configuration is now represented by the system configuration description (SCD) file. The next step in the engineering process is to export the configured IED description (CID) files from the system configurator. The CID file represents a single IED section of the SCD file and contains the address and specified names used in the SCD system. The CID file for each IED can be loaded into each IED using an IED configurator tool. The IED is now configured for its designed purpose in the substation protection and automation system.

2.3 Communication Technologies and Topologies

2.3.1 Substation Communication Networks

The backbone of an IEC 61850 substation protection and automation system is the communication network. Prior to the IEC 61850 standard, majority of the communication between substation protection and automation devices were performed by proprietary serial communication systems to communicate control and monitoring functions of the substation. With the introduction of time critical protection functions onto the substations protection and automation system, a high degree of reliability, dependability and deterministic behaviour would be vital for the substation communication networks (Yadav & Kapadia, 2010). Both the station and process bus in an IEC 61850 substation is based on industrial Ethernet technology. Ethernet was chosen due to its cost effective, high speeds, and its high degree of flexibility with regards to the communication architecture (Wimmer & Wolfgang, 2005). Ethernet is a simple layer 2 protocol and makes use of flexible communication devices such as switches and routers.

2.3.2 Substation Ethernet Topologies for IEC 61850 Station Bus

The IEC 61850 standard does not specify any independent Ethernet network topology. Ethernet Local Area Networks (LANs) in an IEC 61850 substation protection and automation system can be built and configured using any physical topologies like trees, stars or rings. The network also has the capability to carry both station and process bus traffic. Ethernet Rings and Ethernet Redundant Trees are the two main topologies commonly used by network manufacturers implementing IEC 61850 substation protection and automation systems due to their superior physical redundancy. L Zhang & N.C. Nair (2008) performed test to measure the transmission speed of the GOOSE message on a station bus between four IED’s from the same manufacturer using star, peer-to peer and ring topologies. The research identified that the different topologies did not make significant difference on transmission times of the GOOSE message.

2.3.3 Network Redundancy

Redundancy of the station bus network is the most important function of the network. A high degree of reliability is critical for protection functions carried on the station bus network. A failure to a time critical protection message on the communication network could potentially cause safety and reliability issues to the greater transmission or distribution network. IEC 62439 *Industrial communication networks – High availability automation networks* defines the requirements for substations protection and automation system network redundancy solutions. IEC 62439 series considers two classes of network redundancy. Redundancy managed within the network and redundancy managed in the end nodes. Part 3 of the standard defines two redundancy protocols that are specifically designed for station bus IED's. The first is the Parallel Redundancy Protocol (PRP) where the node is connected to two different redundant networks and the node chooses independently the network to use (Kirrmann., et al., 2008). The second is High-availability Seamless Redundancy (HSR) protocol, where the nodes are solely connected the network and the network provides redundancy through links and switches. Both protocols provide static network redundancy mechanism and provides seamless switchover during failures to communication links and switches (Midence & Iadonis, 2009). Figure 12 illustrates a station bus network using HSR and PRP protocol.

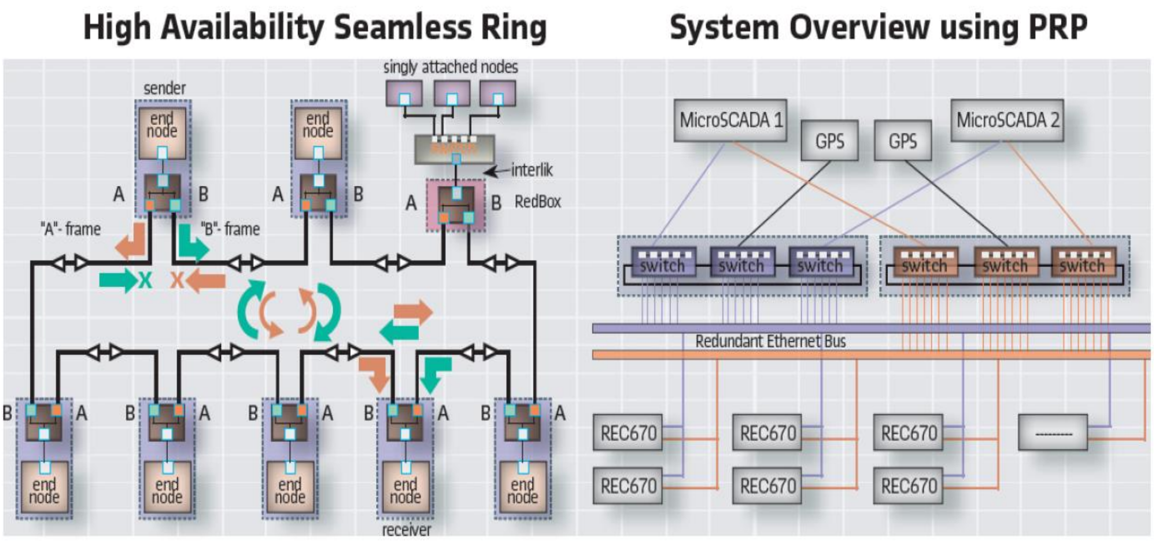

Figure 12: Station bus network using HSR and PRP protocol (Kirrmann., et al., 2008)

2.4 Testing and Commissioning of an IEC 61850 Substation

2.4.1 IEC 61850 Part 10: Conformance testing

Part 10 of the IEC 61850 specifies standard techniques for testing of conformance of client, server and sampled value devices and engineering tools, as well as specific measurement techniques to be applied when declaring performance parameters (International Electrotechnical Commission , 2012). The details of the testing are under a laboratory environment with only two IED's connected onto the test network. This part of the standard is intended mainly for IEC 61850 developers and allows insurance that the device or tool operate correctly and is fully supported as per the standard. This allows the integrator of an IEC 61850 substation protection and control system confidence that each device work as intended.

2.4.2 IEC 61850 Edition 2

Edition 2 of the IEC 61850 standard was developed to fix technical issues, improve inconsistencies and clarify interoperability encountered from different IED manufacturers under Edition 1. The second edition of the standard provides new functionalities and enhancements that could potentially be utilised during the testing and commissioning of an IEC 61850 substation. Some of these additional features have the potential to be used as mechanisms for in service protection isolation.

2.4.2.1 Function Test Mode

IEC 61850 Edition 2 part 7-4 defines the behaviour of an IED in response to test signals while set in test mode. IEC 61850 Edition 2 IED's have the capability to set a logical node or a logical device into test mode using the data object Mod of the LN or of LLN0. Figure 13 illustrates the behaviour of the IED with the test flag set to "FALSE". A command to operate the IED can be initiated by a GOOSE message or control operation that is interpreted by the subscriber as a command (Apostolov, 2015). With the test mode of the IED disabled, a command initiated with the test flag set to "FALSE" and the function (logical node or logical device) is "ON", the IED will behaviour as normal. This will include the operation the IED's physical or virtual outputs. GOOSE messages emanating from devices under test will not be processed by the IED. If the IED is set to test mode, any commands that are received will not be executed by the IED. Including the operation the IED's physical or virtual outputs.

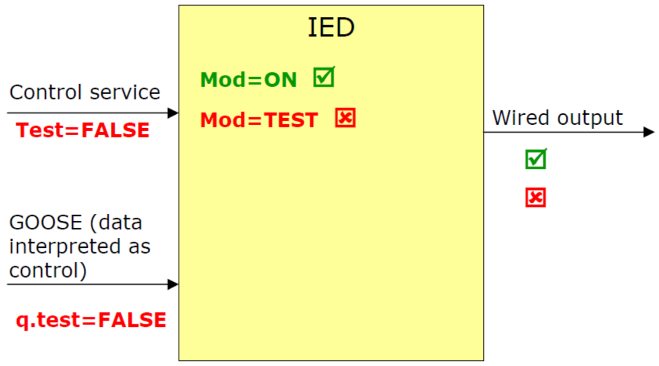

Figure 13: Test Mode - Command with Test Mode = False (Apostolov, 2015)

Figure 14 illustrates the behaviour of the IED with the test flag set to “TRUE”. With the test mode of the IED disabled, a command initiated with the test flag set to “TRUE” and the function (logical node or logical device) is “ON”, the IED will not execute the command. Enabling the test mode of the IED and the IED function to “TEST” will enable the IED to operate when a command is initiated with the test flag set to “TRUE”. This will include all protection functions, outputs from the IED will be operational and the IEC 61850 GOOSE messages from the IED will have the quality parameter set to test. If the function is set to “TEST BLOCKED”, any command will be processed, the IED protection functions remain enabled and the outputs from the IED are disabled. Preventing any tripping to connected in service equipment.

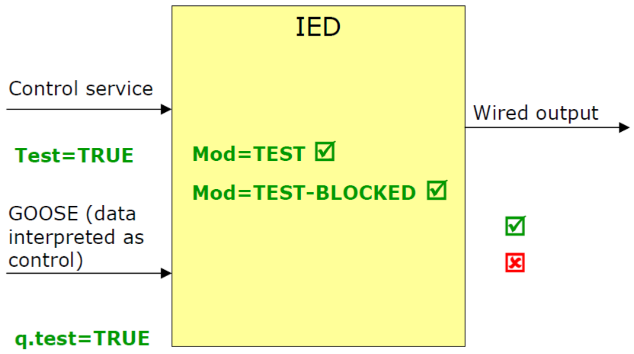

Figure 14: Test Mode - Command with Test Mode = True (Apostolov, 2015)

2.4.2.2 Simulation Mode

IEC 61850 Edition 2 part 7-4 defines the structure in which enables an IED to subscribe and accept GOOSE messages or sampled value messages generated from test equipment, when an IED is set in simulation mode. Figure 15 illustrates the subscription changeover for an IED set to simulation mode. The GOOSE message has a flag that indicates if the message is from a real message or the message has been produced from a simulation device. The logical node LPHD that represents the physical device has a data object “Sim” that is used to define if the device receives a real GOOSE message or simulated message. If the data object Sim is set to “FALSE” within the subscribing IED, all simulated GOOSE messages are disregarded and the IED will continue utilising the real messages. If the data object Sim is set to "TRUE", the subscribing IED will utilise the simulated messages within its internal processing. The subscribing IED continues to use the real GOOSE 1 message until the first simulated GOOSE 1 message is received by the subscribing IED. When the simulated message is received, the IED ignores any further real GOOSE 1 messages. The IED continues to process the real GOOSE 2 and 3 messages. The data object SimSt (simulation status) within the logical node LGOS (GOOSE subscription monitoring) provides indication when the particular subscription has successfully switched over to a simulation source. The simulated GOOSE 1 message will continue to be processed until the LPHD.Sim.stval parameter is changed to "FALSE".

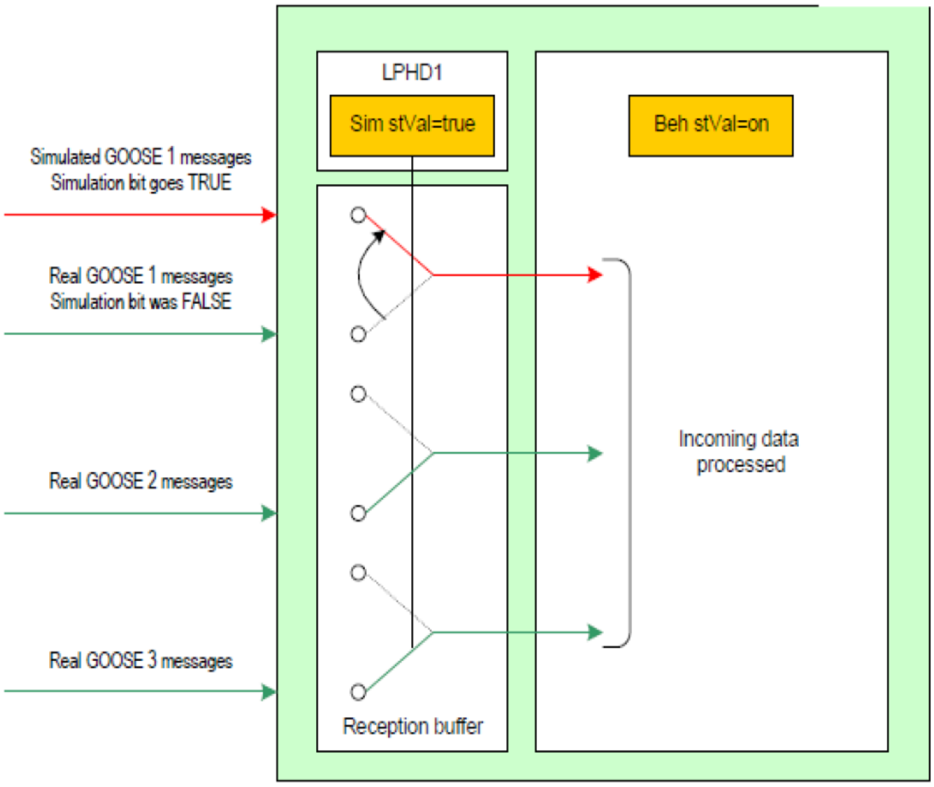

Figure 15: Edition 2 IED Simulation Mode (Alstom Grid, 2015)

2.4.3 Conference Publications and Journals

Apostolov (2008) discussed the test system architecture and principles for the testing of individual devices using sample values and protection schemes that involve multiple IED devices. Apostolov (2008) splits the principles of testing into functional and system testing. Functional testing applies a top-down method of verification of any function or sub function and ensuring the tested element has the expected behaviour under different realistic test conditions. Valid or invalid inputs should be provided to the functions and the expected output for each test condition defines the results. Compared to system testing which evaluates the overall performance of the system.

Apostolov & Vandiver (2007) functional testing of IEC 61850 base protection relays paper discusses a high level comparison between testing conventional based protection relays with protection relays using IEC 61850 station bus technology. Figure 16 illustrates the difference between the two technologies. The test device for conventional IED functional testing simulates the substation current and voltage signals, binary (opto) inputs and the IED outputs through hard-wired interface. The IED outputs are measured to detect the operational performance of the IED against its specified design. Function testing of an IED using GOOSE messaging has the same approach expect the inputs and outputs between the test device and the IED are simulated and monitored through the station bus network. Apostolov & Vandiver (2007) discusses that its good practice to monitor and compare the operation of an IED's output and a GOOSE message driven by the same functional element in the IED logic.

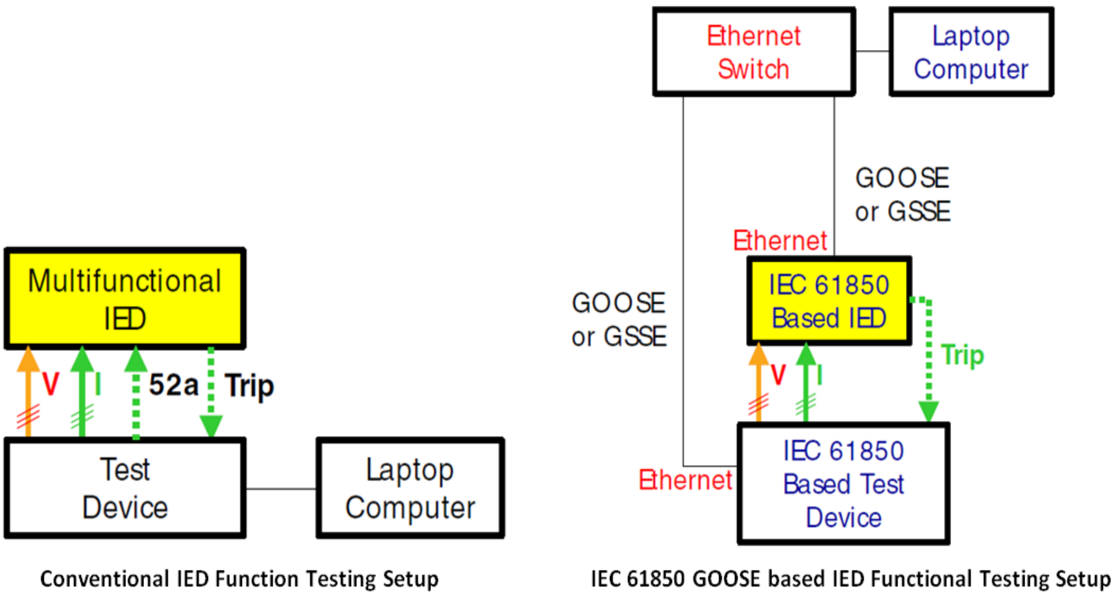

Figure 16: Conventional Vs IEC 61850 GOOSE Testing Setup (Apostolov & Vandiver, 2007)

Kanabar & Parikh (2011) described the importance of GOOSE integration and communication network configuration verification testing. Verification test were achieved using the wireshark tool to capture the GOOSE message over the network and check the data fields of the message. Verification of the Ethernet switched network was essential using a network analyser to confirm the MAC address of all connected devices as well Multicast domains (VLAN) of Ethernet switches.

2.5 Risk Assessment Methodology

CIGRE working group B5.32 (2009) discuss the importance of test coverage during testing. Their recommendation is to implement the Hazard and Operability Studies (HAZOP) or Failure

Mode and Effects Analysis (FMEA) risk assessment methodologies for identifying potential functional and component failures and possible physical and logical node failures to systems. The working group describes physical components like IED's and switches as typically programmed electronic devices (PED), while logical nodes are treated as black boxes and their failure modes are limited to loss or degradation of an expected behaviour. Logic nodes are defined by IEC 61850 as having all of the properties of a programmed electronic system (PES) and therefor the guide words used by IEC 61882 for a PES can be utilised for a HAZOP assessment on an IEC 61850 logical node.

Fenelon & Hebbron (2007) discusses the increasing use of HAZOP for analysing programmable electronic systems and the starting point for a HAZOP study is the deviation from the design intent. Once identified the HAZOP then aims to identify potential causes (faults) and consequences (System-level failure modes) of that deviation. The system allows the use of protection, detection and indicating mechanisms to identify possible potential causes (faults) and consequences (System-level failure modes). Fenelon & Hebbron (2007) describes the HAZOP methodology particularly useful for identifying weaknesses in systems.

Pentti & Helminen (2002) describes the use of FMEA as an important procedure by which each potential failure mode in a system is analysed to determine the results or effects thereof on the system and to classify each potential failure mode according to its severity. Pentti & Helminen (2002) discusses the use of FMEA in safety-critical software-based automation and industrial automation systems and provides examples for its use to perform a functional approach that recognizes that every item is designed to perform a number of outputs. The outputs are listed and their failures analysed.

Chapter 3

Project Design Methodology

3.1 Overview

With only a handful of small IEC 61850 substations commissioned and placed into service in Australia, with majority of them designed, constructed, tested and commissioned by IED manufactures like ABB and SIEMENS. It is critical to develop a design methodology to understand the design rules and specifications to implement GOOSE messaging on a station bus network. The project design methodology will use a top down engineering approach to critically analysis the following.

3.2 Current Protection and Circuitry Design

3.2.1 Overview

Ergon Energy currently has a number of design standards for implementation of new and refurbishment substation projects. All of these standard designs utilise the use of conventional protection relays, Remote Terminal Units (RTU), conventional primary plant (CT's and VT's) and hard copper wiring between secondary systems and primary plant. It is critical to understand Ergon Energy's current protection and circuitry design philosophies to be able to establish a connection between current practices and future practices using GOOSE messaging at a station bus level. This section will identify and describe the protection and interlocking functions that could potential be implemented utilising GOOSE messaging at a station bus level. A simplified substation protection single line diagram using Ergon Energy's current substation standards and conventional infrastructure is illustrated in Figure 17.

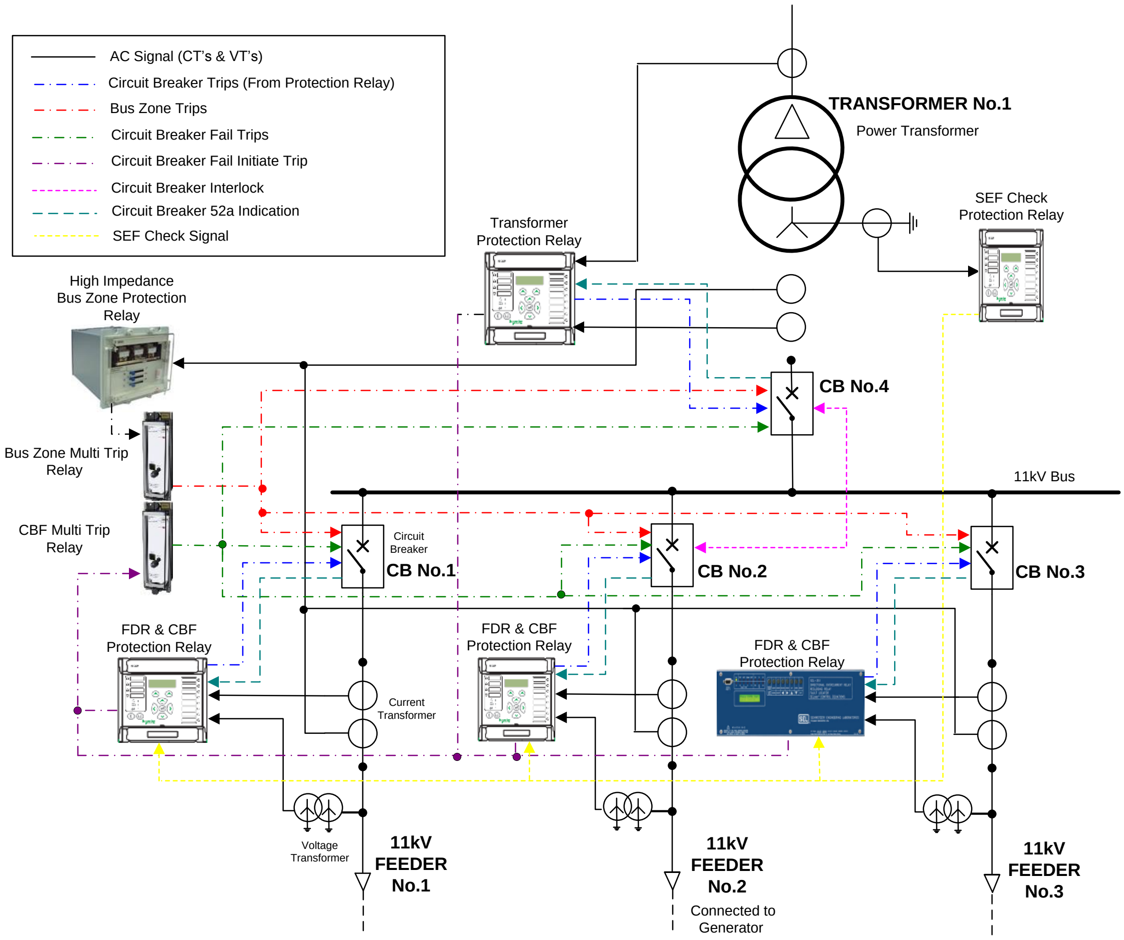

Figure 17: Current Ergon Energy Substation Standard Protection Single Line Diagram

3.2.2 Circuit Breaker Failure Protection (CBF)

If a protection relay detects a fault or abnormal operating state on the power system the protection systems intended purposes is to clear the fault by opening the circuit breaker nearest to the fault. If the circuit breaker fails to open due to a mechanical or electrical malfunction, a backup protection scheme is essential. Without a backup protection scheme there is a potential risk of damage, injury or loss of life, and disruptions to the security and reliability of the network. Circuit breaker fail protection, provides this backup functionality and is used to trip upstream circuit breakers to ensure the fault is isolated from the network. Figure 18 illustrates Ergon Energy's current circuit breaker fail protection logic. The CBF protection scheme is initiated from all protection functions that have the potential to trip the circuit breaker for a power system fault. Two conditions need to be satisfied before a CBF trip is sent from the initiating protection relay to the upstream circuit breakers. Firstly, the current going through any of the phases needs to be above the required pickup level that indicates that the circuit breaker is still closed with current flowing in one or all of the phases. If there is still current flowing through the circuit breaker and there has been an attempt to trip the circuit breaker via a protection function trip, the CBF timer is initiated and starts timing down from its settable value. If the protection function and current check elements are still high after the CBF timer expires, a trip will be initiated from the CBF relay or function to the upstream circuit breakers, which in turn will clear the fault on the power system.

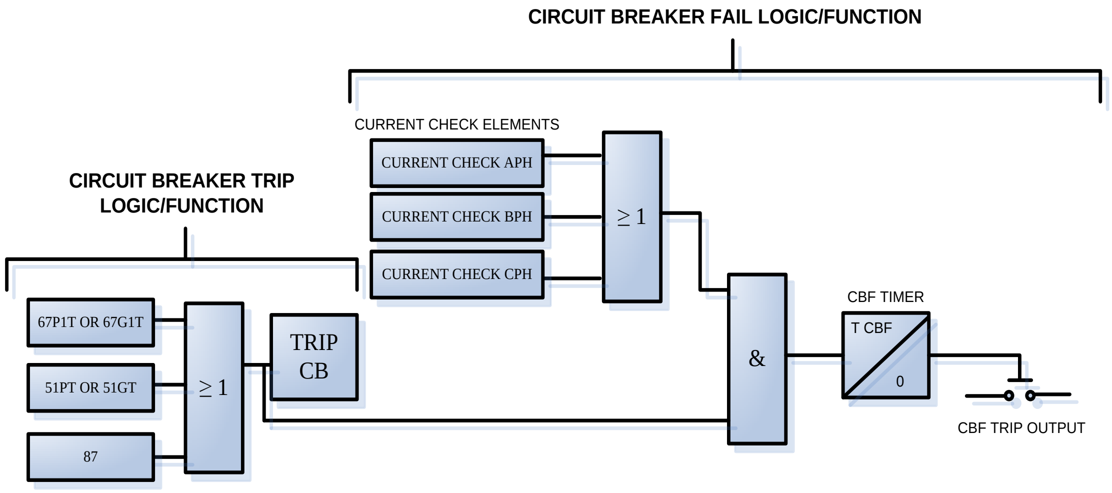

Figure 18: Circuit Breaker Fail Logic

Figure 19 Illustrates a typically CBF scenario on the simplified substation configuration. If Feeder No.1 has a fault on its distribution cable, circuit breaker (CB) No.1 is designed to trip and open and will clear the fault from the network. If the fault is still present and circuit breaker No.1 fails to open within the settable CBF time and the current is above the settable current check threshold, a CBF event will occur. The remaining circuit breakers connected to the 11kV bus will need to trip. This is achieved using copper cabling and auxiliary relays. When the CBF trip output are initiated from the No.1 11kV Feeder protection relay, the signal is sent to the 11kV bus circuit breaker failure multi trip relay. The multi trip relay is energise and it's normally closed contacts will close and a trip signal will be sent to all of the 11kV circuit breakers on that particular 11kV bus. This will remove the fault from the network. As shown in Figure 19, CB No.2, CB No.3 and CB No.4 will trip.

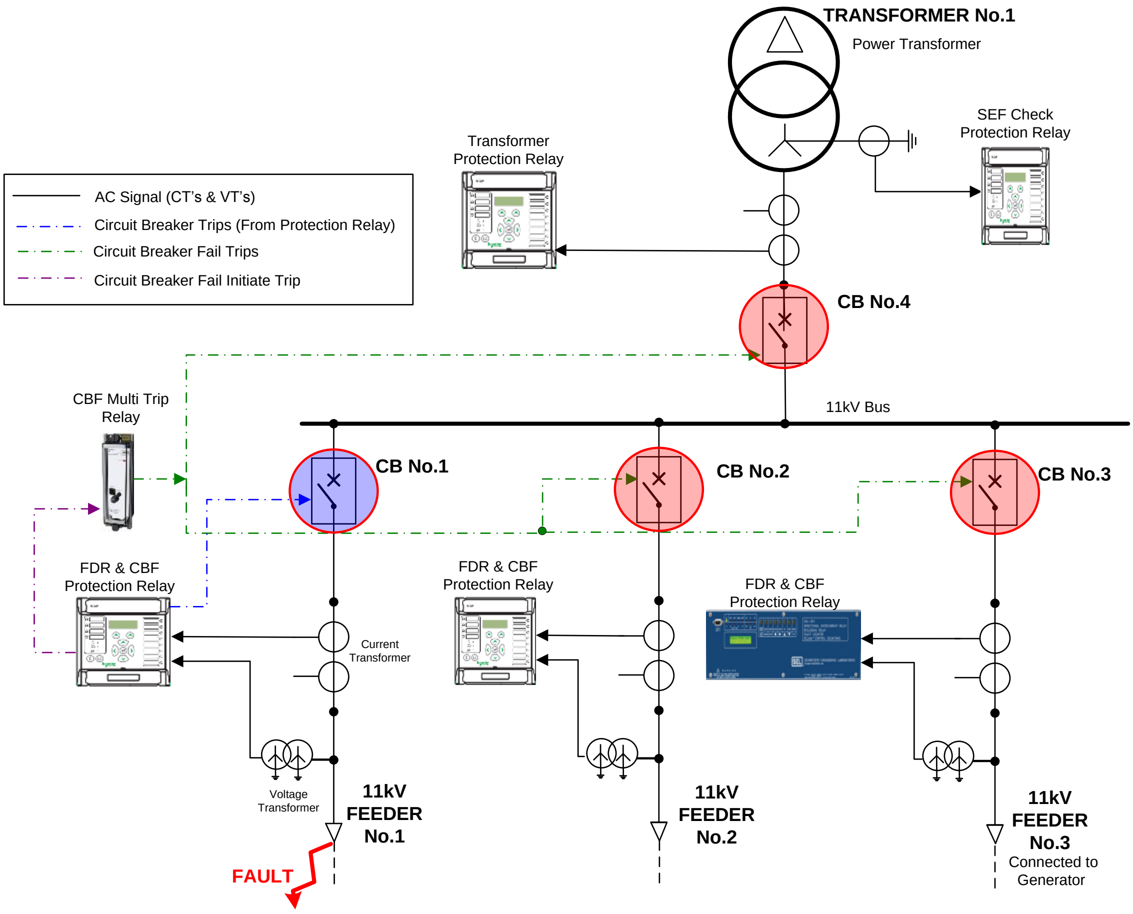

Figure 19: CBF Event on the Substation

3.2.3 Sensitive Earth Fault (SEF) Check Scheme

A large majority of earth faults on the distribution network are high impedance in nature because of the resistivity of the return ground path. If conductors fall down onto a road or into a tree there is a potential of having limited earth fault current and the standard earth fault element of the protection relay will not operate. Ergon Energy currently use a Sensitive Earth Fault (SEF) check protection scheme that allows the protection to trip for low current earth faults and is independent to the IDMT earth fault protection function within the protection relay. The protection scheme uses a current checking functionality via a SEF check relay that measures the return current in the substation power transformer neutral connection. If the current flowing in the neutral of the transformer is above the SEF check pickup current setting, the SEF check relay will initiate a SEF check output, which will in turn energise the SEF auxiliary relay. The SEF auxiliary relay normally closed contacts will open and the SEF check input to all of the 11kV feeder protection relays will change to a low state. This is sent to every 11kV protection relay on the connected 11kV high voltage bus via separate copper cabling. If the SEF input is low on the 11kV feeder protection relay, the SEF is armed and the stage one definite time neutral over current function is operative. The SEF function can be turned on via the SCADA system or locally on the protection panel, using a SEF enabled selector switch. The SEF can also be disabled if the operator enables the work clearance control. The associated logic and functions of the SEF scheme is illustrated in Figure 20.

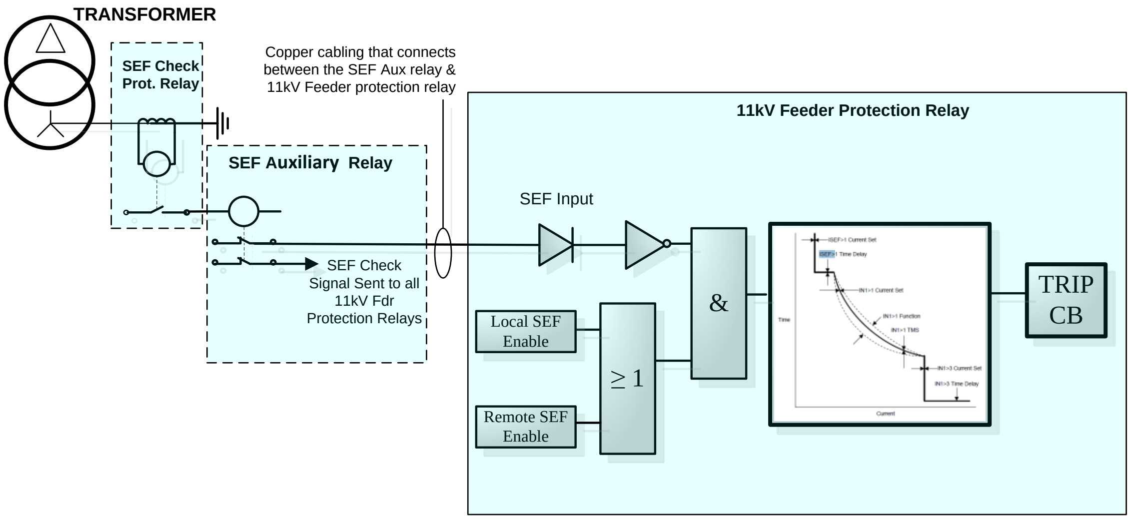

Figure 20: SEF Check Protection Scheme Logic

3.2.4 Bus Zone Protection

Bus zone protection schemes are critical in the event of a fault to the substation high voltage busbar due to their high fault currents. Failure to clear the fault could potentially be catastrophic to equipment and the safety of personnel working within the substation. Significant damage to the busbar and associated equipment from an explosion or fire could result in loss of supply to the entire network connected to that particular substation. Ergon Energy currently has a number of bus zone protection schemes that are used at different voltage levels. The two that will be discussed due to their flexibility and benefits in an IEC 61850 design is the high impedance and low impedance bus protection schemes.

3.2.4.1 High Impedance Bus Zone Protection

High impedance bus zone protection schemes are based on Kirchhoff's current law. The high impedance scheme is a simple, stable, secure and reliable protection scheme. The high impedance scheme compares the current entering the bus, with the current leaving the bus. If the difference is above the allowable threshold, the scheme will trip all breakers that are connected to the bus zone. Figure 21 illustrates a simplified example of the high impedance scheme. If current is flowing through the CT's in the case of load current or a fault external to the busbar, all of the secondary current circulates around the CT wiring. The secondary current flowing through the operating protection relay sums to zero and the relay will not operate. If a fault occurs on the protection busbar, the secondary current will summate which will equal the total secondary fault current. The secondary current will flow through the protection relay and if the current is above its settable threshold, the relay will operate. A multi trip relay will energise and will trigger a trip signal to every circuit breaker on that particular bus zone, clearing any potential sources to the busbar fault.

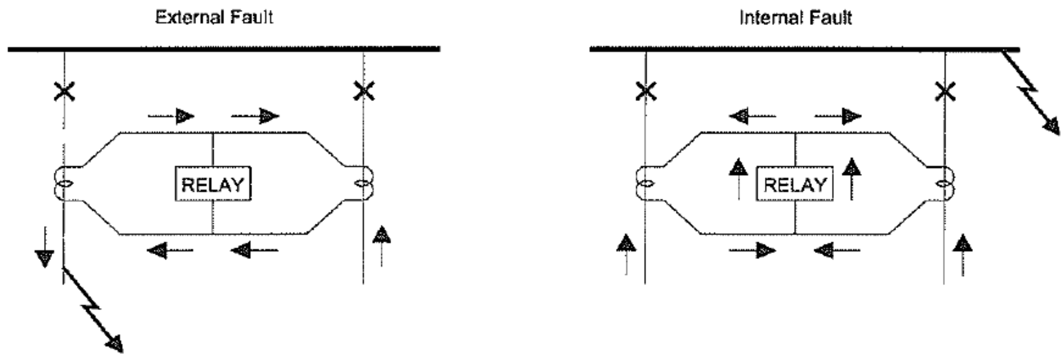

Figure 21: High Impedance Bus Zone Protection Scheme

3.2.4.2 Low Impedance Bus Zone Protection

Similar to a high impedance bus zone, the low impedance bus zone scheme measures and compares the current entering the bus, with the current leaving the bus. If the difference in current is above the allowable threshold, the protection relay will initiate a trip to all circuit breakers connected to that particular bus zone. One of the main differences is that each of the currents entering or leaving the bus zone through a CT has separate low impedance current inputs to the protection relay. Figure 22 illustrates a typical low impedance bus zone protection scheme configuration. Similar to the high impedance scheme, all of the breakers should remain closed for a fault external to the bus zone (F1) and in the case of a fault in the bus zone (F2), all of the circuit breakers connected that particular bus zone will trip for a fault within the zone.

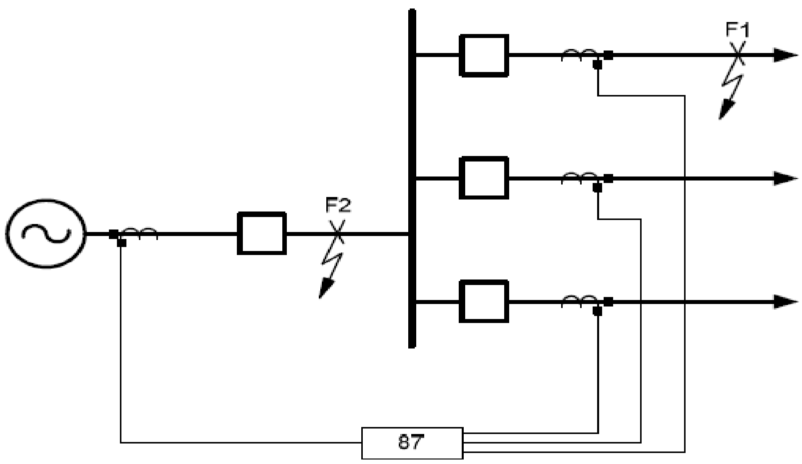

Figure 22: Low Impedance Bus Zone Protection Scheme (Schweitzer Engineering, 2013)

The protection relay operates using its sophisticated algorithms to vectorially sum the normalized currents from all individual current inputs to calculate the differential current (I_{op}) in the bus zone. The algorithm also arithmetically sums the current magnitudes to create a restraint current (I_{RT}). Figure 23 illustrates a typical current differential characteristic of a low impedance bus protection relay. The differential current (I_{op}) is compared with the restraint current (I_{RT}). If the differential current (I_{op}) exceeds the threshold above the characteristic curve, the protection has identified that an internal bus fault is present and will operate, tripping the circuit breakers connected to that particular bus zone. The main advantage of using a low impedance scheme is the flexibility of the configurations due to the microprocessor-based technology. CT inputs to the relay can be set to different ratios and polarity, where in high impedance schemes they need to set the same to ensure the current summate correctly. Multiple bus protection zones can be set using isolator or circuit breaker status in conjunction with the flexible logic within the protection relay.

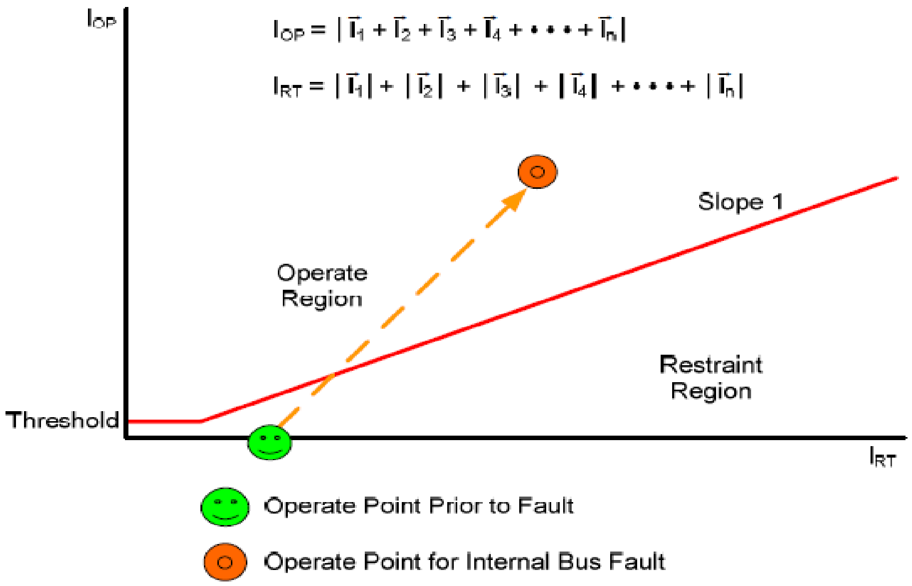

Figure 23: Current Differential Characteristic of a Low Impedance Bus Protection (Schweitzer Engineering, 2013)

3.2.5 Interlocking Schemes

Interlocking schemes play a vital role in ensuring high voltage equipment is operated correctly. Majority of interlocking schemes are designed to protect the operator of the equipment and prevents the operator from performing an incorrect sequence of manoeuvres. The interlocking is achieved using the switching mechanisms and in the electrical control circuits of the circuit breaker. It is critical to have interlocking on high voltage circuit breakers that are connected to embedded generation. The interlocking scheme ensures the generator is isolated from Ergon Energy's network by its high voltage distribution circuit breaker when the main sub-transmission supply is isolated from the substation. This ensures that the network does not loose synchronisation and that the transformer 11kV circuit breaker is not closed on to a system that could potentially be unsynchronised with the greater network. Ergon Energy currently has no synchronisation facilities and relies on this tripping and interlocking of circuit breakers to ensure synchronisation is maintained throughout the network.

3.3 Implementation of GOOSE Messaging at Station Bus Level

3.3.1 Overview

With the potential GOOSE messaging protection functions and interlocking functions identified in section 3.2, a high-level protection single line diagram has been developed. Due to the availability of IEC 61850 hardware and software a simplified substation layout will be deployed to enable a practical approach for future analysing. The protection single line diagram illustrates the changes from using Ergon Energy's current standards to the introduction of GOOSE messaging on the station bus network. The new protection single line diagram with the station bus topology is shown in Figure 24. The new protection single line diagram will be used to develop the design of the station bus GOOSE messaging. To reduce the potential of human errors during the system design and communication engineering, design rules have been kept to a minimum and where possible auto-assigned facilities will be used within the engineering tools.

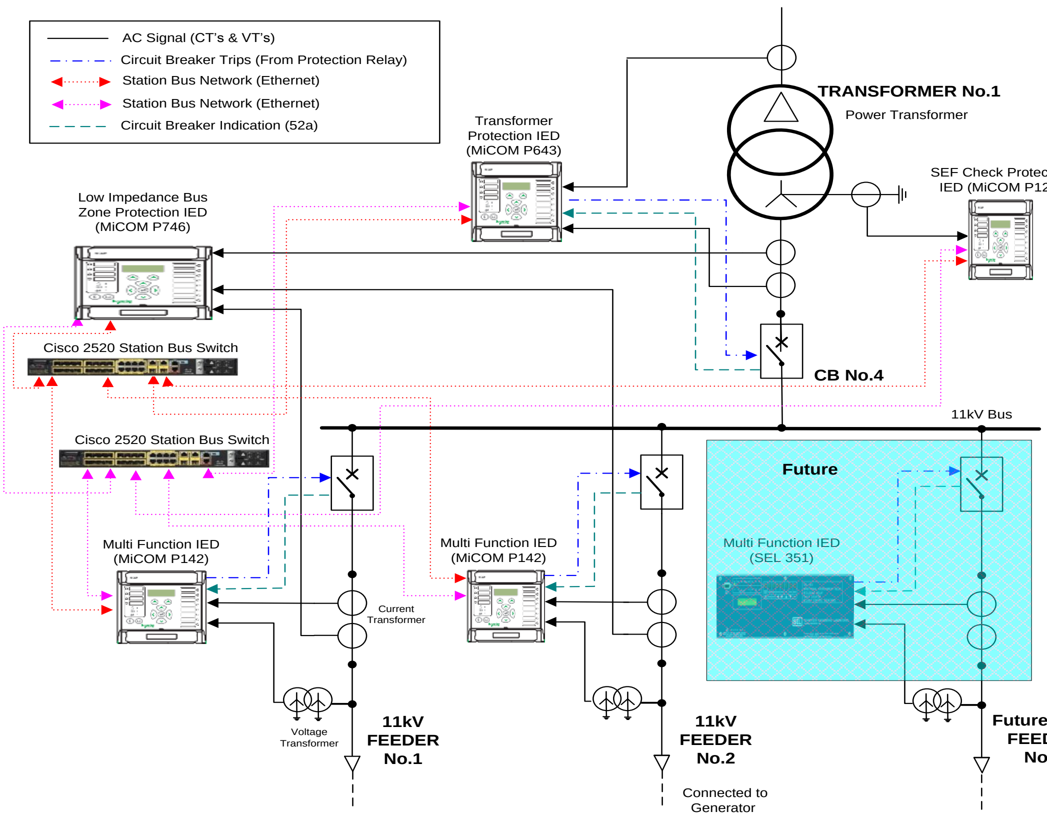

Figure 24: Protection Single Line Diagram Using IEC 61850 Station Bus

The first step of the design process will be developing a GOOSE direction communication diagram detailing the directions of the datasets from each IED. This will provide an overview of the IED's that will be publishing and subscribing to each other over the network. A GOOSE Protection and Control matrix will be developed detailing each IEDs publishing and subscribing datasets and the GOOSE Data items within each dataset. This will provide a logical approach for specifying the senders (publishers) and the receivers (subscribers) of messages. This will also allow Ergon Energy's current protection logic configuration files to be modified to enable the use of GOOSE messaging within the logic, instead of using conventional opto inputs and contact outputs in the design. Generic pickup and timer values will be used for the settable protection functions such as CB fail current pickup and timers. The modified logic and setting files will need to be loaded into the IEDs using their manufacturer's proprietary software. The second step of the design process is to create the required IEC 61850 configuration files for each IED. This process will follow the steps as shown in Figure 25.

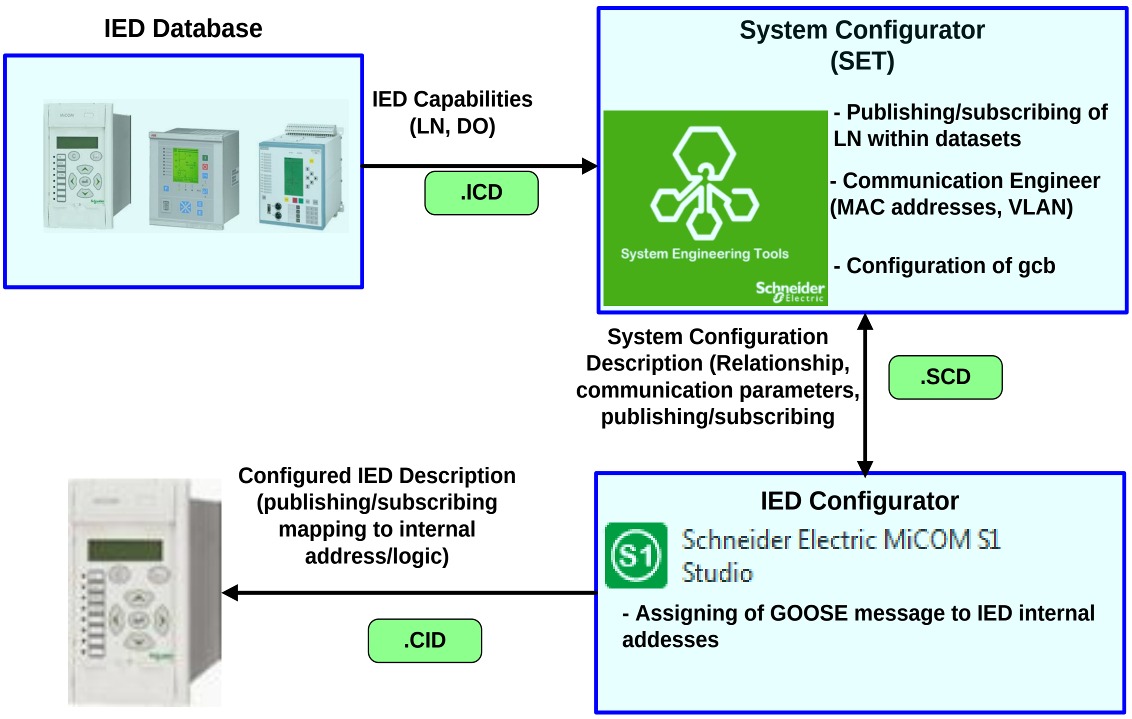

Figure 25: Project IEC 61850 Design Process

IED Capability Description (.ICD) files for each IED that will be connected to the substation protection system will be imported into the system configuration tool. Schneider Electric SET system configurator tool will be utilised to configure the data exchange between IED's and communication parameters for the substation protection system. This will include specifying the senders (publishers) and the receivers (subscribers) of messages. This will be designed from the GOOSE connection diagram and GOOSE Dataset matrix. A system configuration description (SCD) file will be created after completion of this process. The next step in the engineering process is to export the configured IED description (CID) files from the system configurator tool. The CID file for each IED can be loaded into each IED using the Schneider Electric MiCOM S1 Studio IED configurator tool and will contain the address and specified names used in the SCD system. The third step of the design process will be developing configurations for the two LAN switches and setting up the station bus network.

3.3.2 GOOSE Directional Communication Diagram

Figure 26 illustrates the GOOSE directional communication diagram for the simplified substation. CIGRE working group B5.32 describe a number of design considerations when developing a GOOSE messaging network. If GOOSE datasets are represented in directions towards the subscribing IED's, increases the understanding of which IED's will be affected by different GOOSE messages. This is very important during protection isolation. Having datasets directionally sent to IED's for summation of common functions can also potentially decrease traffic on the network. An example of this is that a CBF initiate from a failed circuit breaker relay can be sent in the dataset that is subscribed by the bus protection IED. The bus protection IED would initiate the trip to the remaining breakers on that particular bus via an item within the dataset that is used for tripping the substation circuit breakers during a bus zone fault. This also applies a similar philosophy as conventional wiring and the use of multi trip relays for tripping multiple circuit breakers.

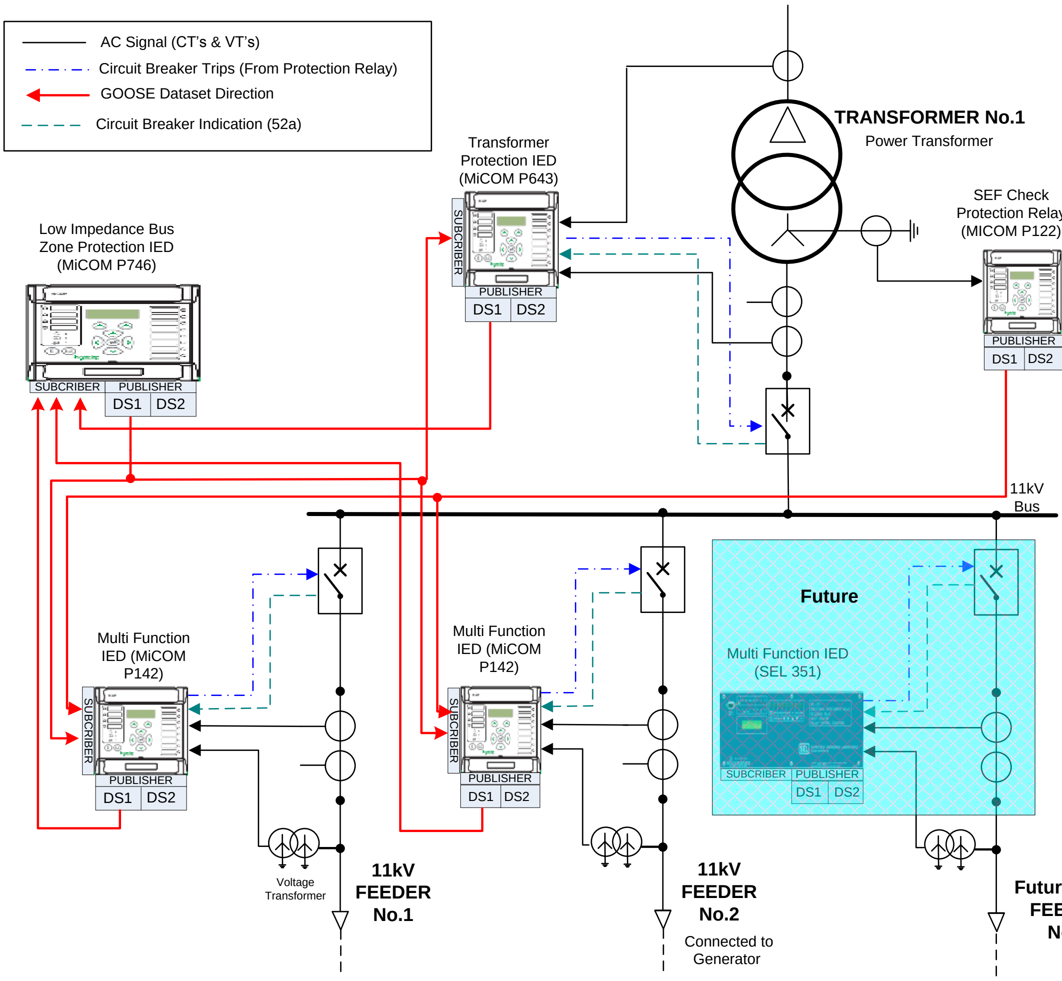

Figure 26: GOOSE Directional Communication Diagram

3.3.3 GOOSE Protection & Control Matrix

A GOOSE Protection and Control matrix have been developed to provide a detailed network overview of the GOOSE Protection and Control messages that are sent by the publishing IED and received by the subscribing IED, with reference to the GOOSE directional communication diagram. The GOOSE publisher section provides detail of the Publishers GOOSE control block, the dataset item number, the IED internal reference or logic node description and the GOOSE source path. While the GOOSE subscriber section of the matrix provides a description of the receiving message and the IED's internal reference addresses. The GOOSE matrix is illustrated in Table 3.

IED Name		SUBSCRIBER AND FUNCTION			MiCOM P746 PUBLISHER INFORMATION							MiCOM P122 PUBLISHER INFORMATION			MiCOM P142 PUBLISHER INFORMATION			MiCOM P142 PUBLISHER INFORMATION			MiCOM P643 PUBLISHER INFORMATION		
		Description	Ref. In IED	GOOSE Control Block	No.1 11kV BUS PROT & CBF MGT							SEF CHECK PROT			11kV FDR 1 MGT & CBF			11kV FDR 2 MGT & CBF			TFMR 1 PROT & CB FAIL		
					gcb01							gcb01			gcb01			gcb01			gcb01		
					DATASET 1 (DS1)							DATASET 1 (DS1)			DATASET 1 (DS1)			DATASET 1 (DS1)			DATASET 1 (DS1)		
				Description (ref in IED)	No.1 Differential Bus Trip (LN:PDIF1)			CB Fail Bus Trip (VO11)		CB Interlock Trip		SEF Check (PTOC)			No.1 CB Status	No.1 CB CBF (RBRF)		No.2 CB Status	No.2 CB CBF (RBRF)		No.4 CB Status	No.4 CB CBF (RBRF)	
				61850 Dataset Reference	Protection/BbpT01PDIF1.OP.general	Protection/BbpT02PDIF1.OP.general	Protection/BbpT04PDIF1.OP.general	System/GosGGIO2.ST.Ind11.stVal		System/GosGGIO2.ST.Ind12.stVal		Protection/efdPTOC1.OP.general			Control/XCBR1.Pos.stVal	Protection/cbfRBRF1.OPEx.general		Control/XCBR1.Pos.stVal	Protection/cbfRBRF1.OPEx.general		System/GosGGIO2.ST.Ind20.stVal	Protection/cbf2RBRF1.OPEx.general	
		Dataset Item No.			1	2	3	4		5		1			1	2		1	2		1	2	
MiCOM P142 SUBSCRIBER INFORMATION	11kV FDR 1 MGT & CBF	Bus Zone Trip REC	Virtual Input 1		x																		
		CBF Trip REC	Virtual Input 2					x															
		SEF Check	Virtual Input 3									x											
		SPARE	SPARE																				
		SPARE	SPARE																				
MiCOM P142 SUBSCRIBER INFORMATION	11kV FDR 2 MGT & CBF	Bus Zone Trip REC	Virtual Input 1			x																	
		CBF Trip REC	Virtual Input 2					x															
		SEF Check	Virtual Input 3									x											
		CB Interlock Trip	Virtual Input 4							x													
		SPARE	SPARE																				
MiCOM P643 SUBSCRIBER INFORMATION	TFMR 1 PROT & CB FAIL	Bus Zone Trip REC	Virtual Input 1				x																
		CBF Trip REC	Virtual Input 2					x															
		SPARE	SPARE																				
		SPARE	SPARE																				
MiCOM P746 SUBSCRIBER INFORMATION	BUS PROT & CBF MGT	No.1 CB CBF Event	Virtual Input 1													x							
		No.2 CB CBF Event	Virtual Input 2																x				
		No.4 CB CBF Event	Virtual Input 3																			x	
		No.1 CB Status	Virtual Input 4												x								
		No.2 CB Status	Virtual Input 5															x					
		No.4 CB Status	Virtual Input 6																		x		

Table 3: GOOSE Protection and Control Matrix

3.3.4 IED Protection and Control logic

Existing protection and control logic configuration files have been modified for each IED utilising the information contained in the GOOSE Protection and Control Matrix. As per IEC 61850-7 series, standard logical nodes for protection and control will be utilised where possible when elements and functions within these systems are broadcasted onto the network. The protection IED's logic will be configured using MiCOM S1 studio and the modifications to the existing PSL will produce a file for the required logic changes to each IED.

This enables the link between the protection IED internal logic and functions and their association with the receiving and sending GOOSE messages. The IED logic developed and IED's internal logic utilised in this design is illustrated in Appendix B

3.3.5 Substation Configuration Language (SCL)

The system design and communication engineering of the simulated substation was performed using the Schneider Electric SET system configurator tool, which is utilised to configure the data exchange between IED's and communication parameters for the substation protection system. The GOOSE Protection and Control Matrix was used to configure the datasets, logical nodes and the publishing/subscribing relationship of each IED. A redundant station bus network was configured with the associated IED's connected to the network. All of substation IED's ICD files were imported into the system configuration tool to their associated IED's. Once the ICD files were imported into the system, each IED's GOOSE control block and dataset's were configured with the proposed published logical nodes within each control block. The network communication and GOOSE control block communication parameters were configured which included the MAC address, APPID, VLAN ID, VLAN priority and retransmission times. The next step of the process was to specify the senders (publishers) and the receivers (subscribers) of each GOOSE message. The GOOSE control blocks MAC address and APP IDs were auto-assigned to a unique number using the tool. This reduced the need to have a design rule in place for these parameters and the need to change the parameters manually, which will reduce the risk of human error during the configuration process and therefore testing of these parameters. One of the advantages of only using Schneider Electric IED's within this simulated network was that the system configuration tool enabled the direct mapping of each GOOSE message to the IED's internal virtual input address. If alternative manufacturers IED's were used in the system, this engineering task would have to be performed within the manufacturers IED configurator tool. This manual engineering task could potentially create additional engineering and design errors during the mapping of the messages to the IED's internal addresses. Figure 27 illustrates the logical view of the publishing and subscribing relationship of the network and the mapping between the IED's internal virtual input address. A system configuration description (SCD) file was created after completion of this process. The next step in the engineering process was to import the SCD file into the Schneider Electric S1 studio IED configuration tool where configured IED description (CID) files were created and sent to each IED on the network.

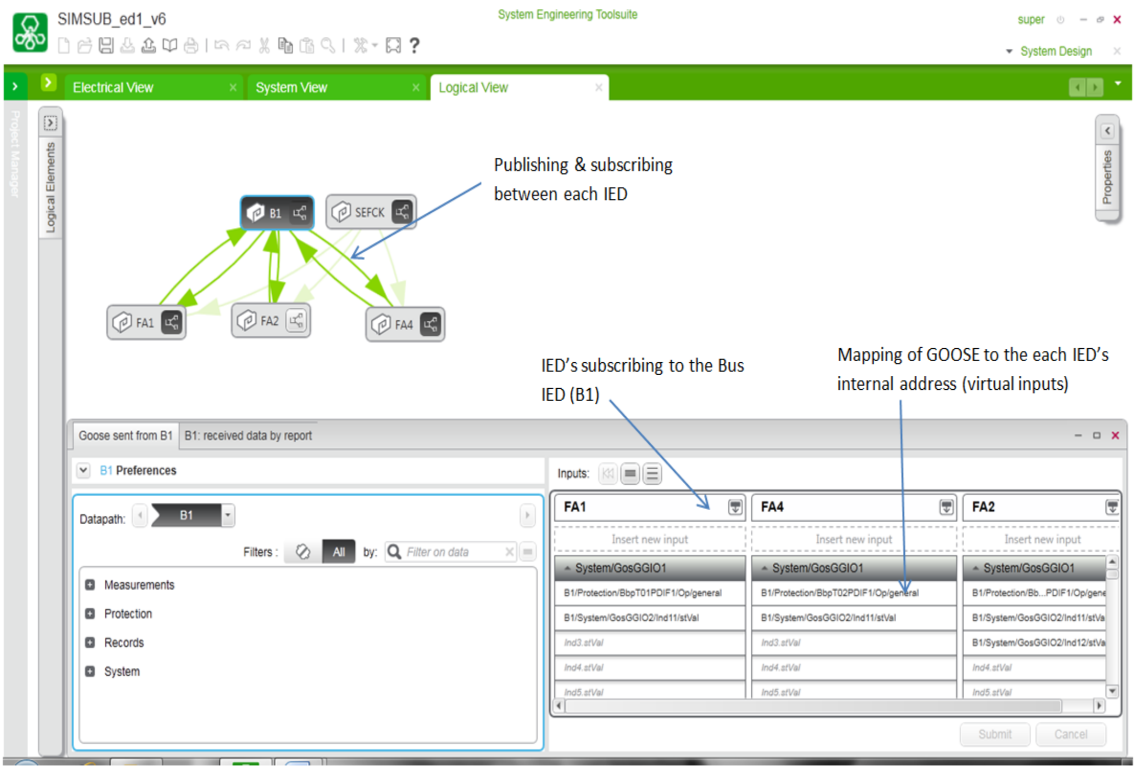

Figure 27: SET System Configuration

3.3.6 Station Bus Network Design

The simulated substation bus communication network was developed using the topology shown in Figure 24. Multimode fibre optic cables were used to connect between each IED and the 2520 CISCO switches on the station bus network. The CISCO switches and their associated ports were configured for the GOOSE specified VLAN ID of 01 and 10. Traffic control management and quality of service (QoS) parameters were set as per recommended default parameters. Appendix B provides a list of the CISCO switch configurations.

3.3.7 IED Isolation Design

During installation, testing, alteration, upgrading or maintenance of protection and control equipment, it is often necessary to isolate protection and control signals to in service equipment. Incorrect or no isolation could potentially result in inadvertent tripping which would compromise network security and develop interruptions to the network. Additional consequences of incorrect or no isolation could lead to associated primary plant without adequate protection or control. It is essential to recognise ways in which protection and control equipment can be removed from service and the implications of incorrect or no isolation.

3.3.7.1 Current Design and Practices

Majority of power utilities that perform work on equipment that is physically connected to in service systems and networks have processes in place to ensure correct isolation procedures are maintained. Conventional protection and control systems isolation design relies on a physical break in the circuit that is connected to the in service secondary systems. This is pronominally achieved utilising slide links or knife blade type terminals or withdrawable links. Figure 28 illustrates a typical conventional protection scheme and the links that would be removed during isolation of the in service equipment. This method for isolation is simple and provides physical visibility of the isolation. There are also a number of inherent issues with this method. Majority of the time the isolation points are not monitored. If the links are not restored correctly or there is a mechanical failure to the isolation point, there is a risk that the protection scheme may not operate correctly during a fault condition. The system also has limited functionality when integration is required to the in service equipment. All outgoing circuits are isolated or the receiving protection device will also need additional isolation, which could potentially lead to reduced protection coverage on the network.

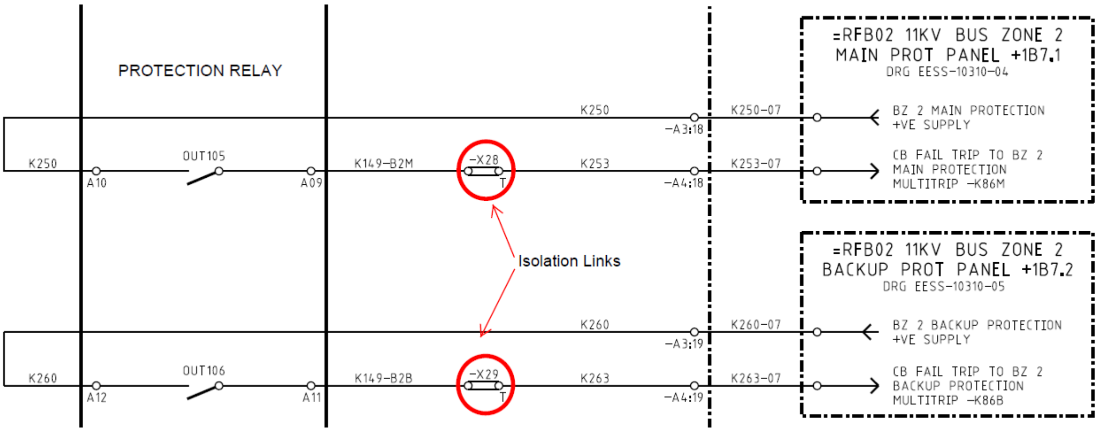

Figure 28: Conventional Protection Isolation

3.3.7.2 GOOSE Isolation Design and Practices

With the introduction of GOOSE messaging and the removal of physical outputs and hardwiring, new isolation design and practices are essential. A physical isolation to the in service network can only be achieved by unplugging the station bus fibre optical cable that is connected to the IED. This action would result in the loss of the communication network, rather than specific signals sent from the IED. An appropriate design is required to ensure the network can be maintained and virtual isolation is achieved. This would require the blocking of the GOOSE signal from the publishing IED or its effect on the subscribing IED. IEC 61850 does not define or provide the methods to virtually isolate GOOSE signals. Prior to IEC 61850 edition 2, the described purpose and requirements of the “Test” flag (Ed1) was limited and the implementation of the “Test” and “Blocking” modes were option. This lead to inconsistent implementation of these features by different manufacturers and interoperability could not be guaranteed between different manufacturers. Isolation design of an IEC 61850 Edition 1 system would have to rely on creating an independent isolation strategy. This could potentially be achieved a utilising a blocking signal within the GOOSE dataset from the published IED or a blocking signal applied to the subscribing IED, indicating the received messages from a publishing IED is actually under a test condition. Implementing separate test GOOSE messages into the system when a publishing IED is under test could provide an alternative solution. This method would be limited to the number of GOOSE subscriptions that could be configured by the IED. All of these methods under edition 1 would provide suitable isolation functions, but would require the need for additional design and testing due to its nonstandard implementation. As described in section 2.4.2, IEC 61850 Edition 2 provides additional functions that could potentially be implemented into a virtual isolation process. Table 4 provides an overview of the performance of the IED Test mode function under IEC 61850 Edition 2. Implementing the IED performance in “Test” mode into a rugged isolation process will allow for integration or maintenance changes to IED’s connected to operational plant and equipment.

IED PERFORMANCE (Under Ed 2)				
SIMULATION Flag (Quality Parameter)	**TEST MODE (Mod) of IED (LD)**	**TEST MODE of Logical Node (LN)**	**Execute the command**	**Physical Output Operation**
FALSE	ON	ON	Yes	Yes
FALSE	TEST	TEST	No	No
TRUE	ON	ON	No	No
TRUE	TEST	TEST	Yes	Yes
TRUE	TEST	TEST-BLOCK	Yes	No

Table 4: IED Test Performance (Ed 2)

Chapter 4

Risk Assessment Methodology & Test Coverage

4.1 Risk Assessment Methodology

4.1.1 Overview

Only a structured and systematic analysing process will help identify what hardware, configurations, and functions that require testing prior to commissioning a substation using IEC 61850 Station bus GOOSE messaging. This analysing process will be achieved using a risk assessment methodology. This will determine if mechanisms are required to validate or verify the intended design during the testing and commissioning process. The risk assessment methodology that will be implemented to determine these mechanisms is the Hazard and Operability Studies (HAZOP) methodology. The two main systems that will be assessed are the protection IED's and the station bus network.

4.1.2 HAZOP Methodology

A HAZOP study is a detailed hazard and operability problem identification process. HAZOP deals with the identification of potential deviations from the design intent, examination of their possible causes and assessment of their consequences (International Electrotechnical Commission, 2003). The IEC 61882 standard will be used as the reference standard for this assessment. Figure 29 illustrates the flow chart of the HAZOP examination procedure.

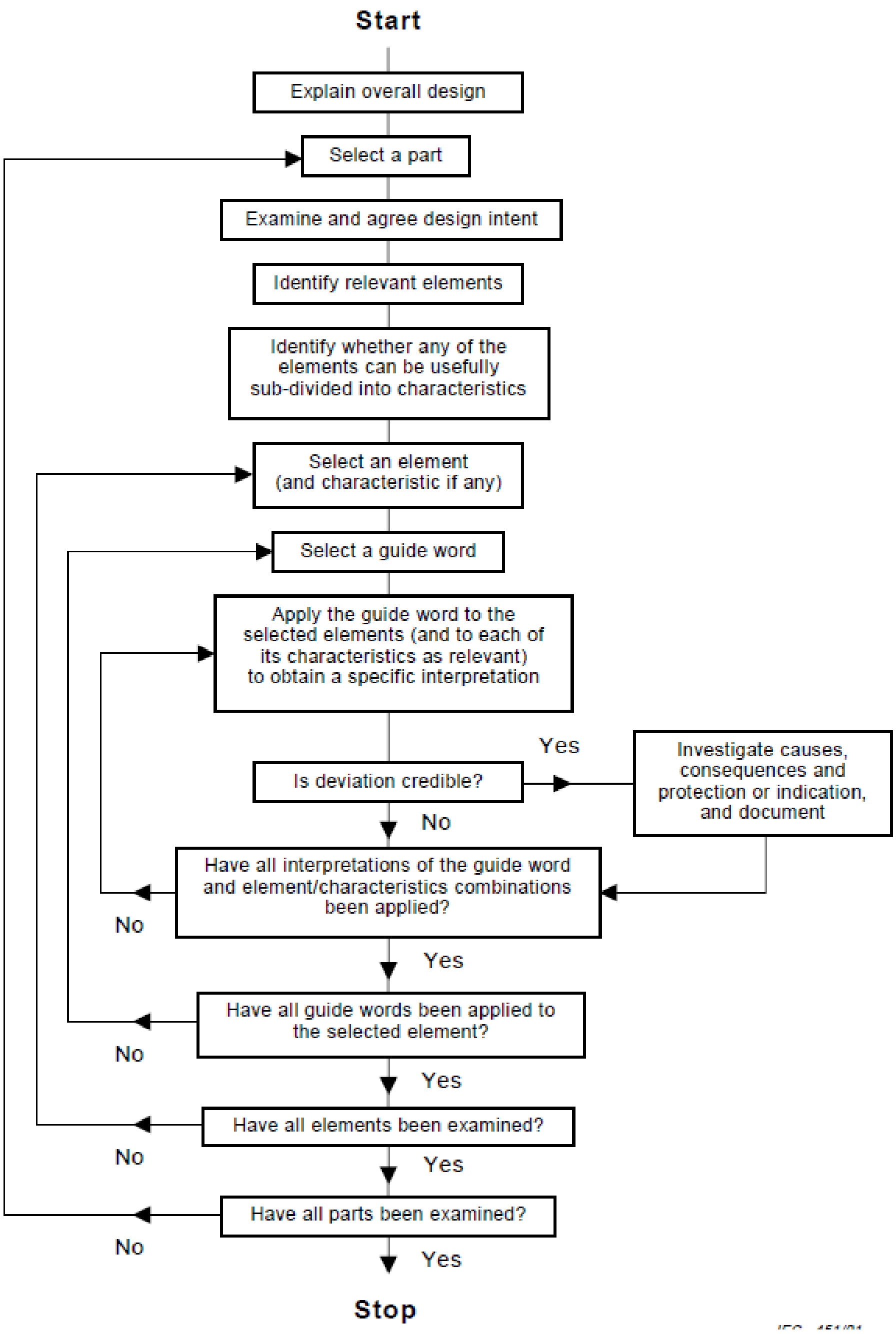

Figure 29: Flow chart of the HAZOP examination procedure (International Electrotechnical Commission, 2003)

The first step of the procedure is to select a part of the overall design, examine, and agree of that parts design intent. The design intent of that part of the design is explained by the use of block logic diagrams and the relevant elements, input values and functions associated with these identified. A guide word is selected to assess if the relevant elements, input values and functions being studied could potentially have a deviation from the design intent. If a deviation from the design intent is identified during this step, it is assessed for possible causes and consequences. CIGRE working group B5.32 (2009) and the IEC 61882 recommend the use of the HAZOP guide words for Programmable Electronic Systems (PES) and modified guide words for logical nodes. The working group describes physical components like an IED and switches as typically programmed electronic devices (PED), while logical nodes are treated as black boxes and their failure modes are limited to loss or degradation of an expected behaviour. Logic nodes are defined by IEC 61850 as having all of the properties of a programmed electronic system (PES). This allows for specific meaning for each guide word. The recommended guide words are detailed in Table 5 and Table 6.

Guide Word	Interpretation for Programmable Electronic System (*)
No	No data or control signal passed
More	Data is passed at a higher rate than intended
Less	Data is passed at a lower rate than intended
As well as	Some additional or spurious signal is present
Part of	The data or control signals are incomplete
Reverse	Normally not relevant
Other than	The data or control signals are incorrect
Early	The signals arrive too early with reference to clock time
Late	The signals arrive too late with reference to clock time
Before	The signals arrive earlier than intended within a sequence
After	The signals arrive later than intended within a sequence

Table 5: IEC 61882 HAZOP Guide Words for a PES (International Electrotechnical Commission, 2003)

Guide Word	Status	Measures	Controls	Settings
No	No status	No measurement	No Control	No settings
More		Measure > expected		Setting > expected
Less		Measure < expected		Setting < expected
As well as			Wrong control	
Part of	Not all status	Not all measures	Not all controls	Not all settings
Reverse	Inverted status	Inverted measure	Inverted control	Inverted setting
Other than			Unknown control	Unknown setting
Early				Too few timing setting
Late	Status delay	Measuring delay	Control delay	Excess timing setting
Before		Sample out of order		
After		Sample out of order		

Table 6: IEC 61882 HAZOP Guide Words for Logical Nodes (CIGRE WG B5.32, 2009)

The guide words for a logical node have been developed around failure modes of a logical node and its input and output model. This is illustrated in Figure 30

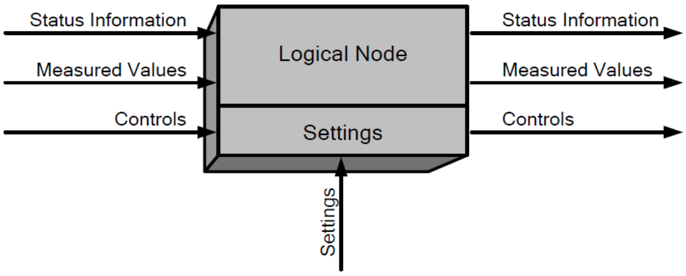

Figure 30: Logical Node Model (CIGRE WG B5.32, 2009)

If a deviation from the design intent is identified and the possible causes and consequences cannot be reduced or eliminated by a redesign of the system, a mechanism to validate or verify the design will be introduced into a test coverage matrix. A test coverage matrix will be used to identify the relevant elements, input values and functions that will require validating or verifying of the intended design through inspection, testing, measurement or simulations during the testing and commissioning process.

4.1.3 Protection IED Assessment

A protection IED can be modelled as a mathematical function or be simplified to a basic device, where given values of inputs, produces the given value of outputs depending on the parameters set or configurations within the IED. This is illustrated in Figure 31. The inputs to the IED are typically the analogue current and voltage signals and digital status from the substation process such as a circuit breaker indication. The outputs of the IED are determined by the IED's settable configurations or parameters and the value of a certain input to the IED. This typically includes the internal logic or parameters that determine behaviour of protection functions within the relay such as a CBF event or SEF pickup. The outputs to the process could be used to produce an alarm or protection trip to the relevant circuit breakers. The correct functionality of the IED is determined by the intended design, but incorrect functionality of the IED can be driven by failures to the IED.

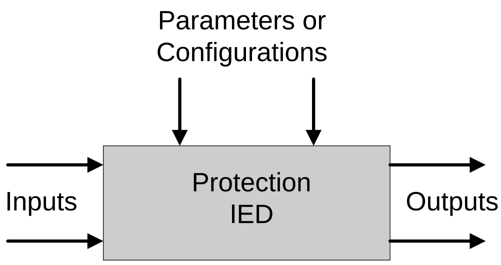

Figure 31: Simplified Protection IED

4.1.3.1 IED Failure Modes

CIGRE working group B5.32 (2009) describe failure modes of an IED can be broken down to functional failures and component failures. Functional failures a defined as conditions where the function or in this case the IED has not performed the expected output. These failures within a protection scheme could be the protection IED failing to trip a circuit breaker for a fault or tripping the incorrect circuit breaker. The following conditions can represent a functional failure of an IED and in turn the system.

- Incorrect output signals/messages or destination of signals/messages
- Output signals/messages sent to early or to late
- No output signals/messages sent or incorrect sequence of output signals/messages

The IED will be broken down to two different component failure modes, physical and logical node failures. Physical component failures are failures to the IED's physical hardware and are normally caused by the environment, such as broken hardware, short circuits or physical wear and tear or aging on hardware. Where logical node failures are conceptual components such as software modules and the logic or code within the IED that act as components. The following conditions can represent a logical node failure of an IED and in turn the system.

- Incorrect setting or parameters
- Incorrect configuration
- Incorrect code, firmware or software bugs
- Incorrect or no input/output signals/messages
- Input/output/processing signals/messages sent to early or to late

Establishing correct settings, configurations or parameters on an IED is critical for its intended operation and performance. IEEE/PSCR Working Group I18 identified that errors in IED settings can arise from many different sources, some technical, some procedural, some administrative and some inadvertent (IEEE WG I18, 2011).

4.1.4 Station Bus Network Assessment

The station bus network is the backbone of an IEC 61850 substation protection system using GOOSE messaging. While the protection IED ensures signals are sent and received for a given protection function. The station bus network is the virtual highway for these signals, ensuring the signals transmitted from the publishing IED's are received by the subscribing IED's. In a conventional protection system, copper wiring between IED's performed this function. The design of the station bus network needs to ensure the network architecture provides EMI immunity, reliability, availability, redundancy and maintainability. With the GOOSE model only mapped directly to the Link (layer 2) and Physical (layer 1) components, the station bus network can be broken down to these components to identify potential failures in the design intent. The physical layer consists of the hardware used as the medium to transfer the data such as optical fibre or twisted pair copper cabling. While the link layer consist of bridges such as network switches. Similar to the protection IED a bridge can be simplified to a basic device, where given values of inputs, produces the given value of outputs depending on the parameters set or configurations within the device. The most important function of the bridge is to enforce network management and provide network redundancy. Dolezilek & Dearien (2015) discuss one of the major challenges of testing a station bus network is ensuring the network architecture is design to accommodate the required traffic on the network and traffic control methods are in place to ensure that the time critical protection data is sent and received in the allowable times. IEC 61850-90-4 section 18 provides guidance on network testing for IEC 61850 communication networks. The standard recommends that integrator acceptance and verification tests should be completed to verify which products meet the functional and performance requirements for the intended network configuration under worst-case conditions (International Electrotechnical Commission, 2013). This testing is normally completed on several design standards and products and the results of the testing are used to decide which is the best design and product for the integrators future design standards and installations.

4.1.4.1 Network Failure Modes

Similar to the IED the network failure modes are physical component failures to the network physical hardware and logical node failures to the switches such as software modules and the logic or code within the device. The following conditions can represent a physical failure to the network hardware.

- Damaged fibre or cable and/or associated connectors
- Failure to the switch power supply or electronic circuits

The following conditions can represent a logical node failure of a network bridge and in turn the system.

- Incorrect setting or parameters
- Incorrect configuration
- Incorrect code, firmware or software bugs
- Incorrect or no input/output signals/messages
- Input/output/processing signals/messages sent to early or to late

4.1.5 IEC 61850 Station Bus GOOSE Messaging HAZOP Assessment

With the intended design identified in section 3.3 and the potential failures and possible causes of the failures to an IED or network device identified in section 4.1.3 and 4.1.4, a HAZOP risk assessment can be carried out on a protection scheme and its associated IED's, network devices and functions that utilise GOOSE messaging on the station bus network. The HAZOP flow chart illustrated in Figure 29, the HAZOP examination template in Figure 32 and a data/control flow diagram for the scheme will be the tools used to assess the scheme and its intended design. This will drive the required testing requirements and actions during the testing and commissioning process for this particular scheme.

STUDY TITLE:						**SHEET:**	
REFERENCE DRAWING No.:						**DATE:**	
TEAM COMPOSITION:							
PART CONSIDERED:							
DESIGN INTENT:							
No.	**Element**	**Characteristic**	**Guide word**	**Deviation**	**Possible causes**	**Consequences**	**Safeguards &/or Test Action**

Figure 32: HAZOP Examination Template

4.1.5.1 Circuit Breaker Fail Protection Scheme

Utilising the data/control flow diagram illustrated in Figure 33 and the design of the circuit breaker failure scheme, a HAZOP assessment of the circuit breaker fail scheme was developed. Appendix C provides the full details of the HAZOP examination and assessment.

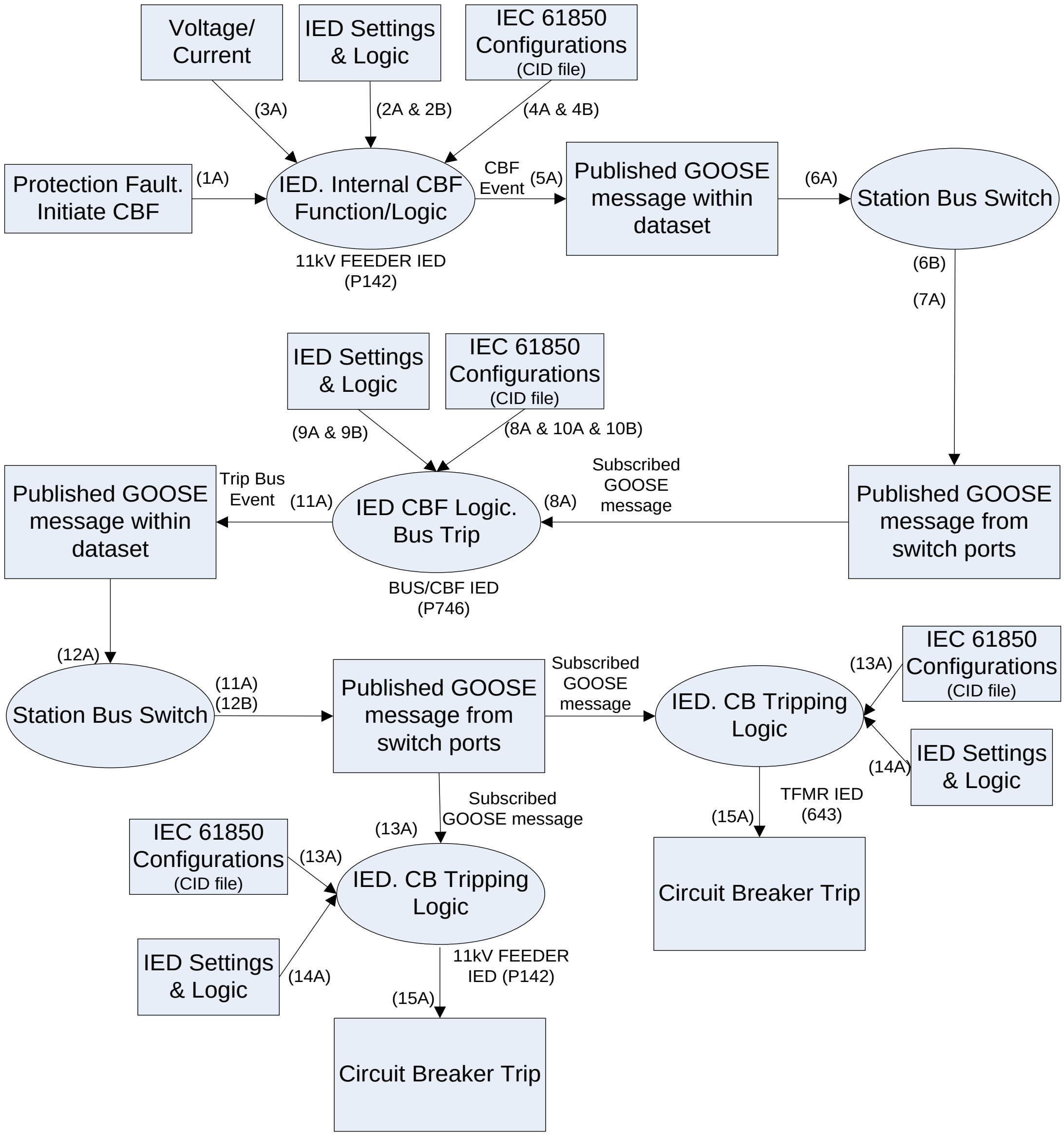

Figure 33: Data/Control Diagram for CBF Scheme

4.2 Test Coverage

4.2.1 Overview

The results obtain from the HAZOP assessment have identified parts of the system and protection elements, settings, parameters, functions, systems and characteristics that need to be validated or verified during the testing and commissioning phase to ensure intended design is achieved. Appendix D provides details of the full test coverage for the circuit breaker failure scheme. This provides methods and practices that will be deployed to validate or verify identified parts of the system and protection elements/functions of a circuit breaker failure scheme. The following section provides a brief overview of the findings of the assessment and proposed philosophies that could potentially be deployed during the testing and commissioning phase.

4.2.2 IED & Protection Scheme Test Coverage

4.2.2.1 Conventional IED & Protection Scheme Test Coverage

With conventional microprocessor based IED’s there are three testing and commissioning philosophies exist. These are element testing, logic testing and integration testing (IEEE WG I18, 2011). Throughout the industry there are two theories exist for element testing. The first is to prove that each programmable element and setting within the IED operates at its settable value. This practice continues to utilise the methods that are performed on electromechanical and electronic relays when verifying that electronic or mechanical components operate correctly at their settable values. The second theory relies on the digital nature of the IED and that no or reduced element testing is required. The concept behind this theory is that microprocessor based IEDs have superior self-monitoring or supervision capabilities and element testing only provides confirmation that the element setting has applied correctly within the IED. While both theories recommend that verification, be performed on non-monitored parts of the IED. This may include the current and voltage transformers, A/D converters and the IED’s inputs and outputs. Figure 34 illustrates the components of a microprocessor based IED.

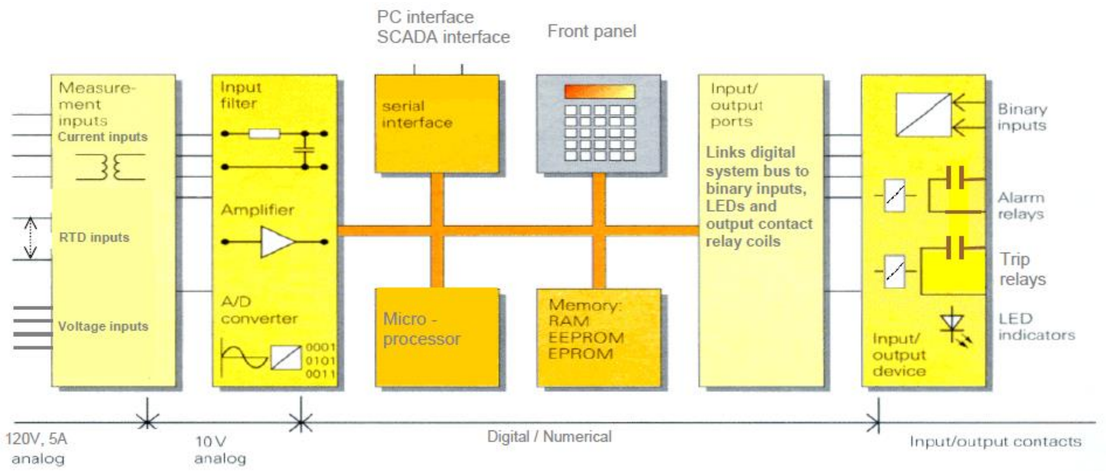

Figure 34: Microprocessor IED Typical Components (Power System Relaying Committee, 2009)

Programmable logic enables the IED to be customised to the specific design of the protection or control system. This is implemented utilising logical gates, timers, protection elements, opto-inputs and outputs. Logic testing of microprocessor IED’s verifies the programmable logic set within the IED operates as per its intended design, such as a protection element delivers a signal within the logic to an output that performs a protection trip to a physical circuit breaker. While element testing only verifies that the particular element is set correctly within the IED, logic testing verifies that the logical sequence integrated into the IED are valid and operate the IED outputs as per the intended design specifications. The integration testing of a protection and control system is the method utilised on site to prove that a piece of plant or equipment is correctly connected and integrated into the site to form a complete operational system. This ensures that an output from a particular IED sends a signal to the designated piece of plant or equipment and the required action is processed and executed. This could potentially be a signal to a circuit breaker to trip or a signal to another IED to enable a part of the internal logic or protection function.

4.2.2.2 IEC 61850 IED & Protection Scheme Test Coverage

IEC 61850 substation systems are based on the open exchange of standardised information between any of the substation IED's. While this concept takes on a similar nature as software applications, the IED still takes on the same protection philosophies as a conventional IED. With respect to an IEC 61850 station bus system, the main difference is that the I/O of the IED is achieve using digital GOOSE messages over the LAN, instead of utilising a physical inputs or outputs. An IEC 61850 protection IED still requires settings applied for the protection elements and programmable logic configured for internal mapping between virtual inputs and outputs. This conceptual model enables an IEC 61850 station bus IED to be broken into three testing and commissioning philosophies, similar to conventional IED testing and commissioning. These are element testing, logic testing and publishing/subscribing testing. However, a system approach to testing can be taken due to the relationship between the elements, logic and publishing/subscribing of the IED. These tests can be achieved separately or as an entire system depending on proposed implementation of the protection system.

Similar to conventional microprocessor IED element testing, both theories can exist for an IEC 61850 IED. If the second theory is applied, that the digital nature of the IED and that no or reduced element testing is required, it is critical to ensure other processes and control measures are in place to ensure that the potential to have incorrect settings applied are significantly reduced. Extensive evaluation and standardisation of IED hardware, firmware and software utilised to apply the settings can potentially reduce technical issues. Developing standard configurations for the IED's and testing the standards prior to releasing the files for operational or project use can potentially reduce technical issues. While implementing a rugged quality assurance system, configuration management system and establishing an audit and validation process can potentially reduce procedural, administrative and inadvertent issues. These are recommendations from IEEE standard C37.231, IEEE/PSCR working group I18 and C3. Verification of non-monitored parts of the IED such as the current and voltage transformers, A/D converters are still critical. The extent of element testing on either a conventional or IEC 61850 IED requires additional engineering justification and assessment. This is outside the scope of this project. If element testing can be performed in conjunction with other testing to optimise and reduce the number of test required, this should be included during the testing and commissioning process. This will ensure the protection system is not solely relying on the digital nature of the device to protect and reliably operate the required equipment.

With this consideration, all future testing coverage will investigate and implement additional coverage if possible to cover element testing of the IED. One of the major differences between a conventional and IEC 61850 IED is the signal sent from an IED to other parts of the secondary systems. While conventional IED's utilise configurable logic and internal mapping to physical outputs to perform this task, station bus IED's utilise a GOOSE message to be published onto the network via the assigned logical nodes (LN) within the dataset. This function is closely compared to logic testing of a conventional IED, where test are performed to ensure that the configurable logic and protection elements drives the correct output. Adapting this testing practice to an IEC 61850 station bus protection will enable the confirmation that the correct logical nodes (LN) utilised within the dataset has been assigned and is published onto the network. Including element testing into this test can provide additional test coverage. An example of this is to measure the operation and accuracy of the circuit breaker failure time during this testing. While this is not elements testing, the element that are deployed within the GOOSE message can potentially be verified for their correct settable value determined by the protection study. In most cases, power system simulation of the protection element would be performed. This would confirm the operation and accuracy of the protection IED and the IED associated protection element would be measured. While this is a very similar approach to testing conventional protection relays, one of the major differences is the sensing of the operation of the element. The measurement of the element operation would be performed on the station network for the GOOSE message, not a physical contact within the protection relay. If the SCL files for the IED under test are utilised within the testing, the GOOSE control block and dataset items number can be verified during the same test. Majority of IEC 61850 complaint test sets import the SCL files for simulation of the GOOSE messages that could potentially be published or subscribed by the IED. This would confirm that the configuration that drives the protection function logical node has been configured within the IED correctly and the logical node has been assigned within the dataset.

With the above testing confirming, the IED is publishing the correct GOOSE message and some type of element testing, verification of that message to the subscribing IEDs is critical. The system configuration tool can simply add IEDs as subscribers, but ensuring the IED is subscribing to the correct GOOSE message needs to be verified. The system configuration engineering process assigns items within each publishing dataset manually to the virtual inputs of the subscribing IEDs. This task could also potentially create a mismatch with the virtual input mapping within the system configuration tool and the mapping of the virtual inputs within the IED's internal address mapping or settable protection logic. Testing of the IED's settable logic associated with the GOOSE virtual input mapping can be performed on the individual IED similar to the publishing/element testing. While this testing will verify that the correct mapping of the GOOSE virtual inputs to the IED and IED associated logic, this testing does not verify the entire system. Verification that the IED's and plant is correctly configured, connected and integrated into the site to form a complete operational system is required. With this consideration and to optimise testing, testing of the IED's settable logic associated with the GOOSE virtual input mapping and publishing/subscribing configuration of the system can be performed together because of their link between multiple IEDs within the IEC 61850 network. This testing takes on the same philosophies as integration testing. This ensures that a GOOSE output from a particular IED is published onto the network and the subscribing IED receives the message and the required action is processed and executed. While the system configuration tool enables checking to ensure that the maximum GOOSE messages are not exceed on the station bus network. This allows measurement of the full protection scheme and the effect the network latency has on the time critical protection GOOSE message under potentially normal circumstances. This also provides confirmation that the station switches are configured correctly for their traffic control management and quality of service (QoS) parameters for that particular system.

4.2.3 Network Test Coverage

Fibre optical cables play an import role as the links between the IEDs and network switches. Most physical failures to the fibre optic cable occur during the installation of the cable. The Telecommunication Industry Association (TIA) of America describe the importance of ensuring fibre optic cables are installed correctly. Their Failure Mode and Effects Analysis (FMEA) on networks identified connector contamination and damage to fibre optic cables is the leading root cause of fibre optic networks failures. Although physical failures to the fibre optic cable present themselves as either operational or not operational during the testing and commissioning stage, it is important to reduce the potential of failure after the commissioning phase. AS/NZS ISO/IEC 14763.3:2012 Telecommunications installations—Implementation and operation of customer premises cabling Part 3: Testing of optical fibre cabling provides a guideline for inspection and test schedules. Utilising the guidelines presented in 14763.3:2012, performing a microscopic visual inspection of all end connectors, confirming continuity & polarity of cores from end to end provided confirmation that the fibre optical systems has not been damaged during construction activities. Conducting end-to-end level check (Light &

Source) of each multimode fibre would also eliminate the risk of future issues that maybe encountered during or after the commissioning phase.

As described in IEC 61850-90-4 section 18, switches configurations that affect the GOOSE messaging need to be verified, these may include IP addresses, port settings, multicast and VLAN filtering and clock settings. This can be achieved using remote access over SNMP or IEC 61850 objects. IP connectivity between devices on the station bus network can be performed using an ICMP messaging tool such as Ruggedping. Running this test for an increased interval will enable the monitoring of any loss data packets during the testing. Removal of fibre optic cables and switches from the network should be completed to test redundancy and network resiliency. This testing will confirm that the GOOSE traffic will continue to flow and failures to the network are reported and messages are received within the required times. While its critical to ensure network switches have been design to cover the systems traffic control management and quality of service (QoS) requirement, IEC 61850-90-4 recommend that these parameters a verified during type testing of systems not during the onsite testing and commissioning.

Chapter 5

Laboratory Simulation & Testing

5.1 Overview

This chapter provides details of the practical Laboratory testing using the simulated protection system illustrated in Figure 24. The test coverage matrix that was developed in section 4.2 will be used to develop methods to validate or verify the intended design of the IEDs and network. Validation and verification will be achieved through the inspection of the network using network analysing software and simulations of network faults to operate protection functions using an IEC 61850 compliant secondary injection test set. The laboratory testing will provide a greater understanding of the methods and technical requirements to safety, reliably and efficiently test, commission, and place in service a substation using IEC 61850 station bus GOOSE messaging for a circuit breaker failure scheme. This will provide a future reference and reasoning on what and why certain functions and components of the GOOSE messaging are tested and commissioned prior to placing the plant into service

5.2 Laboratory Setup & Hardware

The physical hardware setup of the test racks for the laboratory testing is illustrated Figure 35. Only the IED's associated with the circuit breaker failure scheme have been configured and will be utilised for all future laboratory simulations. Each IED associated with the protection scheme have been mounted within a number of test racks. The IED's and switches are powered up from the local 48 volt DC power supply utilising copper cabling. Multimode fibre optic cables have been used for the connection between the IED's and the station bus switches. While Ethernet cabling will be used as the communication medium between the test set, PC and network switch. Test leads will be used to inject the secondary currents and voltages into the IED and for monitoring the physical trip contacts from each of the IED's under test.

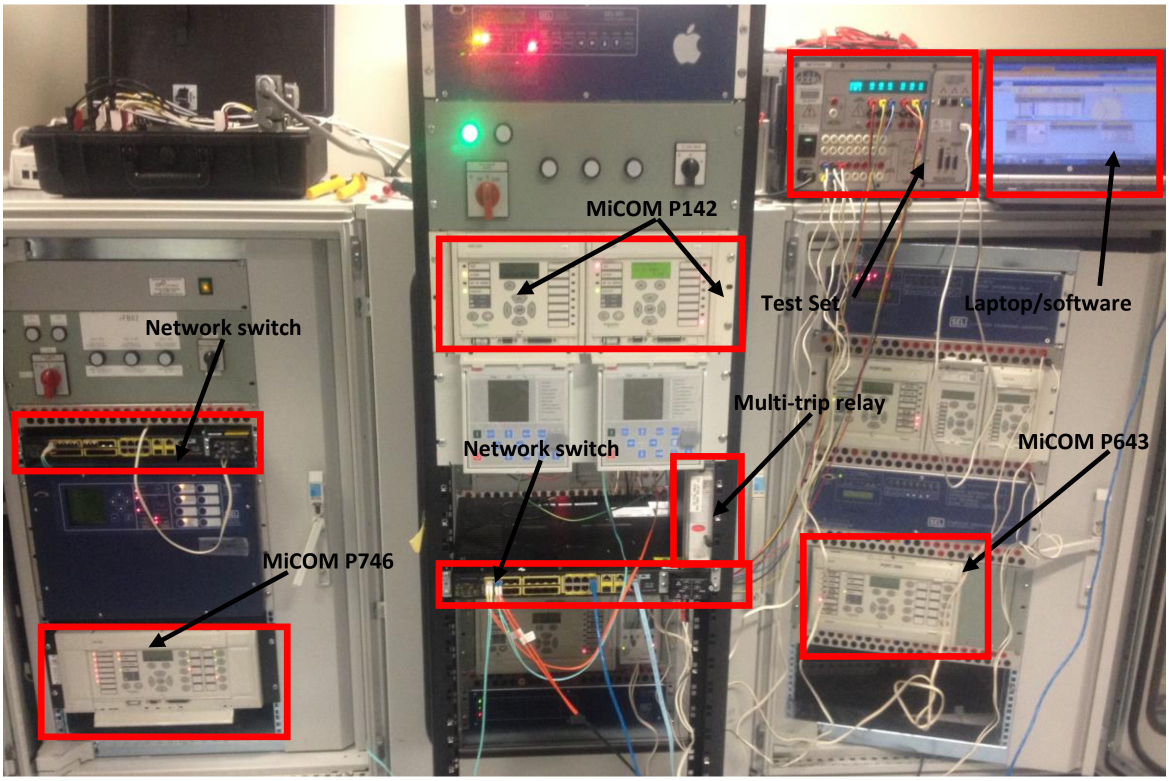

Figure 35: Test Bench Physical Hardware Setup

5.3 Test Equipment Hardware & Software

In order to simulate a power system fault that could potential be on the power network an IEC 61850 compliant (part 8) test set that can communicate with the station bus has been deployed. The test set has the capacity to inject secondary currents and voltages into the IED's, while sensing on the communication network for the protection or control GOOSE message. The test set has been setup to sense for a change in state to the physical output contact that is used to trip each circuit breaker. The test set will also be setup to monitor the physical contact outputs that are mapped to the protection functions and elements deployed within the IED's logic. This will help to compare and confirm test results expected when monitoring the expected GOOSE message.

5.3.1 Doble F6150 Test Instrument

Ergon Energy currently has twenty-four F6150 Doble power system simulators within their test sections, where the instruments are currently used for testing and commissioning of conventional protection relays and protection schemes. Due to the familiarly with this instrument and its operating software and the financial investment Ergon Energy has outlaid already to purchase these instruments, only the Doble F6150 instruments will be investigated and deployed as part of this project. The F6150 provides up to 12 sources used to test high-burden electro-mechanical relays and multifunctional numerical protection relays. The test set has the capability to inject voltage, current and frequency utilising the settable macros and parameters within the interface software. Configurations of the sources are internal and are independently controlled by the interface computer. The instruments can be configured for multiple logic input and logic output channels that allow the simulation and a mean to measure the protection scheme performance for the simulated power system fault. The Doble can be purchased or upgraded to enable IEC 61850 communications with IEC 61850 IED's or station bus network. The instruments F6860 IEC 61850 GSE Interface module option needs to be purchased and enabled via a firmware upgrade to existing test instruments. This allows the instrument to support IEC 61850 GOOSE messaging as per part 8 of the IEC 61850 standard. The front panel of the instrument that is used to interface between the F6150 and IED's/ PC is illustrated in Figure 36 and the hardware architecture of the F6150 and F6150sv is illustrated in Figure 37.

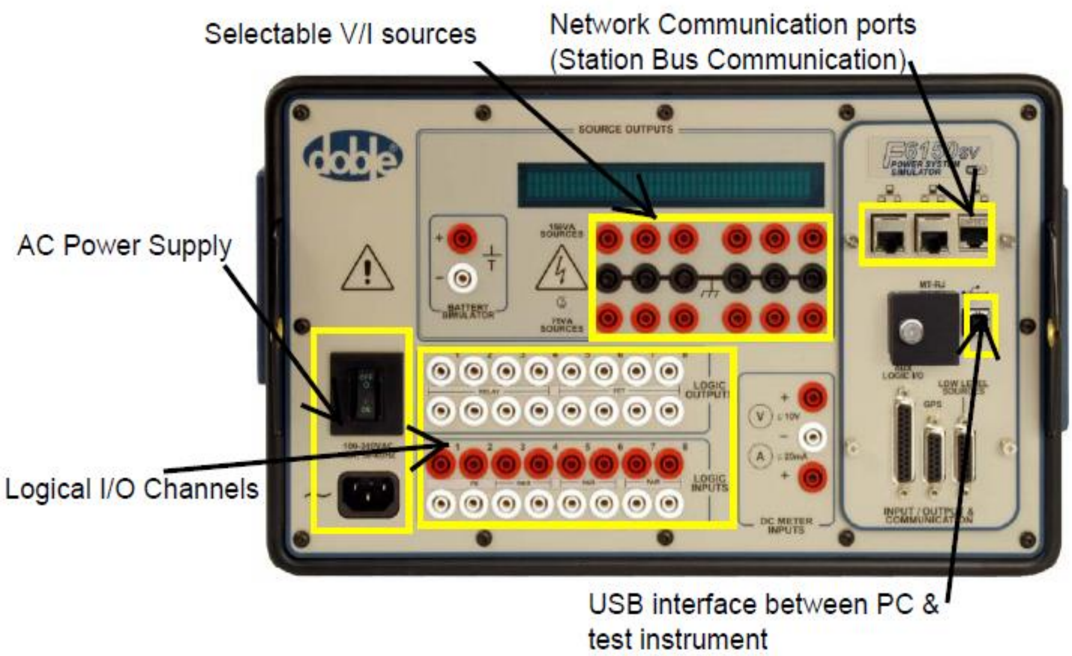

Figure 36: Doble F6150 Front Panel

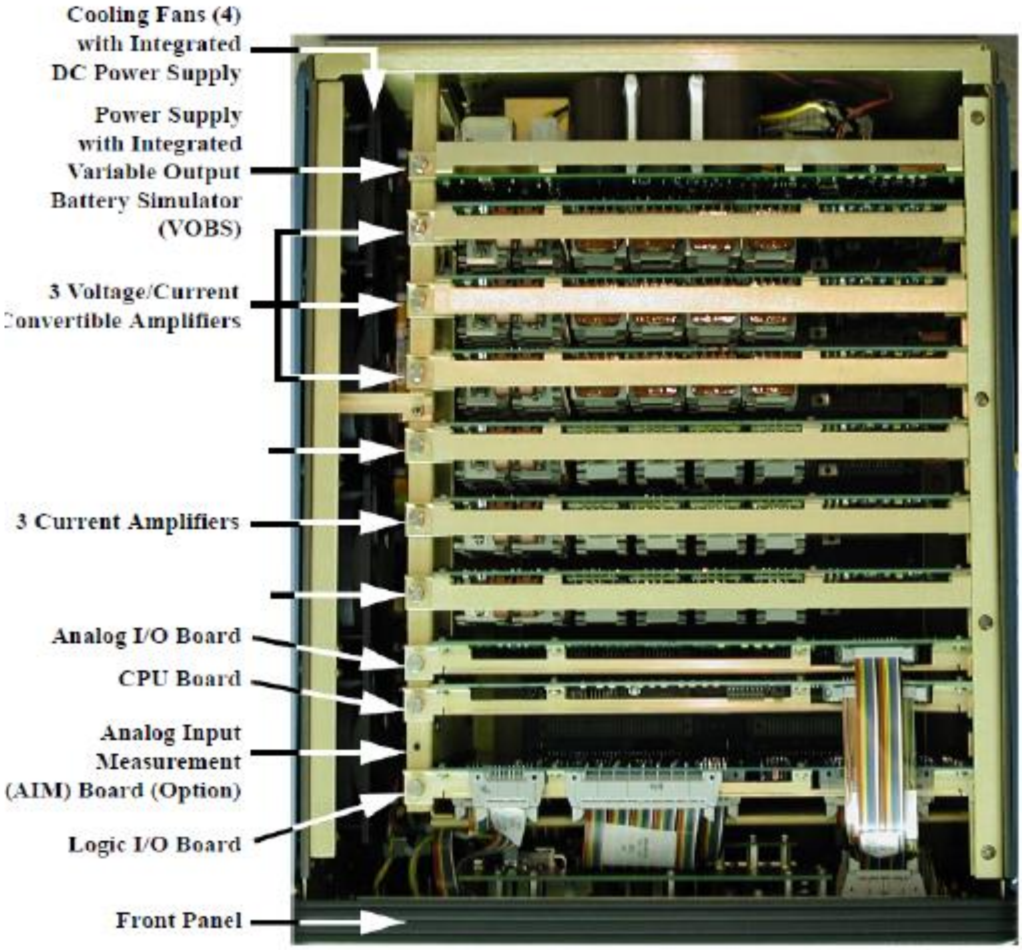

Figure 37: Doble Hardware Architecture

5.3.2 Doble Protection Suite & GSE Configurator Tool

Protection Suite is the software application used in conjunction with the Doble F6150 test instrument. Protection suite enables the operator to setup the automated power system simulations to the IED's and protection schemes. The automated test plans have a number of pre-defined test types and simulation macro's that allow the user to confirm the operation and accuracy of the IED and IED functions as well as the performance of the complete protection scheme. The Doble F6150 test instrument needs to be configured to the correct network parameters and GOOSE messaging parameters as per the site SCL files. To enable these changes, Doble's IEC 61850 GSE configurator software is required to configure the F6150 power system simulator. This allows testing of the protection schemes and IED's that use the IEC 61850 standard for sending and receiving of GOOSE messages over the Ethernet substation LAN. The GSE configurator tool utilises the IEC 61850 SCL to interface and configure the protection suite software, which enables the use of GOOSE messaging within the required test simulations. The project or site SCL files (ICD, SCD, CID) are imported into the GSE configurator, which results in a detailed listing of the messages and the dataset items within the imported

SCL file. The GOOSE subscription and publishing services are used within the GSE software to configure the required subscription (Input or Reception) and publishing (Output or Transmission) between the IED's under test and the F6150 hardware. This setup takes on a similar role to conventional protection testing, where opto inputs or contact outputs from the relay would be deployed and configured within the protection suite software to simulate and confirm the operation and accuracy of the protection relay. To enable the F6150 instrument to send and receive GOOSE messages within the protection suite test plan, each item within the dataset that is required in the test simulation is assigned a virtual input (GN) or virtual output (GP). Two file formats are developed using the GSE configurator tool. The Substation Messages File (.GSX) contains all of the listed messages, dataset items and user given names. The Test Configuration File (.GSX) contains saved substation messages and selected dataset items that are used in the mapping of the F6150 inputs (GNx) and outputs (GPx). The .GSX file is sent to the F6150 to enable to selected configuration. Figure 38 illustrates the process for configuring the instrument and Protection Suite software.

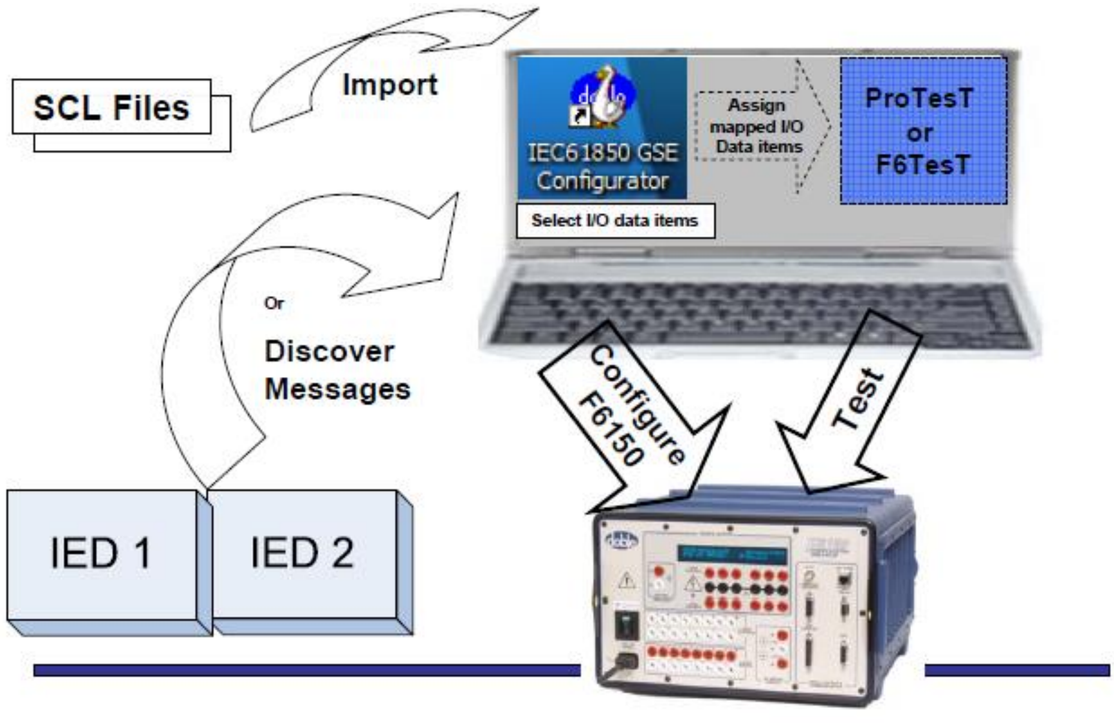

Figure 38: Doble F6150 IEC 61850 Configuration Process

5.3.3 Wireshark

When conventional hardwired inputs and outputs are deployed in a protection system, the analysing and investigation of the signals over the network of copper cabling could be performed by measuring voltages at the required point of interest. With GOOSE messaging this is not possible and a network protocol analyser is needed to view the packages of data that is travelling within the communication network. Wireshark® is a free and open-source packet analyser that is used for network troubleshooting, analysing and software development. Wireshark captures and interactively browses the traffic running on a computer network and runs on most computing platforms. The GOOSE filter within the Wireshark software enables the user to view the GOOSE messaging traffic on the network. Figure 39 illustrates a captured GOOSE message frame using the Wireshark software. The details within the GOOSE message shows that the message has the frame structure as defined in IEC 61850-8-1 and section 2.2.3.3. Note, the GOOSE message priority tagging and VLAN section of the message is stripped from the capture due to the PC network interface card (NIT). Software changes to the NIT driver and register will enable this capture function.

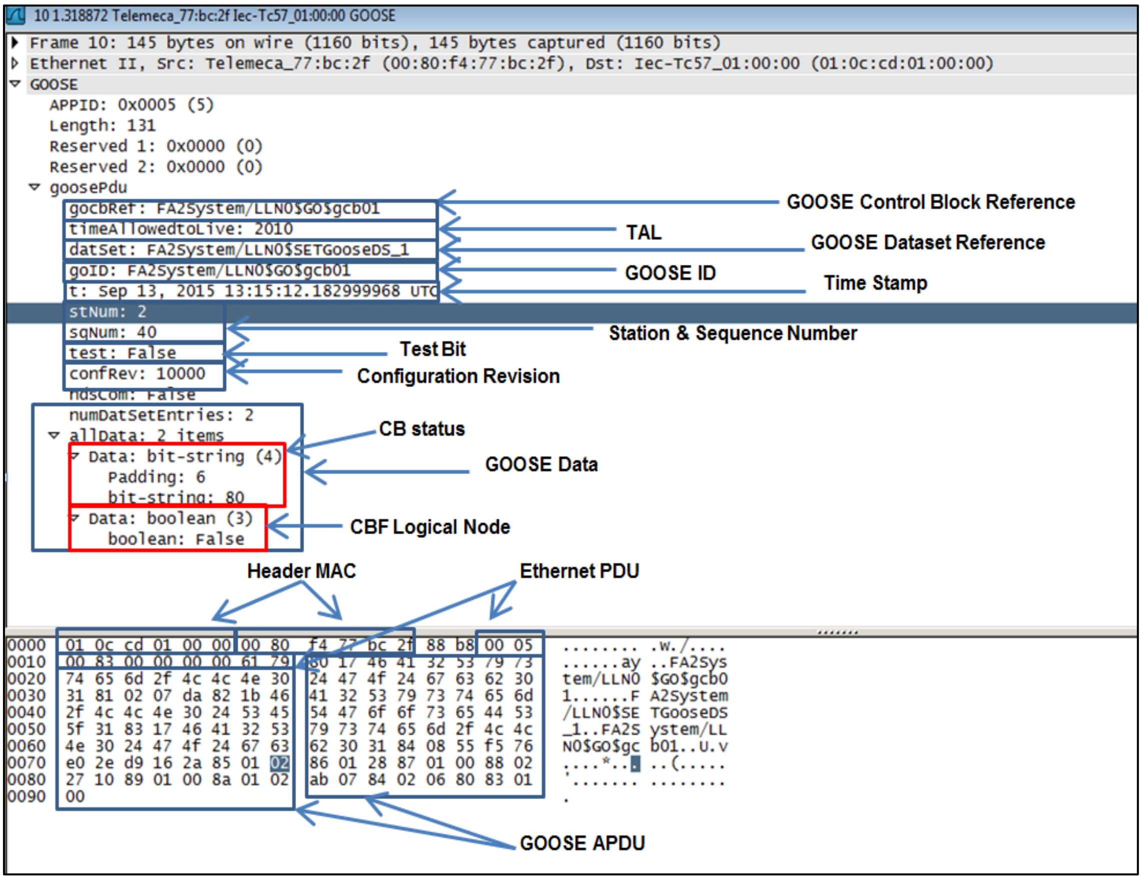

Figure 39: Wireshark GOOSE Message Capture

5.4 11kV Feeder IED CB Failure Simulation & Testing

5.4.1 Overview

The 11kV Feeder IED circuit breaker failure (CBF) simulation will be used to demonstrate methods to verify and validate item 6 under the test coverage matrix. This test will ensure that the circuit breaker failure logical node (RBRF) is assigned within the GOOSE dataset and is publishing on to the network. The following section provides the details of the hardware and software setup to achieve this test simulation. The I>2 definite time protection element will be used to trigger a circuit breaker failure event. The I>2 definite time elements is set at a current setting of 1A secondary and a time delay of 500ms. The CB fail time is set to 200ms and the current check element is set to 100mA. A measurement will be performed at the station bus switch and the test set will be sensing for a change in state to the FA2 GOOSE CBF trip message. This test will not just confirm the correct publishing of the CB fail logical node onto the network, but will also confirm the correct operation and accuracy of the IED CB failure timer setting. A measurement will also be performed at the existing conventional CB fail output contact to compare the performance.

5.4.2 Hardware Setup

Figure 40 illustrates the hardware setup of the station bus network, IED, test set and test leads used for injecting secondary current and voltage and measuring the operation of the CBF output contact.

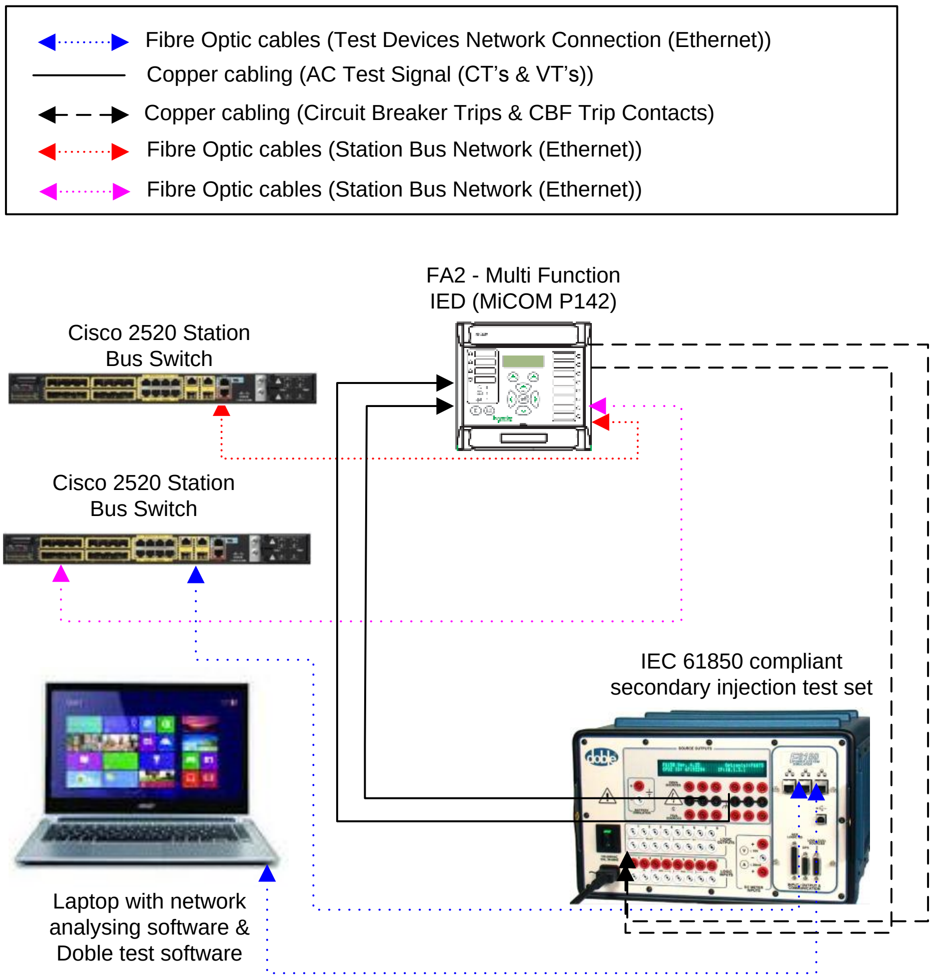

Figure 40: IED CB Failure Hardware Setup

5.4.3 Software Setup

5.4.3.1 GSE Configurator

The GSE configurator software has been configured to allow the sending and receiving of the GOOSE messages over the substation LAN from the FA2 IED. The project SCL file (SCD) has been imported into the GSE configurator, which results in a detailed listing of the messages and the dataset items within the imported SCL file. The GOOSE subscription and publishing services are used within the GSE software to configure the required subscription (Input or Reception) and publishing (Output or Transmission) between the IED's under test and the F6150 hardware. This software setup is illustrated in Figure 41.

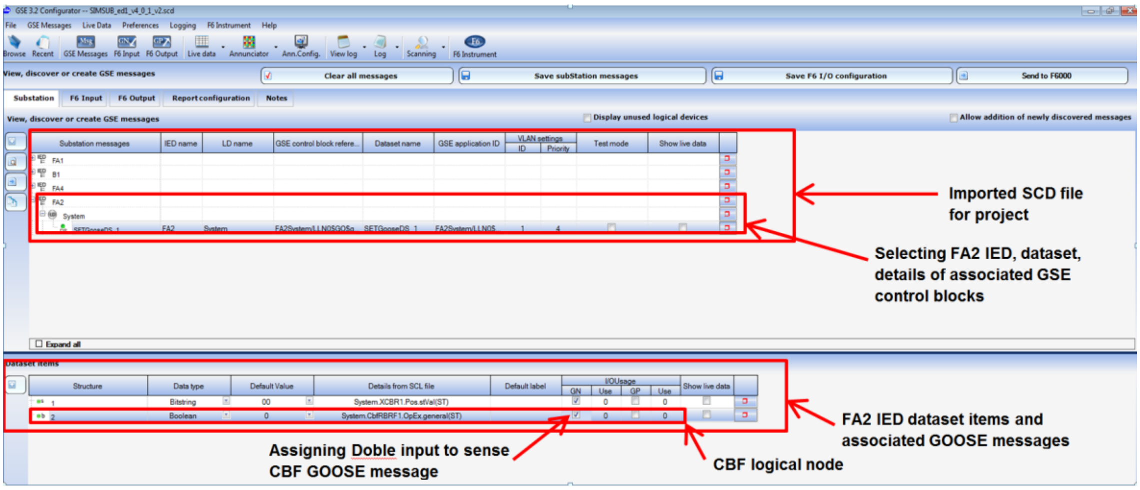

Figure 41: GSE Configurator Setup

To enable the F6150 instrument to send and receive GOOSE messages within the protection suite test plan, each item within the dataset that is required in the test simulation is assigned a virtual input (GN). The .GSX file that contains the listed messages, dataset items and user given names is sent to the F6150 to enable to selected configuration. Figure 42 illustrates the process for configuring virtual inputs (GOOSE messages) for the Doble.

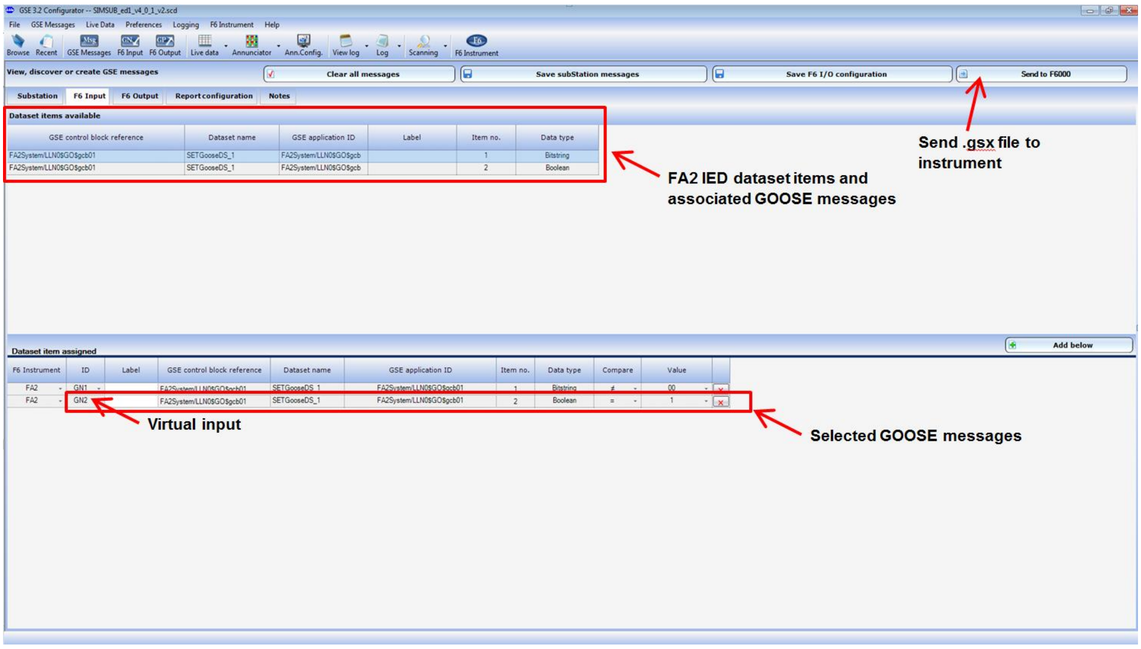

Figure 42: GSE Configurator Virtual input setup

A Protection Suite test plan was configured for the testing of the GOOSE CB fail simulation. This is illustrated in Figure 43. The test plan was setup for a pre-fault condition; this simulation acts as a normal operating state on the network. There is no fault present during this state that could potentially trigger a CB fail event. After the prefault condition (500ms), a definite time fault (I>2) was injected by the test set and the definite time pickup would be reached. This event would trigger the circuit breaker failure logic illustrated in Figure 18. The CB fail timer is initiated and starts timing down from its settable value (200ms). If the protection function and current check elements are still high after the CBF timer expires, a CBF trip will be initiated via the CBF output contact and a change in state to the GOOSE message CBF bit.

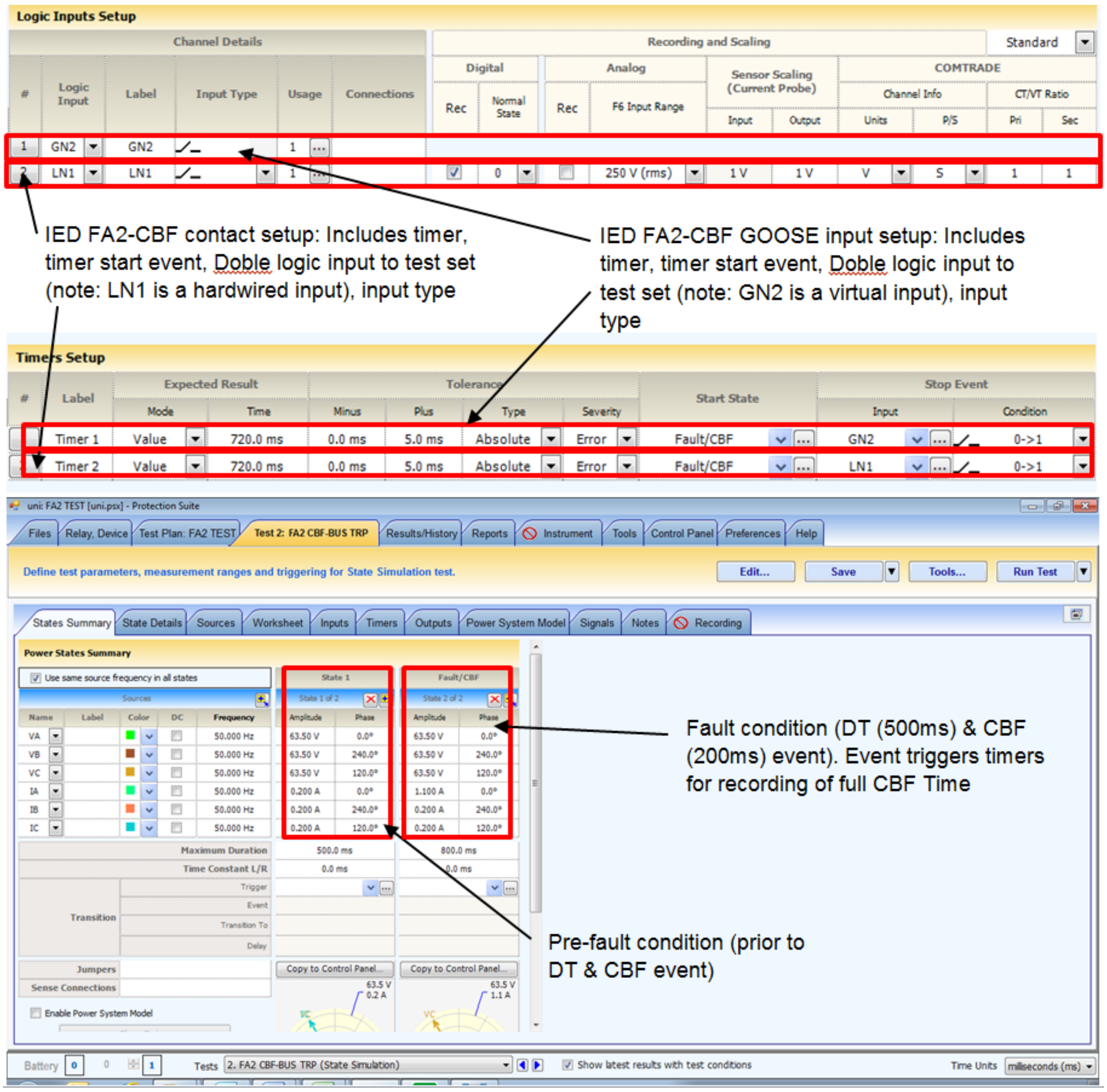

Figure 43: Protection Suite Test Plan – GOOSE & Output contact CBF Event

5.4.4 IED CBF Test Results

The measured test results are illustrated in Figure 44. Timer 1 is the time received at the station bus switch for the CB failure GOOSE message and Time 2 is measured at the FA2 IED CB failure trip contact. This test verifies that the CB failure GOOSE message is published correctly onto the network and that the CB failure timer is set to the correct setting within the IED.

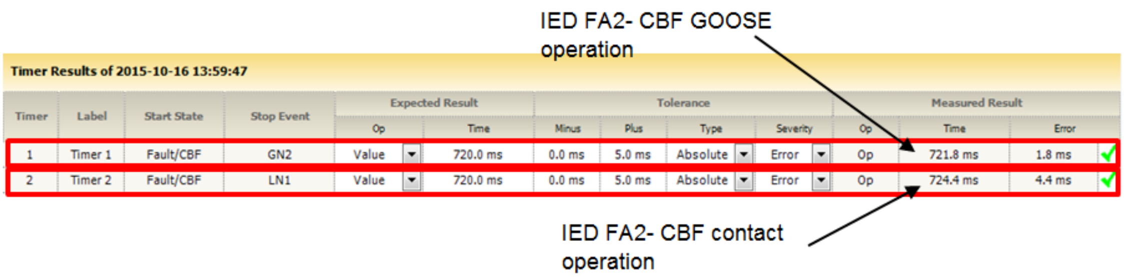

Figure 44: CB Failure GOOSE Message and Output Test Results

5.5 Circuit Breaker Failure Scheme Simulation & Testing

5.5.1 Overview

The circuit breaker failure scheme simulation will be used to demonstrate the simulation and testing methods to verify and validate items 3 and 7 under the test coverage matrix. The following section provides the details of the hardware and software setup to achieve this test simulation.

5.5.2 CBF Scheme Deploying GOOSE Messaging

This testing will simulate and measure the results for a circuit breaker failure scheme utilising the GOOSE messaging on the station bus network. Similar to 5.4, the I>2 Definite Time protection function will be used to initiate a circuit breaker failure protection event on feeder circuit breaker FA2. The I>2 definite time protection function is set at a current setting of 1A secondary and a time delay of 500ms. The CBF time is set to 200ms and the current check element is set to 100mA. FA2 IED CBF function logical node (RBRF) will be used to publish the CBF event onto the network. This will result in a change to the mapped logical node FA2 dataset1. The change in the dataset state will trigger the retransmission scheme, which will allow for a rapid spray of GOOSE messages onto the network. The bus IED has been configured to subscribe to the CBF GOOSE message, where it will process the virtual input within its internal logic. The bus zone IED will process the change in state within its internal logic, which will initiate a CB fail bus zone trip to the remaining breakers connected to that particular bus by broadcasting on its dataset 1. Subscribing IED FA1 and FA4 virtual input 2 will change to a high state. Once the GOOSE message is processed by FA1 and FA4, the IED's internal protection logic will initiate a trip to the circuit breaker trip output contact (via RL3). Measurement to confirm the correct operation, performance and accuracy of the IED GOOSE message will be performed at each IED's trip contact. This testing will verify the time to operate the entire circuit breaker failure scheme to the IED's HV circuit breaker trip contact.

5.5.2.1 GOOSE Messaging Hardware Setup

Figure 45 illustrates the hardware setup of the station bus network, IED, test set and test leads used for injecting secondary current and voltage and measuring the operation of the CBF scheme. Sense leads have been connected to FA1, FA2 and FA4 output trip contacts to measure the operation of trip that would potentially be sent to the HV circuit breaker.

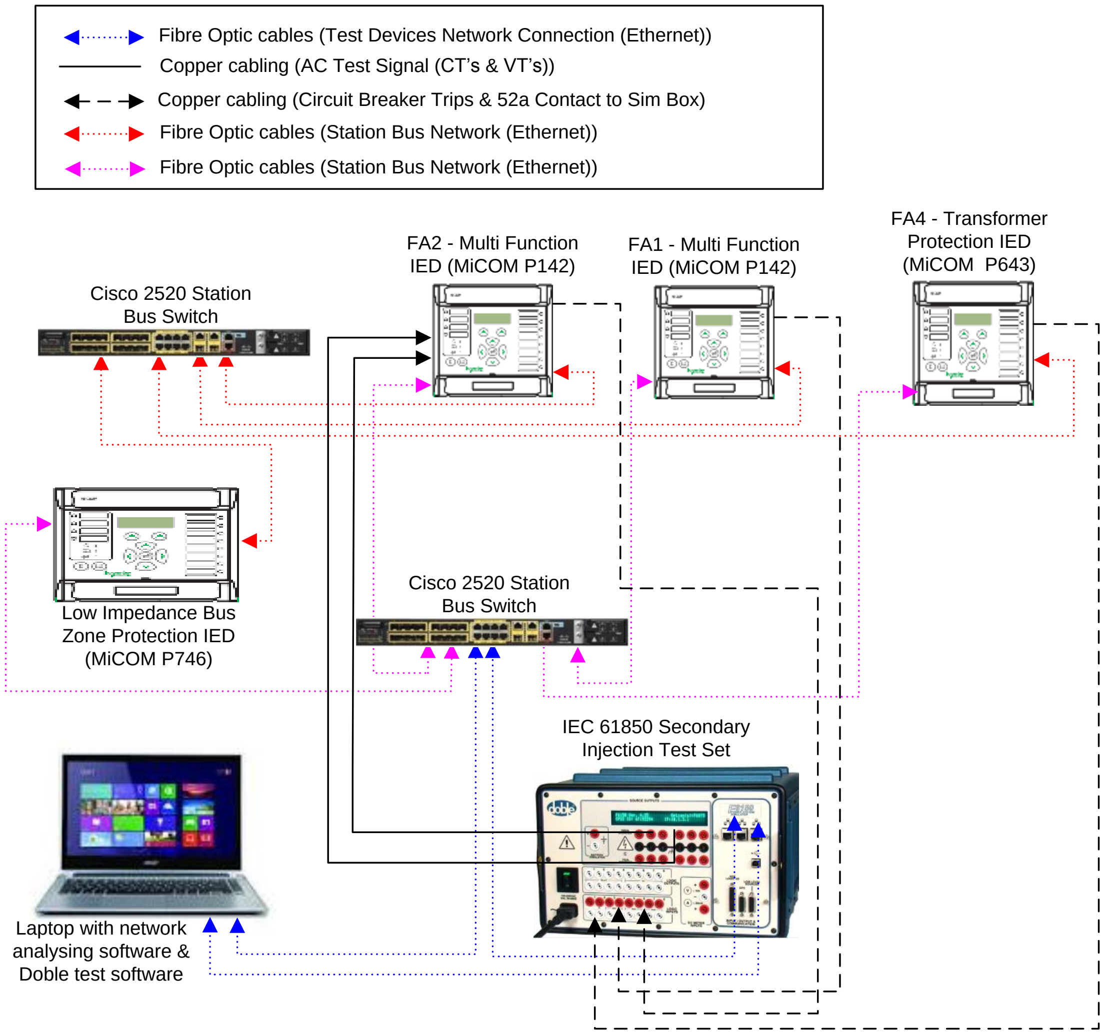

Figure 45: Hardware Setup for CBF Scheme-GOOSE Messaging

5.5.2.2 GOOSE Messaging Software Setup

A Protection Suite test plan was configured for the testing of the GOOSE messaging scheme. This is illustrated in Figure 46. The test plan was setup for a pre-fault condition; this simulation acts as a normal operating state on the network. There is no fault present during this state that could potentially trigger a CB fail event. After the prefault condition (500ms), a definite time fault (I>2) was injected by the test set and the definite time pickup would be reached. This event would trigger the circuit breaker failure logic illustrated in Figure 18. The CB fail timer is initiated and starts timing down from its settable value (200ms). If the protection function and current check elements are still high after the CBF timer expires, a CBF trip will be initiated via the GOOSE message CBF bit.

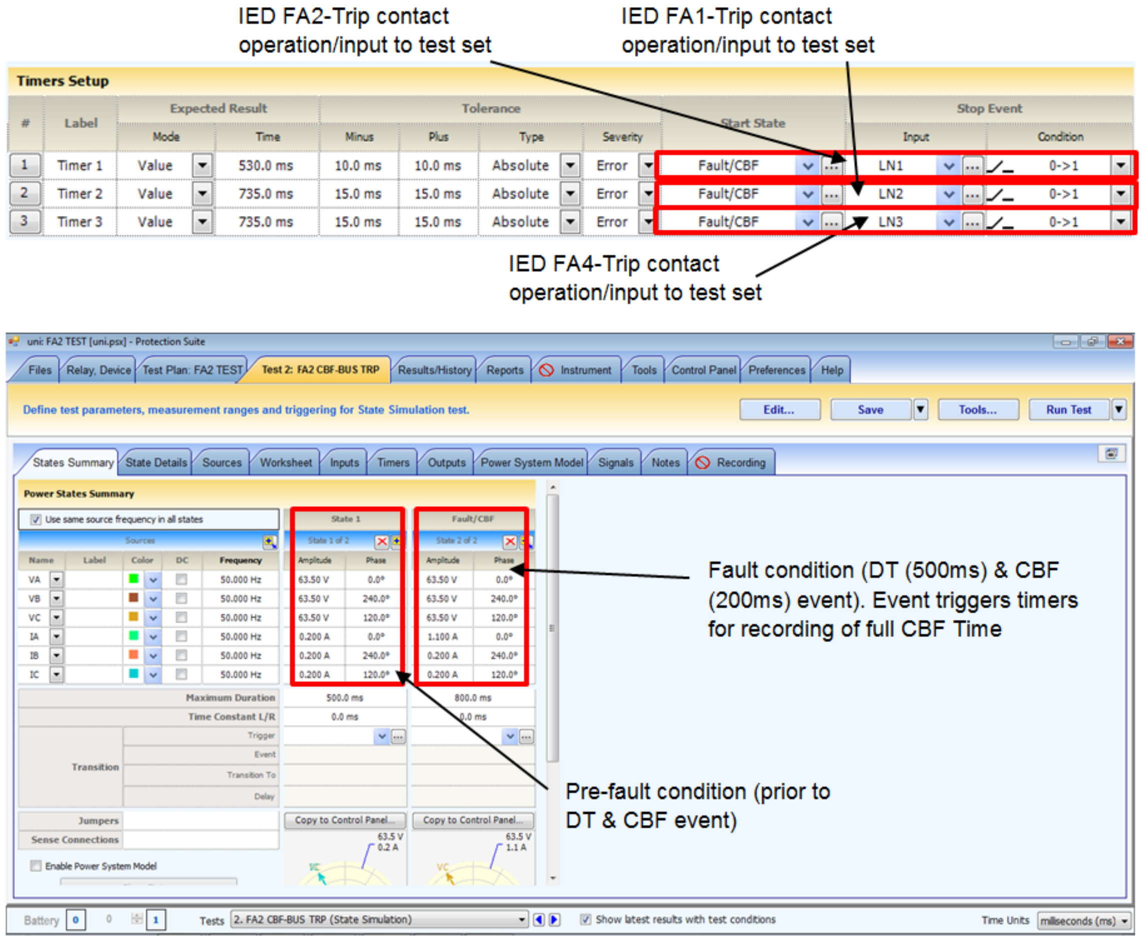

Figure 46: Protection Suite Setup - GOOSE CB Fail Scheme

5.5.2.3 GOOSE Messaging Test Results

The measured test results are illustrated in Figure 47. Timer 1 is the time to operate the FA2 IED trip contact that would be used to energise the high voltage circuit breaker trip coil. The testing shows that the contact takes around 23.3 ms to operate after the fault has been detected by the IED and time delay has expired, this time includes the IED's processing and physical operation of the contact. Timer 2 and 3 are the times measured at the trip contacts of FA1 and FA4. These contacts would be used to trip their associated circuit breakers for a CB fail event. The results show that it takes around 29.4 ms to 31.8 ms after the fault and the CB fail event to send a trip out to the remaining IED's connected to the HV bus. This includes the processing at each IED's internal logic and the transfer of the message between the switch for each IED. Figure 48 illustrates the network traffic captured using Wireshark for a CB fail event. The figure shows the re-transmission scheme that is utilised within IEC 61850 and the change in state to the FA2 IED that is used to publish the CB fail GOOSE message.

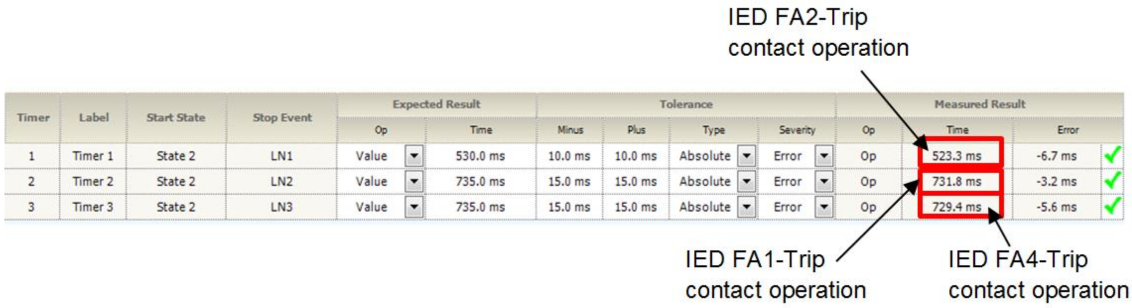

Figure 47: CB Failure Scheme GOOSE Messaging Test Results

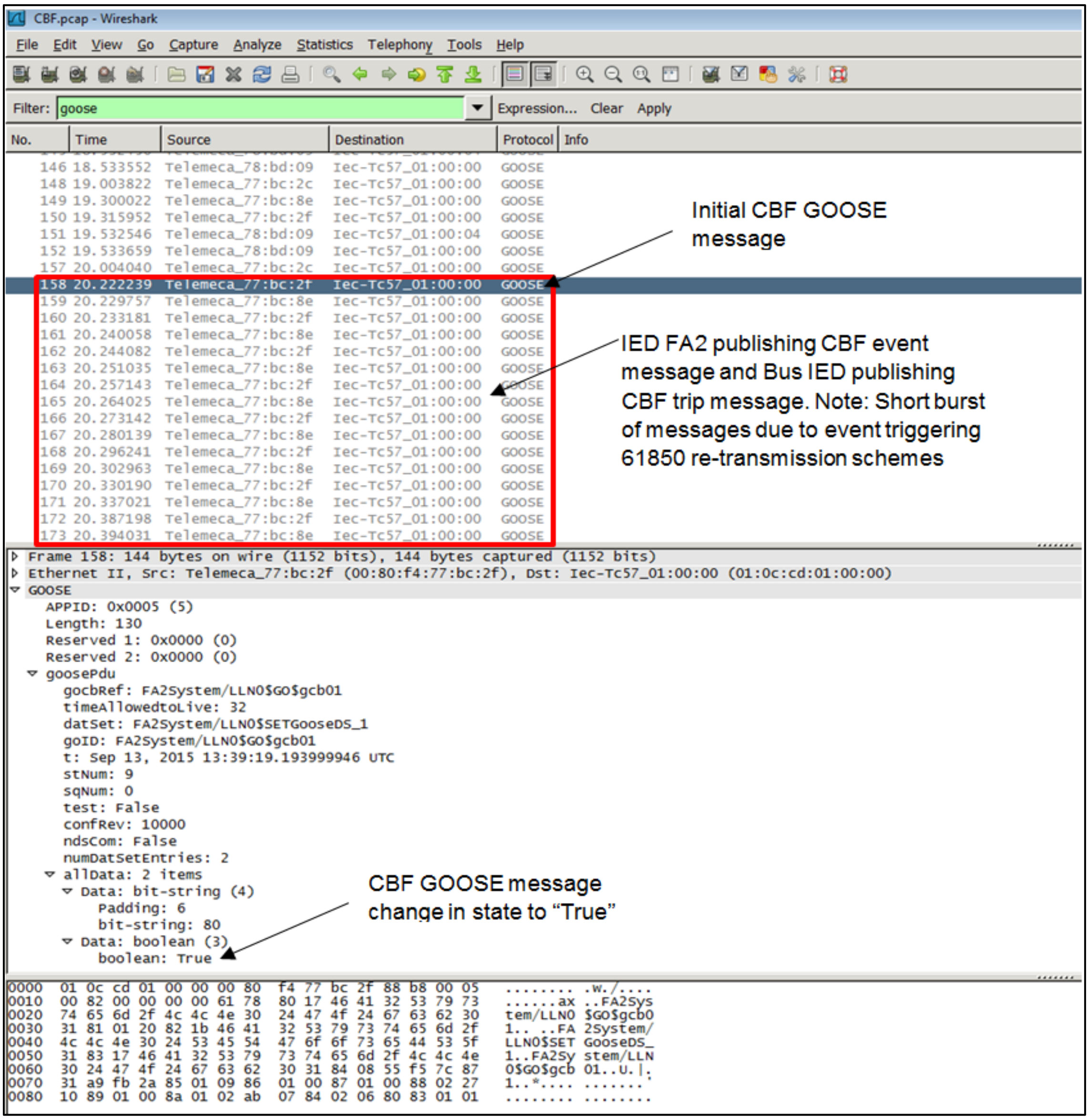

Figure 48: CBF Event Network Traffic Capture

Chapter 6

Conclusion

6.1 Overview

The development of the IEC 61850 station bus technology and introducing this technology into the substation environment has created significant change to current conventional protection and control systems. Implementing a station bus system generates a substantial change to existing design and construction practices. The specific project objectives have been met and will be discussed in this section.

Analysing current protection functions and design standards established a connection between conventional practices and future practices using GOOSE messaging at a station bus level. The circuit breaker fail protection scheme, bus zone protection, sensitive earth fault check and circuit breaker interlocking are potential protection schemes and functions that can utilise the IEC 61850 station bus. While majority of protection philosophies and the need for the protection scheme remain the same, the manner in which the system operates, executes and processes the protection scheme has changed. The introduction of the station bus technology has removed the need to have copper wiring between IED's for the sending and receiving of protection and control signals. The introduction of Ethernet based Local Area Networks (LAN) to send and receive protection and control signals has greatly reduced the circuitry requirements of a substation, but has greatly increased the configuration engineering process. With this change, new engineering processes and standards, new engineering tools, and the skills to perform the engineering have been introduced. Despite the fact that the IEC 61850 engineering process and the use of the substation configuration language are part of the IEC 61850 standard, there are still a number of capability concerns and inconsistencies when different manufacturers are introduced into the design process. The need to perform additional engineering steps with proprietary IED configuration tools introduces additional design errors and therefore additional testing.

The development of IEC 61850 Edition 2 has corrected technical issues, improved inconsistencies and clarified interoperability issues encountered from different IED manufacturers under Edition 1. IEC 61850 Edition 2 “Function Test” and “Simulation” modes have provided greater functionality that could potentially be utilised during the testing and commissioning of an IEC 61850 substation. All of the isolation methods under edition 1 would provide suitable isolation functions, but would require the need for additional design and testing due to its nonstandard implementation. The “Function Test” mode has the capability to be integrated into a virtual isolation process, which would be used as an isolation mechanism for in service protection isolation. This edition 2 method for isolation would need limited testing to verify its intended design because of the conformance testing of this function are performed under part 10 of the standard.

The Hazard and Operability study (HAZOP) has been identified as an effective, structured and systematic analysing process. The HAZOP study identified potential deviations from the IEC 61850 station bus circuit breaker failure protection scheme design intent. The HAZOP identified potential causes (failures or faults) and consequences of that deviation. The highest potential deviations have been identified as logical node failures. These are conceptual components such as software modules, logic, settings or parameters and code within the IED. This is due to the software base nature of IEC 61850. IED physical hardware deviations are limited due to the IEDs having superior self-monitoring or supervision capabilities. Fibre optic cables used to connect the station bus are the main physical hardware deviation on the network. While most deviations occur after the commissioning, it is vital to have inspection and test schedules to reduce the potential of failure during the operation life of the network. Extensive evaluation and standardisation of IED and network hardware, firmware and software utilised to apply the settings can potentially reduce these technical deviations. While implementing a rugged quality assurance system, configuration management system and establishing an audit and validation process can potentially reduce procedural, administrative and inadvertent issues.

Deviations from the design intent identified from the HAZOP assessment were reassessed if the possible causes and consequences could be reduced or eliminated by a redesign of the system. If the possible causes and consequences could not be reduced or eliminated by a redesign of the system, a mechanism to validate or verify the design was introduced into a test coverage matrix. A test coverage matrix identified the relevant elements, settings, parameters, functions, systems and characteristics that will require validating or verifying through inspection, testing, measurement or simulations during the testing and commissioning process.

The testing and commissioning philosophies that exist for conventional microprocessor based IED's and their protection scheme have a similar concept to IEC 61850 IED's and their associated protection scheme. However, a system approach to testing can be deployed on an IEC 61850 system due to the relationship between the elements, logic and publishing/subscribing of the IED. Verification of non-monitored parts of the IED such as the current and voltage transformers, A/D converters are still critical, similar to a conventional microprocessor based IED's. The introduction of reduced or no element testing on an IEC

61850 IED because of its digital nature require additional engineering justification and assessment. To reduce and optimise the number of test required, element testing can be performed in conjunction with publishing verification of the IEC 61850 IED. Testing and confirming that the correct logical nodes (LN) utilised within the dataset has been assigned and is published onto the network is essential, including element testing into this test can provide additional test coverage. Verification that the subscribing IED receives the message and the required action is processed and executed is vital. This testing can achieved separately or as an entire system depending on proposed implementation of the protection system. Testing of the network and fibre optic system should be performed with reference to AS/NZS ISO/IEC 14763.3:2012 and in IEC 61850-90-4 section 18.

New testing and commissioning tools are required to perform the required verification and validation of the protection system, this also drives the need for new and improved skill sets of the personnel performing these tasks. The development of the simulated substation helped to evaluate the new engineering processes and standards and new engineering tools. The laboratory testing utilising the developed simulated substation provided a greater understanding of the methods, tools and technical requirements to perform these tasks identified under the test coverage matrix.

The introduction of the Station Bus technology has a significant change in the way a substation protection system is tested and commissioned with substantial changes to current philosophies and practices.

6.2 Further Work

Investigate and analyse utilising a HAZOP study all protection functions that can be deployed in an IEC 61850 station bus system. This will identify the full testing and commissioning requirements for a station bus system. Testing and commissioning quality assurance documentation can be developed after a full assessment has been achieved and will enable development of the assessment criteria.

Investigate and assess the testing and commissioning requirements if process bus technology, such as merging unit and smart IED's are implemented into the system.

Develop a Mode and Effects Analysis (FMEA) risk assessment to identify potential preventive maintenance requirements on an IEC 61850 station bus system. This assessment will allow utilities to develop maintenance strategies and procedures for an IEC 61850 station bus system.

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Appendix A: Project Specification

University Of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Robert Peter ACCENDERE**

TOPIC: An Investigation into the Testing and Commissioning Requirements of IEC 61850 Station Bus Substations

SUPERVISOR: Dr Tony Ahfock

SPONSORSHIP: Ergon Energy

PROJECT AIM: To investigate and provide a better understanding of the methods and technical requirements to safety, reliably and efficiently test and commission and place in service a substation using IEC 61850 station bus GOOSE messaging.

PROGRAMME: (**FINAL**)

1) Research the background information relating to the IEC 61850 standard, legislation requirements for testing of substation protection systems, testing and commissioning techniques and processes for substation protection systems.

2) Identify the configuration tools, test equipment and software used for the design, testing and commissioning of an IEC 61850 station bus substation using the GOOSE messaging

3) Analyse the protection functions and test required for verifying associated IED's logic/protection functions that uses the GOOSE messaging within an IEC 61850 station bus substation.

4) Analyse the site integration test required for verifying the station bus network, protection inter-tripping schemes and protection isolation within an IEC 61850 station bus substation.

5) Analyse IED's logic/protection functions that uses the GOOSE messaging within an IEC 61850 station bus substation against conventional protection relay logic/protection functions.

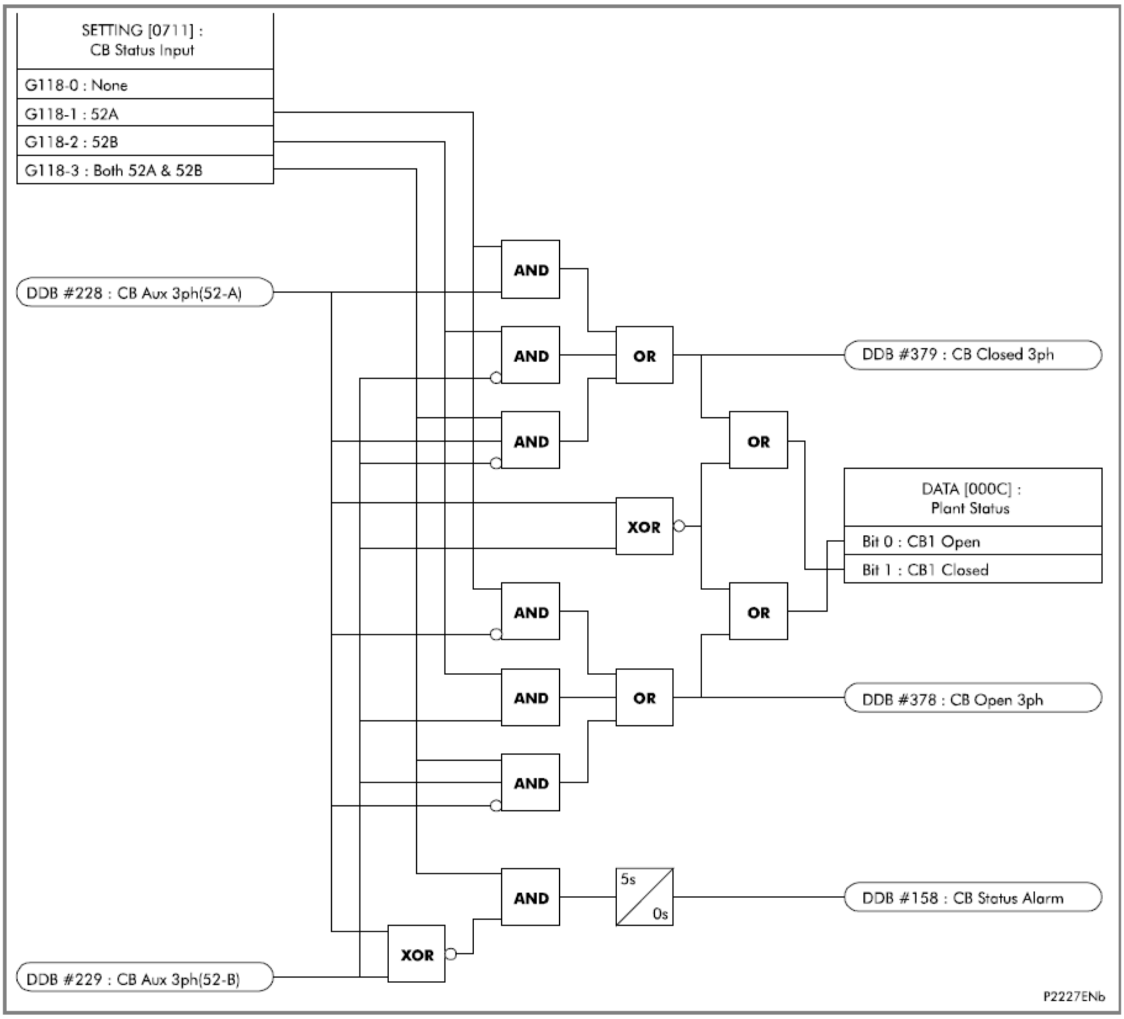
As time permits:

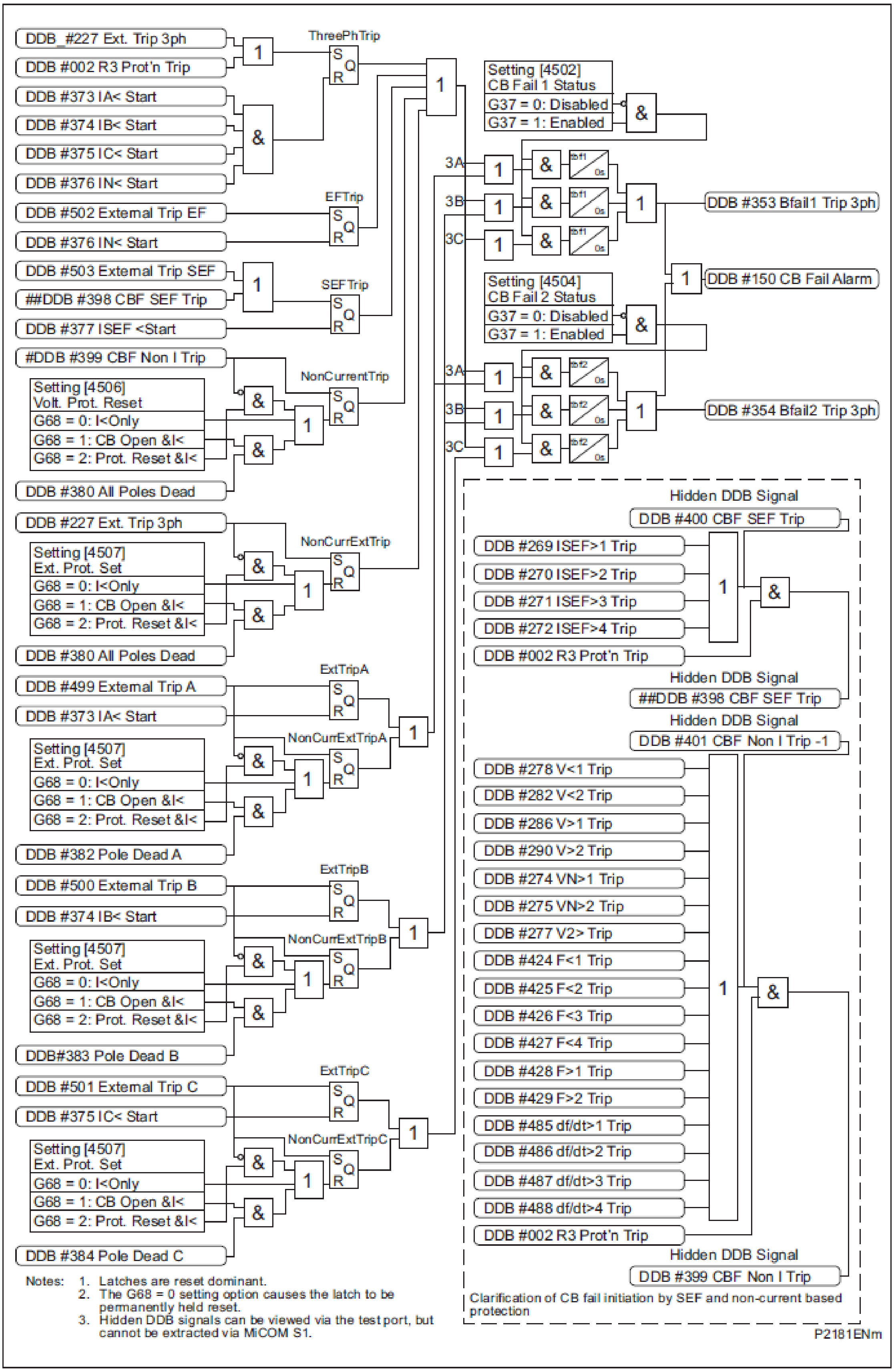
6) Test analysed site integration tests using simulated substation.

7) Analyse the maintenance requirements for an IEC 61850 IED.

Appendix B: Project Design Specifications

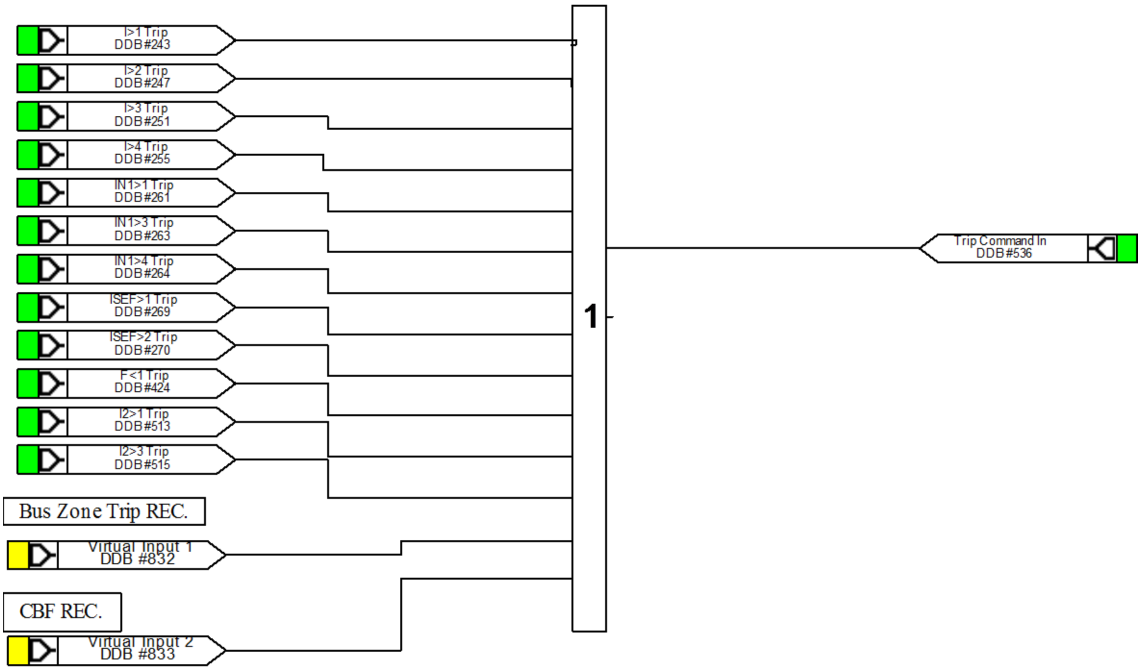
IED Internal Logic



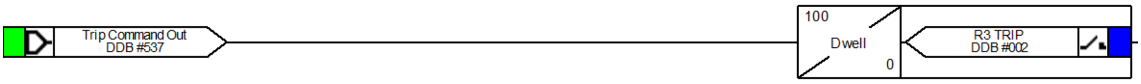

DDB_#227 Ext. Trip 3ph
DDB #002 R3 Prot'n Trip
DDB #373 IA< Start
DDB #374 IB< Start
DDB #375 IC< Start
DDB #376 IN< Start
DDB #502 External Trip EF
DDB #376 IN< Start
DDB #503 External Trip SEF
##DDB #398 CBF SEF Trip
DDB #377 ISEF <Start
#DDB #399 CBF Non I Trip
Setting [4506]
Volt. Prot. Reset
G68 = 0: I<Only
G68 = 1: CB Open &I<
G68 = 2: Prot. Reset &I<
DDB #380 All Poles Dead
DDB #227 Ext. Trip 3ph
Setting [4507]
Ext. Prot. Set
G68 = 0: I<Only
G68 = 1: CB Open &I<
G68 = 2: Prot. Reset &I<
DDB #380 All Poles Dead
DDB #499 External Trip A
DDB #373 IA< Start
Setting [4507]
Ext. Prot. Set
G68 = 0: I<Only
G68 = 1: CB Open &I<
G68 = 2: Prot. Reset &I<
DDB #382 Pole Dead A
DDB #500 External Trip B
DDB #374 IB< Start
Setting [4507]
Ext. Prot. Set
G68 = 0: I<Only
G68 = 1: CB Open &I<
G68 = 2: Prot. Reset &I<
DDB#383 Pole Dead B
DDB #501 External Trip C
DDB #375 IC< Start
Setting [4507]
Ext. Prot. Set
G68 = 0: I<Only
G68 = 1: CB Open &I<
G68 = 2: Prot. Reset &I<
DDB #384 Pole Dead C
ThreePhTrip
EFTrip
SEF Trip
NonCurrentTrip
NonCurrExtTrip
ExtTripA
NonCurrExtTripA
ExtTripB
NonCurrExtTripB
ExtTripC
NonCurrExtTripC
Setting [4502]
CB Fail 1 Status
G37 = 0: Disabled
G37 = 1: Enabled
3A
3B
3C
tbf1
0s
DDB #353 Bfail1 Trip 3ph
DDB #150 CB Fail Alarm
Setting [4504]
CB Fail 2 Status
G37 = 0: Disabled
G37 = 1: Enabled
tbf2
DDB #354 Bfail2 Trip 3ph
Hidden DDB Signal
DDB #400 CBF SEF Trip
DDB #269 ISEF>1 Trip
DDB #270 ISEF>2 Trip
DDB #271 ISEF>3 Trip
DDB #272 ISEF>4 Trip
DDB #002 R3 Prot'n Trip
Hidden DDB Signal
##DDB #398 CBF SEF Trip
Hidden DDB Signal
DDB #401 CBF Non I Trip -1
DDB #278 V<1 Trip
DDB #282 V<2 Trip
DDB #286 V>1 Trip
DDB #290 V>2 Trip
DDB #274 VN>1 Trip
DDB #275 VN>2 Trip
DDB #277 V2> Trip
DDB #424 F<1 Trip
DDB #425 F<2 Trip
DDB #426 F<3 Trip
DDB #427 F<4 Trip
DDB #428 F>1 Trip
DDB #429 F>2 Trip
DDB #485 df/dt>1 Trip
DDB #486 df/dt>2 Trip
DDB #487 df/dt>3 Trip
DDB #488 df/dt>4 Trip
DDB #002 R3 Prot'n Trip
Hidden DDB Signal
DDB #399 CBF Non I Trip
Clarification of CB fail initiation by SEF and non-current based protection
Notes: 1. Latches are reset dominant.
2. The G68 = 0 setting option causes the latch to be permanently held reset.
3. Hidden DDB signals can be viewed via the test port, but cannot be extracted via MiCOM S1.
P2181ENm

IED Modified PSL-P142

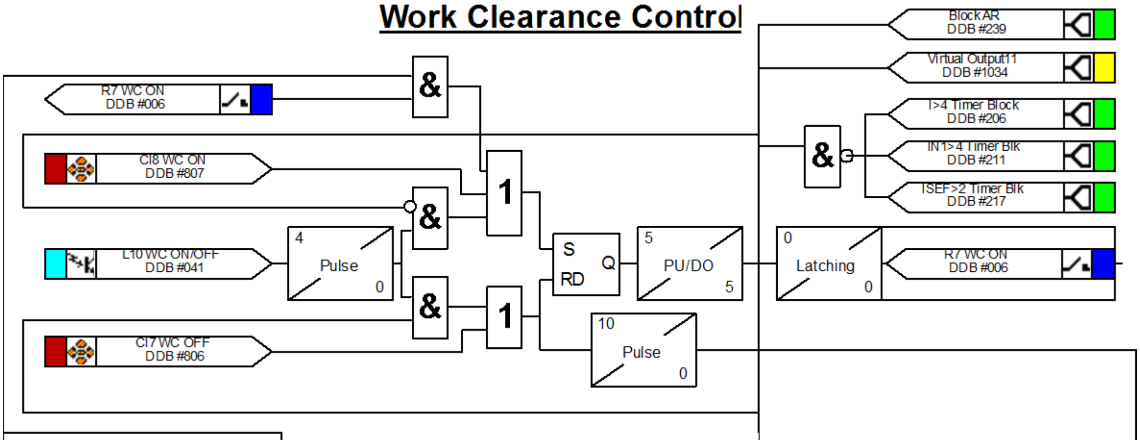
Trip Output Mapping



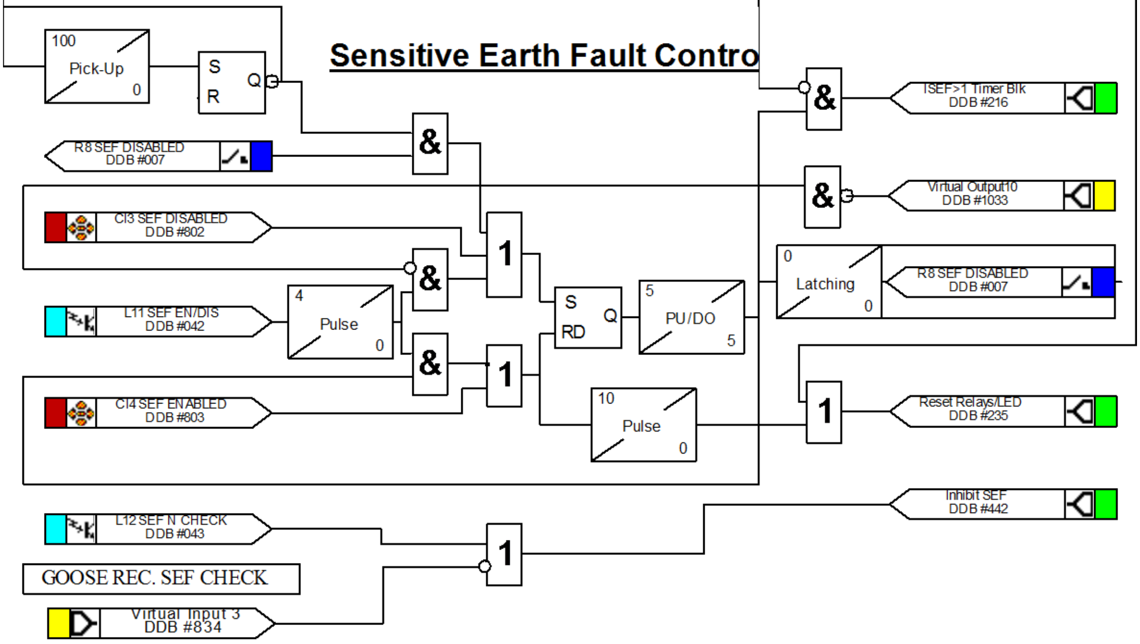
Output Relay Mappings



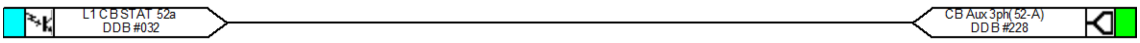
Work Clearance Control



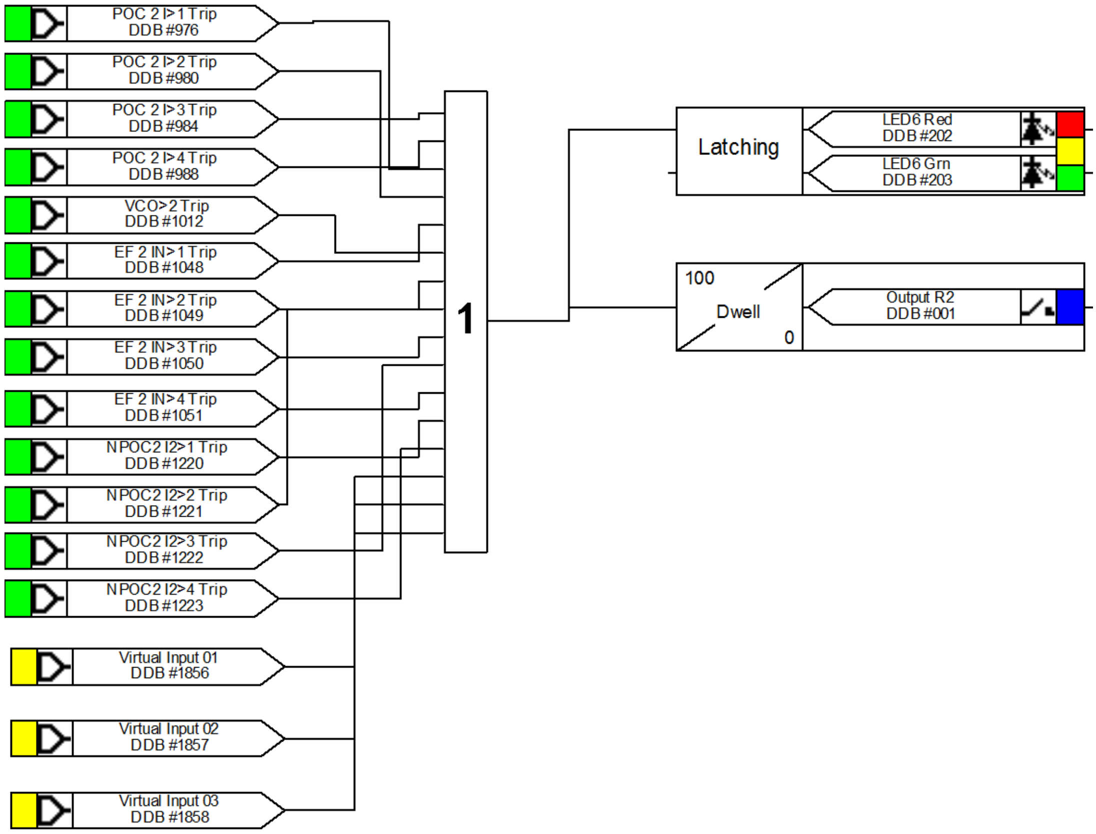
Sensitive Earth Fault Contro



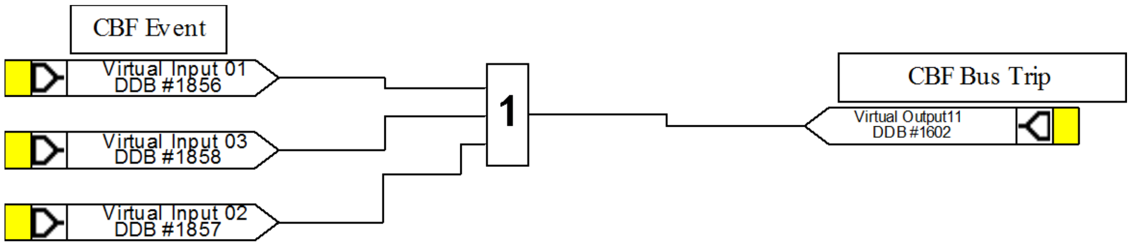
CB Status



IED Modified PSL-P643



IED Modified PSL-P746



CISCO 2520 Switch Configurations

```
Version 2.0
no service pad
service tcp-keepalives-in
service timestamps debug datetime msec show-timezone
service timestamps log datetime localtime
service password-encryption
no service dhcp
!
hostname ErgonSw1
!
boot-start-marker
boot-end-marker
!
logging buffered 64000
username admin password 0 Password
aaa new-model
!
aaa session-id common
clock timezone EST 10 0
system mtu routing 1500
no ptp profile
ptp mode forward
!
no ip igmp snooping
login on-failure log
login on-success log
!
errdisable recovery cause bpduguard
errdisable recovery cause link-flap
errdisable recovery cause storm-control
!
spanning-tree mode mst
spanning-tree portfast bpduguard default
spanning-tree extend system-id
!
spanning-tree mst configuration
 name 61850_MSTP
 revision 1
 instance 1 vlan 01-10
!
spanning-tree mst forward-time 12
spanning-tree mst max-age 16
spanning-tree mst 0-5 priority 32768
!
alarm profile defaultPort
 alarm link-fault not-forwarding not-operating fcs-error
 syslog link-fault not-forwarding not-operating fcs-error
 notifies link-fault not-forwarding not-operating fcs-error
!
alarm relay-mode negative
alarm facility power-supply rps notifies
alarm facility power-supply voltage disable
!
vlan internal allocation policy ascending
!
vlan 01
 name Main
!
vlan 10
 name Backup
!
ip ssh time-out 60
ip ssh authentication-retries 2
ip ssh version 2
!
class-map match-any HIGH_CLASS
 description Match GOOSE COS value for output QOS
  match cos  4  5
class-map match-any GOOSE_CLASS
 description Match Goose VLAN
  match vlan  01
!
policy-map OUT_POLICY
 description Limit total traffic to 10Mb for Relay
 class HIGH_CLASS
    priority
    police 9000000
 class class-default
    shape average 1000000
policy-map GOOSE_TAG
```

```
 description Set all GOOSE VLAN traffic as COS 4
 class class-default
  set cos 4
policy-map IN_QOS_POLICY
 description Tag traffic based on VLAN
 class GOOSE_CLASS
  service-policy GOOSE_TAG
policy-map OUT_QOS_POLICY
 description Limit GOOSE to Priority 20Mb Max, Remaining for default
 class HIGH_CLASS
   police cir 20000000
   priority
 class class-default
   bandwidth percent 80
!
interface FastEthernet0/1
 description Trunk to BUS1
 port-type nni
 switchport trunk allowed vlan 1,10
 switchport mode trunk
 logging event status
 duplex full
 storm-control broadcast level 10.00
 storm-control action trap
 spanning-tree link-type point-to-point
 service-policy input IN_QOS_POLICY
 service-policy output OUT_QOS_POLICY
 no shutdown
!
interface FastEthernet0/2
 description Trunk to FA1
 port-type nni
 switchport trunk allowed vlan 1,10
 switchport mode trunk
 logging event status
 duplex full
 storm-control broadcast level 10.00
 storm-control action trap
 spanning-tree link-type point-to-point
 service-policy input IN_QOS_POLICY
 service-policy output OUT_QOS_POLICY
 no shutdown
!
interface FastEthernet0/3
 description Trunk to FA2
 port-type nni
 switchport trunk allowed vlan 1,10
 switchport mode trunk
 logging event status
 duplex full
 storm-control broadcast level 10.00
 storm-control action trap
 spanning-tree link-type point-to-point
 service-policy input IN_QOS_POLICY
 service-policy output OUT_QOS_POLICY
 no shutdown
!
interface FastEthernet0/4
 description Trunk to FA3
 port-type nni
exit
 switchport mode trunk
 logging event status
 duplex full
 storm-control broadcast level 10.00
 storm-control action trap
 spanning-tree link-type point-to-point
 service-policy input IN_QOS_POLICY
 service-policy output OUT_QOS_POLICY
 no shutdown
!
interface FastEthernet0/5
 description Trunk to FA4
 port-type nni
 switchport trunk allowed vlan 1,10
 switchport mode trunk
 logging event status
 duplex full
 storm-control broadcast level 10.00
 storm-control action trap
 spanning-tree link-type point-to-point
 service-policy input IN_QOS_POLICY
 service-policy output OUT_QOS_POLICY
 no shutdown
!
interface FastEthernet0/7
 port-type nni
```

```
 duplex full
 shutdown
!
interface FastEthernet0/7
 port-type nni
 duplex full
 shutdown
!
interface FastEthernet0/8
 port-type nni
 duplex full
 shutdown
!
interface FastEthernet0/9
 port-type nni
 duplex full
 shutdown
!
interface FastEthernet0/10
 port-type nni
 duplex full
 shutdown
!
interface FastEthernet0/11
 port-type nni
 duplex full
 shutdown
!
interface FastEthernet0/12
 port-type nni
 duplex full
 shutdown
!
interface FastEthernet0/13
 port-type nni
 duplex full
 shutdown
!
 port-type nni
 duplex full
 shutdown
!
interface FastEthernet0/15
 port-type nni
 duplex full
 shutdown
!
interface FastEthernet0/16
 port-type nni
 duplex full
 shutdown
!
interface FastEthernet0/17
 port-type nni
 duplex full
 shutdown
 power inline never
 power inline police
!
interface FastEthernet0/18
 port-type nni
 duplex full
 shutdown
 power inline never
 power inline police
!
interface FastEthernet0/19
 port-type nni
 duplex full
 shutdown
 power inline never
 power inline police
!
interface FastEthernet0/20
 port-type nni
 duplex full
 shutdown
 power inline never
 power inline police
!
interface FastEthernet0/21
 port-type nni
 duplex full
 shutdown
 power inline never
 power inline police
!
interface FastEthernet0/22
```

```
 port-type nni
 duplex full
 shutdown
 power inline never
 power inline police
!
interface FastEthernet0/23
 description Trunk to Testing conncection Port1
 port-type nni
switchport trunk native vlan 1
 switchport trunk allowed vlan 1,10
 switchport mode trunk
 duplex auto
 power inline never
 power inline police
 storm-control broadcast level 1.00
 storm-control multicast level 5.00
 storm-control unicast level 50.00
 storm-control action trap
 spanning-tree portfast trunk
 service-policy input IN_QOS_POLICY
 no shutdown
!
interface FastEthernet0/24
 description Trunk to Testing conncection Port2
 port-type nni
switchport trunk native vlan 1
 switchport trunk allowed vlan 1,450
 switchport mode trunk
 duplex auto
 power inline never
 power inline police
 storm-control broadcast level 1.00
 storm-control multicast level 5.00
 storm-control unicast level 50.00
 storm-control action trap
 spanning-tree portfast trunk
 service-policy input IN_QOS_POLICY
 no shutdown
!
interface GigabitEthernet0/1
 description Capture Device SPAN Port
 port-type nni
 media-type rj45
 spanning-tree portfast
 no shutdown
!
interface GigabitEthernet0/2
 description NFS SPAN Port
 port-type nni
 media-type rj45
 spanning-tree portfast
 no shutdown
!
interface Vlan 1
 no ip address
 no ip route-cache
 shutdown

!
ip default-gateway 10.128.47.1
no ip http server
ip http access-class 23
ip http secure-server
ip http timeout-policy idle 60 life 86400 requests
10000
no cdp run
!
banner login ^C
********************************************
********************
*                             *
*  Unauthorised access      *
*                             *
********************************************
********************
^C
!
line con 0
line vty 0 4
 transport input telnet
!
monitor session 1 source vlan 01 , 10
monitor session 1 destination interface Gi0/1 - 2
encapsulation replicate
end
```

Appendix C: CB Failure HAZOP Assessment

STUDY TITLE:			CBF Protection scheme using GOOSE messaging on a station bus			**SHEET:**	1A
REFERENCE DRAWING No.:			GOOSE Protection matrix and IED internal logic diagrams, GOOSE direction communication diagram, system configurations.			**DATE:**	11/08/2015
PART CONSIDERED:			All IED settings & logic. Publishing and subscribing of dataset contain CBF trips. Network devices				
DESIGN INTENT:			An 11kV CB Fails to trip for a protection fault. Trip remaining CB's on that particular bus to clear fault				
Item No.	**Element**	**Function**	**Guide word**	**Deviation**	**Possible causes**	**Consequences**	**Safeguards &/or Test Action**
1A	Setting value or parameter	CBF Enabled in IED	No	CBF function not set/enabled in IED	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to send trip to upstream scheme/CB to trip. Fail to trip and clear fault. Catastrophic to equipment and safety	Confirm function enabled, after settings have been loaded into IED
2A	Setting value or parameter	CBF Current Check	No	CBF function current pickup set to zero	Human error, incorrect value entered or incorrect template used	Fail to trip and clear fault. Catastrophic to equipment and safety	Confirm CBF current pickup using secondary injection test set or confirmation via setting compare.
2A	Setting value or parameter	CBF Current Check	More	CBF function current pickup higher than design	Human error, incorrect value entered or incorrect template used	Fail to trip and clear fault. Catastrophic to equipment and safety	Confirm CBF current pickup using secondary injection test set or confirmation via setting compare.
2A	Setting value or parameter	CBF Current Check	Less	CBF function current pickup less than design	Human error, incorrect value entered or incorrect template used	Fail to trip and clear fault. Catastrophic to equipment and safety	Confirm CBF current pickup using secondary injection test set or confirmation via setting compare.

2B	Setting value or parameter	CBF Timer	No	CBF function timer set to zero	Human error, incorrect value entered or incorrect template used	Fail to trip and clear fault. Catastrophic to equipment and safety	Confirm CBF current pickup using secondary injection test set or confirmation via setting compare.
2B	Setting value or parameter	CBF Timer	More Late	CBF function timer set more than design	Human error, incorrect value entered or incorrect template used	Fail to trip and clear fault. Catastrophic to equipment and safety	Confirm CBF current pickup using secondary injection test set or confirmation via setting compare
2B	Setting value or parameter	CBF Timer	Less Early	CBF function timer set less than design	Human error, incorrect value entered or incorrect template used	Fail to trip and clear fault. Catastrophic to equipment and safety	Confirm CBF current pickup using secondary injection test set or confirmation via setting compare
3A	Setting value or parameter	CT ratio	No	CT ratio not configured as per physical set ratio	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to trip and clear fault. Catastrophic to equipment and safety	Confirm CT ratio via secondary injection. Confirm non-monitored system of IED during injection
3A	Setting value or parameter	CT ratio	More	CT ratio not configured as per physical set ratio	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to trip and clear fault. Catastrophic to equipment and safety	Confirm CT ratio via secondary injection. Confirm non-monitored system of IED during injection
3A	Setting value or parameter	CT ratio	Less	CT ratio not configured as per physical set ratio	Human error, Incorrect setting or parameters, firmware or software bugs	CBF Bus when there is no CBF event on system. Loss of supply	Confirm CT ratio via secondary injection. Confirm non-monitored system of IED during injection

4A	Setting value or parameter	Logical Node for CBF	No	Logical Node for CBF not set in dataset	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm CBF logical node is in correct publishing GOOSE control block as per design
4A	Setting value or parameter	Logical Node for CBF	Other than	Logical Node for CBF not set in dataset	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm CBF logical node is in correct publishing GOOSE control block as per design
4A	Setting value or parameter	Logical Node for CBF	No	Logical Node for CBF set in dataset, but dataset not configured in gcb.	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm CBF logical node is in correct publishing GOOSE control block as per design
4A	Setting value or parameter	Logical Node for CBF	Other than	Logical Node for CBF set in dataset, but dataset configured to incorrect gcb.	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm CBF logical node is in correct publishing GOOSE control block as per design
4B	Setting value or parameter	GOOSE Control Block & Publishing	No	No network parameters configurator	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to send GOOSE message or received by subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Run validate configuration report
4B	Setting value or parameter	GOOSE Control Block & Publishing	More	gcb configuration revision more than subscribing IED	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm subscribing IED's receive message and have same revision

4B	Setting value or parameter	GOOSE Control Block & Publishing	Less	gcb configuration revision less than subscribing IED	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm subscribing IED's receive message and have same revision
4B	Setting value or parameter	GOOSE Control Block & Publishing	No	No gcb configuration revision	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Run validate configuration report
4B	Setting value or parameter	GOOSE Control Block & Publishing	More	VLAN ID for network parameter set more than VLAN network design	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm subscribing IED's receive message and have same revision
4B	Setting value or parameter	GOOSE Control Block & Publishing	Less	VLAN ID for network parameter set more than VLAN network design	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm subscribing IED's receive message and have same revision
4B	Setting value or parameter	GOOSE Control Block & Publishing	More	VLAN priority for message packet set more than GOOSE priority	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by subscribing device in expected time if traffic on the network is at a level where traffic management is required. Fail to trip CB's on bus and clear fault in design time. Catastrophic to equipment and safety	Confirm subscribing IED's receive message within the expected design time with traffic on network

4B	Setting value or parameter	GOOSE Control Block & Publishing	Less/After	VLAN priority for message packet set less than GOOSE priority	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by subscribing device in expected time if traffic on the network is at a level where traffic management is required. Fail to trip CB's on bus and clear fault in design time. Catastrophic to equipment and safety	Confirm subscribing IED's receive message within the expected design time with traffic on network
5A	Network link	Fibre optic cable	No	No data control signal passed	Failure to fibre optic cable or connectors	No data sent to receiving IED's. Fail to trip CB's on bus and clear fault	Confirm network communication using tools
5A	Network link	Fibre optic cable	Less	Data is passed at a lower rate than intended	Failure to fibre optic cable or connectors	No data sent to receiving IED's. Fail to trip CB's on bus and clear fault	Confirm network communication using tools
6A	Station bus network switch	Port parameters	No	Ingress Port not configurator	Human error, Incorrect setting or parameters, firmware or software bugs	No data sent to receiving IED's. Fail to trip CB's on bus and clear fault	Confirm switch parameters for network and GOOSE message
6A	Station bus network switch	Port parameters	No	Ingress Port not configurator to designed VLAN ID, traffic control management and quality of service (QoS) parameters.	Human error, Incorrect setting or parameters, firmware or software bugs	No data sent to receiving IED's. Fail to trip CB's on bus and clear fault	Confirm switch parameters for network and GOOSE message
6A	Station bus network switch	Port parameters	After Late	Ingress Port not configurator to designed VLAN ID, traffic control management and quality of service (QoS) parameters.	Human error, Incorrect setting or parameters, firmware or software bugs	No data sent to receiving IED's. Fail to trip CB's on bus and clear fault	Confirm switch parameters for network and GOOSE message

6B	Station bus network switch	Port parameters	No	Egress Port not configured to design VLAN ID, traffic control management and quality of service (QoS) parameters.	Human error, Incorrect setting or parameters, firmware or software bugs	No data sent to receiving IED's. Fail to trip CB's on bus and clear fault	Confirm switch parameters for network and GOOSE message
6B	Station bus network switch	Port parameters	After Late	Egress Port not configurator to designed VLAN ID, traffic control management and quality of service (QoS) parameters.	Human error, Incorrect setting or parameters, firmware or software bugs	No data sent to receiving IED's. Fail to trip CB's on bus and clear fault	Confirm switch parameters for network and GOOSE message
7A	Network link	Fibre optic cable		As per 5A			
8A	Setting value or parameter	GOOSE subscribing	No	Bus IED not subscribing to 11kV FDR IED that sent CBF GOOSE message	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by potential subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm subscribing IED's receive message
8A	Setting value or parameter	GOOSE subscribing	No	Bus IED not subscribing to GOOSE source parameters or incorrect data within parameters	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by potential subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm subscribing IED's receive message
9A	Setting value or parameter or Logic	GOOSE subscribing	No	IED not subscribing to message mapped input, due to incorrect virtual input set in relay logic	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by potential subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm subscribing IED (Bus) receive message and mapped to the correct logic within relay PSL

9A	Setting value or parameter or Logic	GOOSE subscribing	Reversed	IED subscribing to message mapped input, virtual input inverted in relay logic	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by potential subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm subscribing IED (Bus) receive message and mapped to the correct logic within relay PSL
9A	Setting value or parameter or Logic	GOOSE subscribing	More	IED subscribing to message mapped input, virtual input index number more than expect in relay logic	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by potential subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm subscribing IED (Bus) receive message and mapped to the correct logic within relay PSL
9A	Setting value or parameter or Logic	GOOSE subscribing	Less	IED subscribing to message mapped input, virtual input index number more than expect in relay logic	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to receive by potential subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm subscribing IED (Bus) receive message and mapped to the correct logic within relay PSL
9B	Setting value or parameter or Logic	GOOSE Publishing	No	No Logic to trip remaining CB's on bus, including mapping to virtual output for publishing	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to send message to subscribing IED's to trip bus and clear fault. Catastrophic to equipment and safety	Confirm publishing IED (Bus) logic for Bus trip scheme
9B	Setting value or parameter or Logic	GOOSE Publishing	Reversed	Logic inverted to trip remaining CB's on bus, including mapping to virtual output for publishing	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to send message to subscribing IED's to trip bus and clear fault. Catastrophic to equipment and safety	Confirm publishing IED (Bus) logic for Bus trip scheme

9B	Setting value or parameter or Logic	GOOSE Publishing	Other than	Unknown Logic to trip remaining CB's on bus, including mapping to virtual output for publishing	Human error, Incorrect setting or parameters, firmware or software bugs	Fail to send message to subscribing IED's to trip bus and clear fault. Catastrophic to equipment and safety	Confirm publishing IED (Bus) logic for Bus trip scheme
10A	Setting value or parameter	Logical Node for Virtual output		As per 4A & 4B			Confirm GGIO logical node is in correct publishing GOOSE control block as per design
10B	Setting value or parameter	GOOSE Control Block & Publishing		As per 4A & 4B			Confirm subscribing IED's receive message and have same revision
11A	Network link	Fibre optic cable		As per 5A			
12A & 12B	Station bus network switch	Port parameters		As per 6A & 6B			
13A & 14A	Setting value or parameter or Logic	GOOSE subscribing		As per 9A & 8A		Fail to receive by potential subscribing device. Fail to trip CB's on bus and clear fault. Catastrophic to equipment and safety	Confirm subscribing IED (FDR) receive message and mapped to the correct logic within relay PSL
15A	Setting value or parameter or Logic	CB Trip	No	No mapping to CB trip output contact	Human error, Incorrect setting or parameters, firmware or software bugs. Failure to hardware	Fail to trip and clear fault. Catastrophic to equipment and safety	Confirm CB trip output contact for received CBF GOOSE message

Appendix D: CB Failure Test Coverage

STUDY TITLE:					Protection functions using GOOSE messaging on a station bus		SHEET: 1A
REFERENCE DRAWING No.:					GOOSE Matrix, IED internal logic diagrams, GOOSE direction communication diagram		DATE: 11/08/2015
PART CONSIDERED:					P142 IED settings & logic. Publishing and subscribing of dataset contain CBF trips.		
DESIGN INTENT:					An 11kV CB Fails to trip for a protection fault. Trip remaining CB's on that particular bus to clear fault		
HAZOP No.	**TEST No.**	**Part of System**	**Element**	**Function**	**Check Item / test**	**Action**	**Expected Result**
4B-1	1	IED	Setting value or parameter	GOOSE gcb	All IED's correct SCL revision & network parameters confi correctly	Run validate report prior to downloading files to IED. Confirm each IED on the network has same file revision	No error during report and same file revisions in each IED on network
5A, 7A, 11A	2	Fibre optic cables	Network link	comm's medium	As per AS/NZS 1476.3:2012. IP connectivity between devices on the station bus network	Microscopic visual inspections of all end connectors. Confirm continuity & maintenance of polarity of cores from end to end. Conduct end to end level check (Light & Source) of each Multimode fibre and record results. Conduct OTDR test on each Multimode core and store results. Using both 850nm and 1300nm wavelengths in both directions. Run ruggedping test for an increased interval will enable the monitoring of any loss data packets during the testing	As per AS/NZS 1476.3:2012. No packet loss during testing

6A,6B	3	Network Switch	Station bus network switch	Port parameters	Port configurated to designed VLAN ID, traffic control management and quality of service (QoS) parameters.	Run compare on files to verify standard configurations have been applied. Integration testing confirm correct VLAN ID and some traffic control parameters. Confirm with Wireshark that network is communicating and operating as expected parameters.	No error during compare, all settings as per design. All traffic communicating as expected. Visual inspection of messages to confirm file revision and VLAN ID. All IED communicating with no alarms or errors
3A	4	IED	Confirm non-monitored system of IED & Setting value or parameter	CT/VT Ratio	Verify CT ratio is correctly set within the IED and confirm non-monitored system	Using a secondary test set inject perform metering check. Injection current values to expected load limits and confirm relay is stable and no elements have started or initiated. Note: To be confirmed during on load test, confirm current & MW	IED current will equal secondary injected current with accuracy as per manufacturers data. No element started or protection trips
1A, 2A, 3A	5	IED	Setting value or parameter	CBF Current Check	Verify CBF current check element is correctly set within the IED and the function is enabled.	**Element Testing:** Using a secondary test set inject current to pickup value, single phase check. Note: It is not possible to confirm this setting using the GOOSE dataset item/Logical node as the sensing element. Elements DDB #373-377 will need to be mapped to a output contact to prove this setting.**No Element Testing:** Using IED configurator compare function, extract settings from IED and verify that settings has been applied. Confirm during timer/LN testing CBF function initiated within IED events to confirm protection function is enabled.	CBF should only operate for current above the setting value. Accuracy (10%) as per manual

2B, 4A	6	IED	Setting value or parameter	CBF Timer & Logical Node for CBF	Confirm CBF timer is correctly set within the IED and therefore Logical Node for CBF set in dataset and configured in gab.	Using a secondary test set, trigger CBF initiate from a protection element. Time CBF GOOSE output from protection event initiate. Measure time at station switch while sensing for dataset item Number. Running a validation check in the IED configuration tool will also confirm the gab is fully configurator.	CBF should only operate after the time setting value. Time (set time + (5% or 40ms)) as per the manual specs.
4B,8A,9A,9B,10A,13A,15A	7	IED, switch, network	Setting value or parameter	GOOSE Subscribing	Verification of message to the subscribing IEDs. If completed as an entire system, verification of publishing virtual outputs for IED to remaining IED completed during testing.	Confirm subscribing IED receive message and mapped to the correct logic within relay PSL. This can be performed on each individual IED using Test to simulate virtual input and verify that the correct message is received and the required action is processed and executed only on that single IED. If possible a full system test can be performed on the system to verify the entire integrated system. A full system test will also verify the network switch parameters. The full system test also ensures that a GOOSE output from a particular IED is published onto the network and the subscribing IED receives the message and the required action is processed and executed without any additional loss in the single time	Protection scheme operates as per the design time. IED subscribe and publish as per the design. No alarms or error identified during testing. No operation of other protection schemes

Appendix E: Project Management & Safety

Project Schedule

The following project schedule has been developed to manage the project milestones, activities and deliverables. Table 7 illustrates the developed project schedule..

Task Name	Duration	Start	Finish
Project Allocation	35 days?	Thu 22/01/15	Wed 11/03/15
Project Specification	5 days	Thu 12/03/15	Wed 18/03/15
Literature Review	4 wks	Thu 19/03/15	Wed 15/04/15
Write Preliminary Report	5 wks	Thu 16/04/15	Wed 20/05/15
Review Ergon's Current Protection and Circuitry Design	**5 days**	**Thu 21/05/15**	**Wed 27/05/15**
Circuitry Design	0.5 wks	Thu 21/05/15	Mon 25/05/15
Protection Design/settings	0.5 wks	Mon 25/05/15	Wed 27/05/15
Preliminary Report Due	0 days	Wed 3/06/15	Wed 3/06/15
Design Implementation of GOOSE Messaging station	**12 days**	**Thu 28/05/15**	**Fri 12/06/15**
Develop Protection SLD & Protection Matrix	0.5 wks	Thu 28/05/15	Mon 1/06/15
Install new IEC 61850 Harware in IED, firmware upgrade if required	2 days	Mon 1/06/15	Wed 3/06/15
Develop IED Files (SSD,ICD, SCD,CID)	1 wk	Wed 3/06/15	Wed 10/06/15
Develop Configs for switches	0.5 wks	Wed 10/06/15	Fri 12/06/15
Risk Assessment Methodology	**15 days**	**Mon 15/06/15**	**Fri 3/07/15**
Develop HAZOP templates for IED's & Network	1 wk	Mon 15/06/15	Fri 19/06/15
Perform HAZOP review	1 wk	Mon 22/06/15	Fri 26/06/15
Develop list of test required from risk assessment (Test Coverage)	1 wk	Mon 29/06/15	Fri 3/07/15
Laboratory Testing	**25 days**	**Mon 6/07/15**	**Fri 7/08/15**
Setup network & load created files	1 wk	Mon 6/07/15	Fri 10/07/15
Performing Testing of system & IED's	3 wks	Mon 13/07/15	Fri 31/07/15
Analyse test results. Complete further testing, if required	1 wk	Mon 3/08/15	Fri 7/08/15
Continue writing Dissertation	4 wks	Mon 10/08/15	Fri 4/09/15
Partial Draft Dissertation submission	**0 days**	**Wed 16/09/15**	**Wed 16/09/15**
Develop Project Presentation for Res School	2 wks	Mon 7/09/15	Fri 18/09/15
Project Presentation	1 wk	Mon 21/09/15	Fri 25/09/15
Feedback from review of partial draft. Continue writing Dissertation.	5 wks	Mon 21/09/15	Fri 23/10/15
Final Dissertation submission	**0 days**	**Thu 29/10/15**	**Thu 29/10/15**

Table 7: Project Schedule

Risk Assessment (DTRMP Template)

The laboratory work will be completed at Ergon Energy's Protection Group test laboratory in Townsville. Ergon Energy's Daily Task Risk Assessment Plan (DTRMP) will be used as the risk assessment tool for all laboratory work. Prior to performing any work in the laboratory any hazards associated with tasks in the laboratory shall be identified and assessed with appropriate control measures implemented and documented in accordance with a Daily Task Risk Assessment Plan (DTRMP). If any risks cannot be managed or reduced to an acceptable level the work will need to stop immediately. Hazards will be assessed according to the DTRMP level of risk matrix that will identify the likelihood and consequence of the hazard. The level of risk matric is shown in Table 8

Consequence	Likelihood				
	Rare	Unlikely	Possible	Likely	Almost Certain
Catastrophic	Medium	High	High	Extreme	Extreme
Major	Medium	Medium	High	High	Extreme
Moderate	Low	Medium	Medium	High	High
Minor	Very Low	Low	Medium	Medium	Medium
Insignificant	Very Low	Very Low	Low	Medium	Medium

Table 8: DTRMP level of risk matrix

If the hazard falls within the Medium, High or Extreme level, additional control measures will need to be set in place. With additional control measures in place the residual level of risk will be assessed according to the DTRMP level of risk matrix that will identify the likelihood and consequence of the hazard with the additional control measures. If any risks cannot be managed or reduced to an acceptable level (Low or Very Low) the work will need to stop immediately. The two main activities that will be performed in the laboratory will be the use of hand tools and test equipment. The hazards and potential consequences associated with performing these tasks and additional control measures to eliminate or reduce the residual risk are identified in Table 9. Appendix B provides a copy of Ergon Energy's DTRMP.

Activity	Hazard	Concequences	Control Measure
Hand Tool Operation	• Loss of control • Misuse	• Sprain, strain injury • Cuts, abrasions • Tool / equipment damage	1. Competence in tool use 2. Tool used for intended purpose 3. Required PPE w orn 4. Ensure tools fit for purpose and operated in competent manner 5. Tools maintained in serviceable condition 6. Defective tools removed from service, tagged as defective and quarantined
Testing & Test Equipment	• Electrical & Inadvertent contact w ith test voltage / current	• Personal injury • Electric shock • Burns • Plant or property damage	1. Required PPE w orn 2. Test equipment w ithin test date and used by competent persons 3. Test equipment used by authorised persons (w here required) 4. Comply w ith electrical industry codes of practice requirements for w ork on or near LV systems. These include:• Tape off / barricade adjacent panels• Isolate danger tag circuits• Test before you touch• Don't use exposed leads or terminals• Comply w ith AS4836• Use LV mats, covers, barriers and 00 gloves, if required, as determined by a risk assessment• Have LV rescue kit available at w ork site 5. Check all connections before use 6. Alw ays physically isolate test equipment from input supply source w hen not in use

Table 9: WHS Risk Control Guide

Daily / Task Risk Management Plan (Safety, Environment, Cultural Heritage)

Work Description:	Work Location:	Date:
Perform LV live work justification: ☐ Needed to do the job ☐ Safety Concerns ☐ Wide Spread Outage ☐ Not Applicable	The SPRMP &/or WHS Management Plans reviewed	☐ Yes ☐ Not Applicable
Identify **Safe Work Method Statements** for High Risk Construction Work (Please tick relevant box and implement controls from related SWMS)	Contractors Licences and SWMS sighted or acquired	☐ Yes ☐ Not Applicable

☐ Work at Heights (Poles & Ladders) ☐ Work at Heights (EWP's) ☐ Work at Heights (Roofs & Fascias) ☐ Work at Heights (Scaffold & Guardrails)	☐ Work at Heights (Structures & Towers) ☐ Working on or near Road or Railway ☐ Live Work (LV) ☐ Live Work (HV)	☐ Disturbance of Asbestos (Underground) ☐ Disturbance of Asbestos (Overhead) ☐ Disturbance of Asbestos (Switchboards) ☐ Pressurised Gas, Chemical, Fuel Lines	☐ Temporary Support of Poles or Structures ☐ Work on Telecommunication Tower ☐ Movement of powered mobile plant ☐ Contaminated or Flammable Atmosphere	☐ Excavations ☐ Confined Space ☐ Working in or on Water

(A) WORK ACTIVITY: (Tick Yes or add others below)	Relevant to Job Yes	IDENTIFIED ONSITE HAZARDS (Not addressed by SWMS or standard control measures)	Inherent Level of Risk	(B) WHAT CONTROLS ARE TO BE APPLIED?	Residual Level of Risk	ALLOCATED TO:
Hazardous Manual Tasks						
Hand / Power Tool Operation						
Hazardous Chemical Use						
Remote and/or Isolated Work						
Working Outdoors						
Working (Fatigue, Wellbeing)						
Hot Work (Grind, Cut, Weld)						
Vehicle Driving / Trailer Towing						
Batteries and Battery Rooms						
Work in Switchyards / Power Stns						
Secondary System Test / Mtce						
Test Equipment Use						
Trans / Lube Oil / Fuel Handling						
Sensitive Area /Protected Species						
Earthworks						
Vegetation Management						
Waste Management						
Cultural Heritage						
Perform HV / LV Switching						

(A) WORK ACTIVITY:	Relevant to Job Yes	IDENTIFIED ONSITE HAZARDS (Not addressed by SWMS or Std Risk Controls)	Inherent Level of Risk	(B) WHAT CONTROLS ARE TO BE APPLIED?	Residual Level of Risk	ALLOCATED TO:

(C) ISOLATION POINT: LOW VOLTAGE		
Op No	Apparatus and Operation (Single Isolation Point)	Time
1	Obtain Clearance from Operations that LV Switching can proceed	
2	Open and DNOB	
3	Test and Proved LV De-energised & advise Crew	
4	Remove DNOB and Close	
5	Advise Operations and Crew that Switching is complete	

OTHER SYSTEMS: (e.g. gas, fuels or electrical generator control)		
Isolation Point (Max of Three Points)	Isolated & Tagged (Time)	Restored (Time)
Permit to Work (PTW) No.		

LV Switching Sheet No.		Tested & Proved De-energised / Isolated	Name:	Time:	Work Crew advised of Restoration	Name:	Time:

(D) RE-ENERGISING / COMMISSIONING CHECKS:			
Test Point(s)	Check Type	Completed By	☑

(E) TRAFFIC MANAGEMENT				
ERECT Date/Time/Initial	CHK Date/Time/Initial	CHK Date/Time/Initial	CHK Date/Time/Initial	REMOVE Date/Time/Initial
WORM Diagram/Clause or Contract Plan No.				

(F) PERSON (ON SITE) IN CHARGE OF WORK RESPONSIBILITIES:

1. Pre-start job briefing conducted.
2. I understand my responsibilities in regards to implementing and supervising control measures on the work site.
3. I understand my responsibilities in regards to supervision of all persons on the work site including Apprentices.
4. I understand I am responsible for ensuring that test requirements are identified assigned and completed.

(G) CREW MEMBER / VISITOR RESPONSIBILITIES:

1. Attended Pre-start job briefing.
2. I understand the job and my role.
3. I understand the standard and other controls for this job.
4. Act in a manner that contributes to personal and group safety

Crew/Visitor Sign On - REQUIRED FOR EVERY JOB				Crew/Visitor Sign On- REQUIRED FOR EVERY JOB				Crew/Visitor Sign On - REQUIRED FOR EVERY JOB			
ROLE	NAME	SIGNATURE	TIME	ROLE	NAME	SIGNATURE	TIME	ROLE	NAME	SIGNATURE	TIME

(H) LOCKABLE ENCLOSURES: I have confirmed locked and checked prior to leaving the site. (For switching do not list each asset ID. Write down switching sheet number only.)											
SWITCHING SHEET NO.		ASSET ID.		ASSET ID.		ASSET ID.		ASSET ID.		SIGNATURE	

Role Legend: PICW – Person(on site)in Charge of Work, ST – Supervising Tradesperson for Apprentices/Trainees, SO – Safety Observer, App – Apprentice or Trainee, SwO – Switching Operator, SOA – Switching Operator Assistant, Vis – Visitor