Cape Peninsula University of Technology

INVESTIGATION OF INTEROPERABILITY OF IEC 61850 PROTECTION FUNCTIONS

by

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Thesis submitted in fulfilment of the requirements for the degree

Master of Engineering: Electrical Engineering

in the Faculty of Engineering

at the Cape Peninsula University of Technology

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DECLARATION

I, Ncedo Richard Mguzulwa, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

_____   _____
Signed   **Date**

ABSTRACT

Introduction of IEC 61850 standard defined substation automation system communication. The need of interoperability among the relevant devices coming from different vendors is a necessity to ensure utilities/municipalities obtain value for money. Vendors used their own proprietary tools to achieve communication in a substation. This caused an Intelligent Electronic Device (IED) from vendor A could not communicate with an IED from vendor B. Utilities/municipalities are forced to depend on single vendor solutions in a substation automation system.

IEC 61850 systems tout Interoperability as a major gain in the Substation Automation System (SAS) environment. The implementation of interoperable systems in SAS environment requires extensive testing and careful selection of vendors. This involves extensive testing to meet the required requirements of a certain SAS. Interoperability implementation and testing methods need to be formulated and tested rigorously with various scenarios of interoperability in an SAS.

GOOSE messages form the foundation of IEC 61850 standard as they are responsible for the copper-less connections for peer to peer communications. GOOSE messages are based on peer to peer communications to enable interoperability at the bay level which is called horizontal communication. IEDs need to be carefully selected to ensure GOOSE messaging interoperability is achieved. Test methods are equally important as methodology to achieve interoperability

The purpose of this research is to perform an investigation on interoperability of IEC 61850 conformant IEDs based on evaluation of their protection functions. The research looks at various vendors on how each has interpreted the IEC 61850 standard. Also an analysis on requirements to achieve interoperability is conducted. Investigation on various vendor independent system configuration tools to ease the implementation burden of a multivendor application is done. Evaluation into flexible object modelling and naming conventions in order to achieve interoperability is performed. Various tests using different tools to assess the integrity of interoperability are completed.

The research delivers a methodology to evaluate and implement GOOSE message interoperability. The interoperability methodology can be used for improvement of interoperability applications. The methodology can also be implemented as procurement requirement to ensure interoperability. The evaluation/implementation of

interoperability can be included in Factory Acceptance Test (FAT). The methodology to achieve interoperability is only usefully when requirements are clear with regard to what needs to achieved by SAS.

ACKNOWLEDGMENTS

DEDICATION

The thesis is dedicated to my mother and late father to acknowledge the lessons/teachings you have both instilled in me that with perseverance anything is possible.

I further dedicate this thesis to my daughter Unakho.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARRY

ACSI - Abstract Communication Service Interface

ANSI - American National Standards Institute

APPID - Application identifier

CID - Configured IED Description

CT - Current Transformer

CTRL - Control logical device

Data set - The content basis for reporting and logging containing references to the data and data attribute values

EPRI - Electric Power Research Institute

Ethernet - A standard for connecting a family of frame-based computer networking technologies into a LAN

FC - Functional Constrain

GCB - GOOSE control block

GoCB - GOOSE control block

GoID - GOOSE control block-specific identifier

GOOSE - Generic Object Orientated Substation Event

GSE - Generic Substation Event

HMI - Human-machine interface

ICD - IED capability description

IEC - International Electrotechnical Commission

IEC 61850 - International standard for substation communication and modelling

IEC 61850-8-1 - A communication protocol based on the IEC 61850 standard series

IEDs - Intelligent Electronic Devices

IEEE - Institute of Electrical and Electronics Engineers

IP - Inter-networking Protocol

LAN - Local Area Network

LD - Logical Device

LN - Logical Node

MAC - Media Access Control

MMS - Manufacturing Message Specification

OSI - Open Systems Interconnection

PD - Physical Device

SAS - Substation Automation System

SCADA - Supervisory Control and Data Acquisition

SCD - Substation Configuration Description

SCL - Substation Configuration Language

SSD - Substation Specific Description

SV Sample Value

TPAA - Two Party Application Association

UCA - Utility Communication Architecture

UCA - Utility Communications Architecture

VLAN - Virtual Local Area Network

VT - Voltage Transformer

XML - Extensible Markup Language

CHAPTER ONE:

INTRODUCTION

1.1 Introduction

The dawn of IEC 61850 standard has brought about many advantages to the Substation Automation System (SAS) environment. The birth of IEC 61850 standard fundamentally brought about the vision of interoperability among Intelligent Electronic Devices (IEDs) from various vendors. Interoperability is defined as the ability of two or more IEDs from different vendors to communicate with one another in order to action any required application in the respective devices. Now the IEC 61850 standard only validates the vendor's IED in retrospect to set requirements in the standard itself. This merely means conformance is tested against the standard's set parameters. This conformance testing leaves out a flagship feature of IEC 61850 standard which is the Interoperability capability and it is left to users (namely municipalities, utilities etc.).

This chapter explains the components that are found in a substation. It also covers the importance of substation protection and its principles. The chapter covers the following topics: 1.2 Substations and their protection equipment, 1.3 Protection, 1.4 Relays, 1.5 Awareness of the problem,1.6 Problem statement, 1.7 Research Aim and Objectives, 1.8 Hypothesis, 1.9 Delimitation of the research, 1.10 Motivation for the research project, 1.11 Assumption, 1.12 Research Methods, and 1.13 Chapter Breakdown

1.2 Substations and their protection equipment

Electrical substation is an interconnection station where voltage is either stepped up or stepped down and distributed/transmitted to various parts of the power system. Stepping up and stepping down is achieved by a device called a transformer. A substation is mainly made up of the following components:

- Transformers
- Switchgear
- Busbars
- Relays
- Instrument Transformers
- Surge arrester

The

Figure 1.1 illustrates a section of a typical outdoor substation
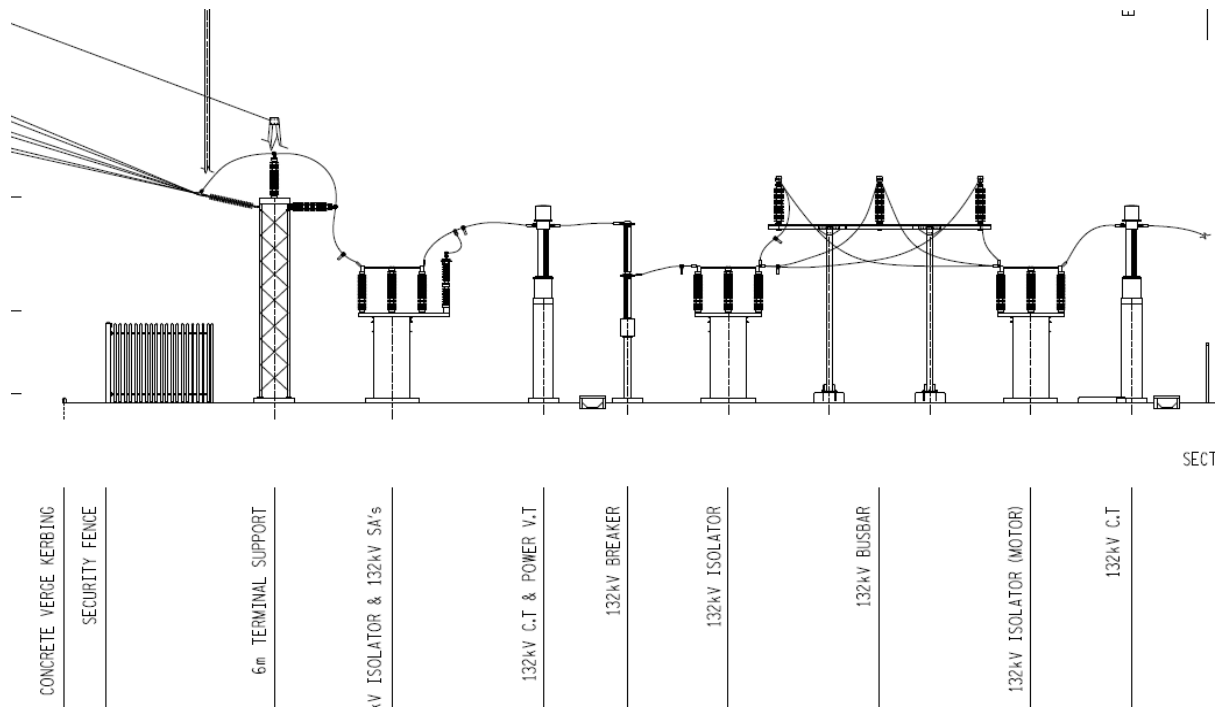
Figure 1.1: Typical Outdoor Substation (Side view)

1.2.1 Transformers

Power transformers basically step up the voltage or step down the voltage. The Figure 1.2 shows a section of a typical outdoor substation indicating the transformer positioning.
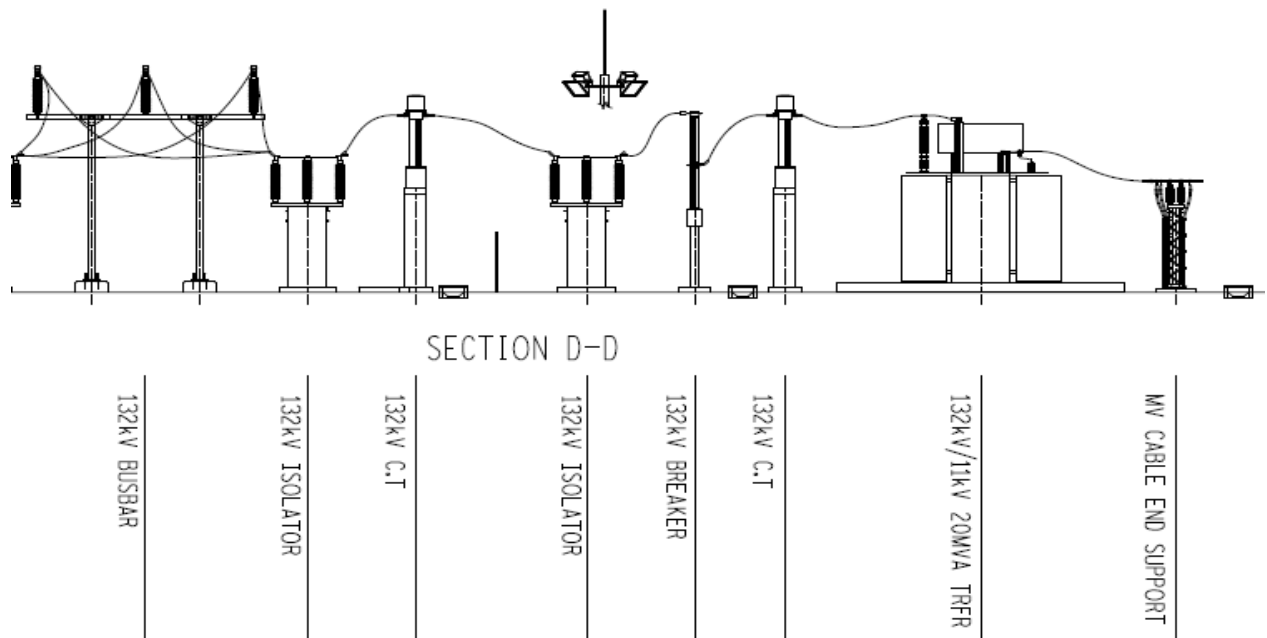
Figure 1.2: Typical Outdoor Substation (Side View)

1.2.2 Switchgear

Switchgears are an important part of a substation because they take the responsibility of isolating the power system in the event of a fault occurring or isolating the substation. Isolators provide isolation under no load conditions. Circuit Breaker main functions are:

- Interrupts large currents
- Receives control commands from the protection system.

1.2.3 Busbars

Point of connection of lines of the same voltage level.

1.2.4 Instrument Transformers

The protection system and metering system at substations require instrument to read system currents and voltages. The system currents and voltages are very high, while the measuring instruments and relays require low values. The instrument transformers are used to lower current and voltage to required levels [Jacobs, 2008]. Instrument transformers are divided into two categories namely:

- Measuring Transformers
- Protection Transformers

Measuring Transformers and protection transformers both consist of Voltage Transformers (VT) and Current Transformers (CT).

1.2.4.1 Voltage Transformer

A VT is an electromagnetic transformer which is a step-down transformer, so that the voltage can be lowered to the level required by the instrumentation and relays. When the voltmeter on the secondary side reads a voltage then the knowledge of the transformer ratio can be used to determine the voltage on the primary side. There is also Capacitive Voltage Transformer (CVT) that is normally used in substations where voltage levels are high (Greater than 11 kV) (Jacobs, 2008).

1.2.4.2 Current Transformer

A current transformer (CT) is an electro-magnetic device which forms an essential part of the protection system (Jacobs 2006). Measuring transformer CT characteristics are: (Jacobs 2006)

- "*Its limits are well defined.*
- *Requires good accuracy up to approximately 120% of rated current.*

- *Permits the use of standard current ratings for secondary equipment (control plant)."*

Protection transformer CT characteristics: (Jacobs, 2006)

- "*Operates over a wide range of currents (load up to fault current level).*
- *Accuracy is not as important.*
- *Requires a low saturation level to protect measurement instruments. Therefore, a nickel iron alloy core with a low exciting current and knee point at a low flux density is used.*"

1.3 Protection

Electric utilities are characterised with a high level of capital investment in a plant (substation) in order to generate, transmit and distribute the electricity. A typical substation could have installed a plant worth a few million rand and therefore it is essential for the company to effectively protect its investment against damage. This is achieved by the installation of protection relays on the network. (Jacobs, 2008)

The five basic facets of protection systems are: (Jacobs,2008)

- "*Reliability: assurance that the protection will perform correctly.*
- *Selectivity: maximum continuity of service with minimum system disconnection.*
- *Operation speed: minimum fault duration and consequent equipment damage.*
- *Simplicity: minimum protective equipment and associated circuitry to achieve the protection objectives.*
- *Economics: maximum protection at minimum total cost.*"

1.4 Relays

Relays are used to ensure a power systems are adequately protected and this is inclusive various network be it simple or complex networks. Relays ensure electrical power systems operate with design limits and in accordance with installed equipment standards. This has made relay technology to evolve to acquire efficient protection systems. The extent of the fault level/current serves a measurement of power to safe guard a power system or impedance is used by other protection functions. Relays can be categorised accordance to the technology used: (Alstom, 2011)

- "*electromechanical*
- *static*
- *digital*
- *numerical.*"

1.4.1 Electromechanical Relays

These relays are pioneer technology in protection systems. A single unit of a relay was tasked with one function of that particular protection scheme. These relays can be divided as follows: (Alstom, 2011)

- *"Attracted armature relay*
- *Moving coil relay*
- *Induction relay*
- *Motor operated relay*
- *Mechanical relay."*

The operation of these relays was by way of mechanical force. Current flow caused a mechanical force in one or more windings on a magnetic core.

1.4.2 Static Relays

These relays were introduced in the 1960's. The down fall of electromechanical relays was the moving parts in the relay which made them failure prone. The advancement of relays came from the disadvantage of electromechanical relays. Static relays implementation avoided moving parts in the relay to ensure reliability. Although static relays still made use of the previous technology of electromechanical relays on their output contacts. (Network Protection Automation Guide, 2011) Static relays made use of analogue electronic devices.

Static relays started with the use of discrete devices i.e. transistors, diode with resistors, capacitors, inductors. The relay technology moved on to linear and digital integrated circuits. This improvement brought about less maintenance compared to electromechanical relays due to the advantage of no moving parts in the relay.

1.4.3 Digital Relays

Digital relays were introduced in the 1980's. These relays brought new technology to protection relays. The static relay circuitry was replaced by microprocessors and microcontrollers. Digital relays convert analogue signal to digital for all measured values. The conversion allowed the microprocessor to implement a protection algorithm. (Network Protection Automation Guide, 2011). Microprocessors at the time of development of digital relays had limited processing capacity. Compared to previous technology used on protection relays digital relays had improved on the following:

- More functionality
- Wider range of settings
- Greater accuracy
- Additional data

1.4.4 Numerical Relays

Numerical relays are an improvement on digital relays with respect to computation speed. The improvement is due to microprocessors improving in processing capacity. This allowed for greater speeds which are due to an increased sampling rate. All relays that have been discussed were manufactured by different manufacturers. Thus numerical relays also have different manufacturers. Numerical relays are now called IEDs (Intelligent Electronic Devices). IED's brought along a lot of benefit/functions namely:

- Metering
- Protection
- Reporting

Different vendors manufacturing IED's aim to achieve better application, reliability and communication. These vendors were using their own proprietary tools to achieve IED functionality. The use of different proprietary tools made it impossible for different vendor IED's to operate within one substation automation system. Vendors used their own specific tools to achieve communication of IED's. Interoperability was only realised by the formulation of the IEC 61850 standard. IEC 61850 brought about a lot of benefits to substation automation namely :(IEC 61850-1, 2003)

- "Self-describing devices enabling access to device configuration over the network are dramatically reducing setup time and cost.
- Standardized device object models provide a higher level of interoperability that reduces variances between different types and vendors of devices lowering start-up cost.
- A Substation Configuration Language (SCL) provides an XML file format that describes power system and device configuration for unambiguous specification of requirements eliminating procurement uncertainty while enabling offline configuration and exchange of system and device setup information.
- Standardized data naming conventions use power system context to avoid arcane number oriented point tags and eliminate manual I/O to power function mapping simplifying setup
- Device models inherently support logical location of data and device functions enabling migration and coexistence of legacy systems.
- Use of shared station level networking for data access, supervisory control, and process functions minimizes point to point wiring and dramatically reduces cost for incremental improvement of existing systems over time.
- Multiple protocol profiles leverage modern networking technology to provide secure, optimized, and reliable performance for a wider variety of applications including, station and bay control and monitoring, IED to IED protection messaging for intra-bay, intra-station, and wide area remedial action, transducer networks for CT/PT interfaces."

1.5 Awareness of the problem

Intelligent Electronic Devices (IEDs) came into effect in the early 1980's. This brought about many more features when compared to their counterpart electromechanically devices. These IED's were also striving for interoperability goals as seen by subsequent developments namely: (Sezi and Duncan, 1999)

- *"Support of different protocols and bus structures, flexible and open communication architecture*
- *PC communication port for Human Machine Interface*
- *Substation Integration/Automation port*
- *Remote communication port of service*
- *Direct Communication port to a second IED for protection.*"

Many communication schemes have been designed by different vendors using their own proprietary protocols. This has caused IED's from different vendors to be incompatible with each other. In cases like these protocol converters would be required to ensure compatibility which would cause considerable delay to the data transmitted.

The introduction of IEC 61850 has addressed the issue of interoperability. Interoperability reduces reliance on a single vendor and this could also reduce implementation costs.

The spectrum covered by the standard IEC 61850 is to support the communication between all functions/applications being performed in a substation (Brand and Janssen, 2005). The introduction of IEC 61850 standard in substation automation has come with its benefits. IEC61850 standard was developed mainly to ensure interoperability between IED's from different vendors (Gupta, 2008). IEC 61850 defines data communication in a substation station. This standard brings a lot of benefits within the substation with regard to substation communication data.

This thesis will provide test and experiments in GOOSE message interoperability on IEC 61850 conforming relays from different vendors. The aim is to achieve interoperability without the intervention of the respective vendors with regards to integration and configuration.

1.6 Problem statement

Utilities have doubts about interoperability because of concerns of cost and time of implementation of such a substation. The research in the thesis is to investigate interoperability between the IEDs from different vendors that conform to IEC 61850

standard. Functional and performance testing are not defined by the standard (Carmo, 2010). Simply meaning that different methodologies need to be put in place for correct implementation of IEC 61850.Previous research into interoperability has shown that a big constraint is the interpretation of the IEC 61850 by the vendors. Previous research has also shown that to successfully demonstrate interoperability vendors need to provide support for the system configuration. A series of tests are conducted with regard to performance of the relays in the thesis. The problem for investigation of interoperability is divided into the following:

- Develop a test bench
  Various test benches are formulated to investigate interoperability. The test for interoperability is conducted without implementing a protection scheme with in an IED. This is achieved by using GOOSE messages and logics in the IEDs. The purpose of the investigation is to establish communication between IEDs of two or more different vendors.

- Develop an interoperable protection scheme using IEDs from various vendors
  A protection scheme is developed using IEDs from various vendors. The chosen protection scheme ensures that interoperability can be demonstrated. Various test tools and methods are employed to evaluate interoperability. Protection principles and requirements are adhered to achieve interoperability of the protection scheme

- Evaluate different system configuration tools
  Different vendors have their own vendor specific system configuration tools. The system configuration tools are evaluated on various aspects of software used for configuration.

- Evaluate/Develop simpler methods for implementation for interoperable SASs (Substation Automation Systems)
  Set requirements for interoperability for easy implementation of an interoperable substation automation system. Recommendations for cost effective interoperability testing methods and test tools are given. Provide modelling methods and configuration conventions to reduce

time of implementation. Analysis of interoperable system configuration tools to implement interoperability is done.

1.7 Research Aim and Objectives

The aim of the thesis is to perform protection functional testing, and evaluate vendor independent configuration tools in order to achieve interoperability. The aim is to evaluate GOOSE message interoperability. The research is around IEC 61850 interoperability in protection systems with focus on GOOSE message transmission, publishing and subscribing, and interpretation of the messages by various vendor IEC 61850 compliant devices. Note that research is limited to horizontal communication (peer to peer messaging) The purpose of interoperability investigation is to investigate the challenges that emerge from this requirement, to support standardization activities and to derive guidelines and recommendations to ease future engineering processes for interoperability.

Objectives of the thesis:

- Analysis of the IEC 61850 standard
- Evaluate requirements for interoperability
- Evaluate various vendor interpretations of IEC 61850 standard
- Analysis of interoperable substation configuration tools
- Evaluation of interoperability using various test methods and test tools.
- Development of a lab-scale protection and control scheme for interoperability evaluation

1.8   Hypothesis

The research work will prove that:

By strictly implementing IEC 61850 standard defined object models interoperability is possible.

1.9 Delimitation of the research

The thesis is to investigate and provide comprehensive methods for achieving IEC 61850 interoperability in substation automation systems between control and protection devices of different vendors. Therefore, a number of test cases are defined and executed. The scope of the investigations is constrained by IEC 61850 standard Edition 1 which is defined on the IEDs to be used for the investigations. All interoperability tests are based on that particular edition defined within the IEDs. The scope of the research is limited to particular test cases and uses common and typical

scenarios found in substations. Two test tools are used for testing during the investigation namely:

- Omicron Test Universe software
- Wireshark

The following tasks are part of the project:

- Evaluate GOOSE message interoperability
- Evaluate configuration tools
- Testing of protection performance
- Evaluation of test tools and test methods

The investigation is limited to GOOSE messaging interoperability at the bay level.

1.10 Motivation for the research project

Multi-vendor solutions are not common in industry. This can be attributed to various reasons, namely: (Makadam, 2008)

- Hesitance by the utilities to be seen as a testing facility for vendors to prove interoperability
- The added engineering costs to find human expertise from each vendor to implement the final solution
- Multiple vendors can mean decreased reliability due to the substation now consisting of different vendor's IEDs

The motivation for the research is:

- Provide vendor independent interoperability solutions
- Show reliability of multivendor substation automation systems applications
- Further development of the previous interoperability research which required vendor intervention for system integration.
- This thesis development is vendor independent (All tools used will be commercial available)

1.11 Assumption

The following assumptions are made:

- The IEC 61850 standard is not changing during the research period (Due to Edition 1 device utilised for the thesis)
- Relevant test equipment is available for the investigation
- Vendors have implemented all requirements of the standard
- The investigated IEDs are complaint to IEC 61850 standard

1.12 Research Methods

This following research methods are applied in the process of development of the thesis::

- Literature review

    Interoperability has been an issue before the introduction of IEC 61850 standard. This was because vendors used their own propriety tools to implant substation automation systems communications. Although

interoperability was realised by the introduction of IEC 61850, the interpretation of it by various vendors causes issues. Different configuration tools have been developed to assist with SAS (Substation Automation System) integration. Test tools and methods have been developed around IEC 61850. The literature review looks at the above mentioned aspects in order not to repeat past mistakes.

- Method for analysis and system modelling
  This part deals with different vendor configuration tools. Matching of system data for different vendor devices. Implementation of vendor independent configuration tools. Evaluation of different independent configuration tools and vendor specific configuration tools.

- Simulation
  Simulation is conducted using different test tools and methods. Various tests are conducted namely:

  - GOOSE message Interoperability tests
  - Protection functionality of the chosen scheme implemented using different vendors.

- Documentation method
  The documentation describes the interpretation of IEC 61850 standard by the vendors and the implications of the different interpretations. Outlines the set requirement to achieve interoperability. Provides results of test cases that are developed. Shows conclusions on different configuration tools, test tools and test methods

In this research project interoperable IEC61850 protection scheme is developed. The main goal is to achieve communication between the IED from different vendors without hampering protection performance. Extensive evaluation of GOOSE messages applications in conjunction with interoperability is provided.

1.13 Chapter Breakdown

1. Chapter One

   Defines the reason behind the research and delimitation of the research. The chapter also outlines the research methodology to be employed. Provides insight to various substation equipment.

2. Chapter Two

This chapter looks into previous research, compares the research findings and identifies any constraints. The chapter provides an overview of literature of various IEC 61850 interoperability investigations.

3.   Chapter Three

This chapter provides an overview of the IEC 61850 standard.

4.   Chapter Four

Analyses of the requirements of the standard for successful interoperability between IEDs of different vendors. Development of new methods to achieve interoperability.

5.   Chapter Five

This chapter provides insights into the engineering configuration of the developed IEC 61850 interoperable system.

6.   Chapter Six
This chapter undertakes various experiments for interoperability.

7.   Chapter Seven

This chapter describes the thesis deliverables, their application, and the future field of research.

1.14   Conclusion

This chapter introduces at research of GOOSE message interoperability. Provides an overview of major components that constitute a substation This also entails stating the problem statement, aims and objectives, research delimitation and research methodologies. The chapter breakdown of the thesis is also provided. Interoperability of IEC 61850 standard is a vast concept in a Substation Automation System (SAS) and is accepted or implemented on case by case scenario.

The next chapter explores various literature with regards to the application of GOOSE message and any other related issues of interoperability. Various papers are review to assess/outline shortcomings or successes achieved

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

IEC 61850 has made a big impact on substation automation system protection communication protocol. The chief motive to the development of IEC 61850 was to achieve seamless interoperability between the protection devices of various vendors. The introduction of IEC 61850 brought about a real solution to interoperability problem for various utilities around the world. The IEC 61850 standard achieves this by defining functionality with blocks. The functional blocks are called object models as illustrated below by Figure 2.1.
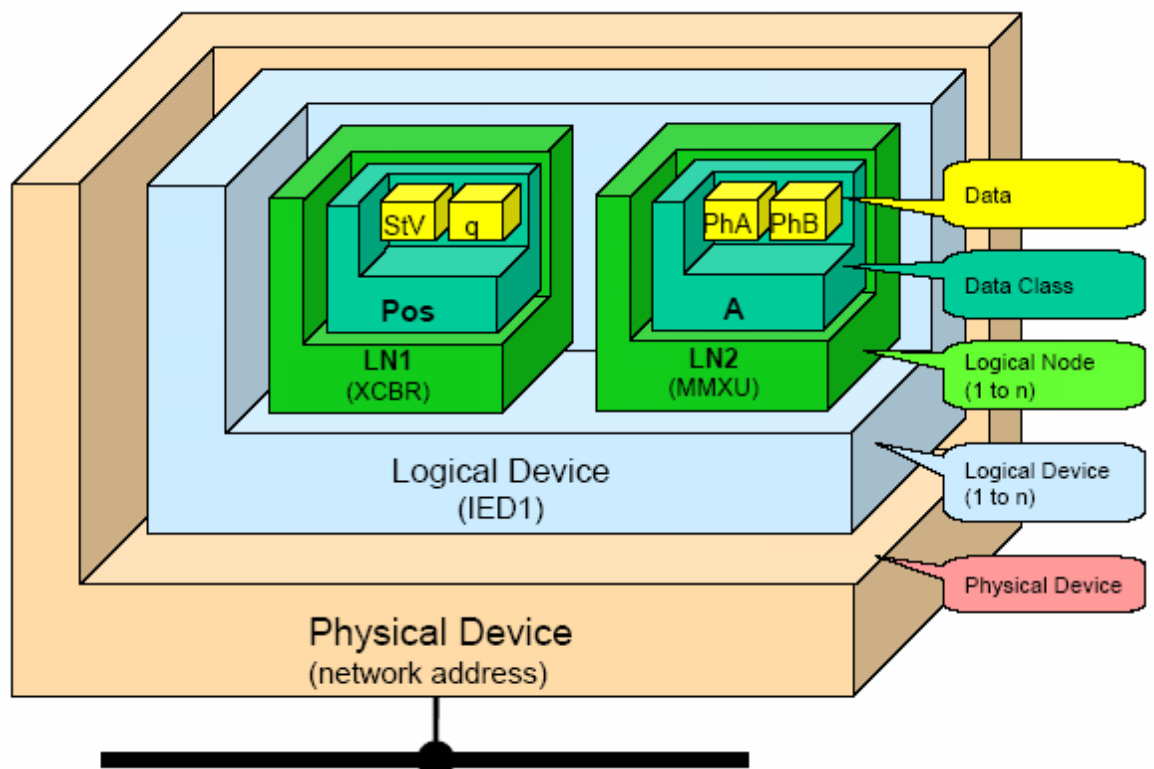
Figure 2.1: IEC 61850 Object Model, Gupta, (2008)

Object models are made of LD (Logical Device), LN (Logical Node) and data attributes (Data Class and Data). The object model defines the entire substation virtually and with standardised object models across all vendors this allows for interoperability. But different vendors interpret IEC 61850 in different ways. Interpretation of the standard by a vendor becomes very important when trying to achieve Substation Automation System (SAS) interoperability. For this reason, utilities have decided to implement an IEC 61850 SAS with a single vendor. IEC 61850 does

not define how information should be interpreted thus interoperability issues arise among different vendors.

This causes two different vendor devices which are IEC 61850 compliant not be able to communicate with each other. It should also be noted interoperability issues may arise with the same vendor IED's due to multi-national vendor manufacturing and interpretation of the IEC 61850. The literature review is to look at IEC 61850 multi-vendor applications that have been implemented and review existing methods for testing interoperable systems and Generic Object Orientated Substation Event (GOOSE) applications. This is to ascertain that interoperable IEC 61850 systems are the future of substation automation systems and ensure flexible systems which are not vendor dependent.

The chapter reviews past and present research to assess the status of GOOSE messaging IEC 61850 interoperability with various protection applications. In 2.2 the methodology of the review of literature is pegged out and discussed. Section 2.3 reviews the literature of existing papers for various GOOSE message applications. Section 2.4 discusses the findings on the review of existing papers. Section 2.5 discusses the findings with reference to the interoperability study.

2.2 Literature search on IEC 61850 interoperability

The research is around IEC 61850 interoperability in protection systems with focus on GOOSE message transmission, publishing and subscribing, and interpretation of the messages by various vendor IEC 61850 compliant devices. Note that research is limited to horizontal communication (peer to peer messaging). The knowledge required to conduct the research is extensive and a review of past and present research is fundamental. It is important to review the existing research with the following criteria:

- Statement of the problem
- Project objective
- Approach of the solution (model/method) of a Substation Automation System (SAS)
- Constraints and drawbacks experienced, and
- Findings

This is to ensure that the research is evaluated in its entirety to ensure possible solutions and pitfalls or shortcomings are identified. Certain keywords were used to obtain the relevant research papers. The keywords are as follows:

- IEC 61850 Interoperability
- GOOSE message applications
- Substation automation horizontal communication
- Interoperability framework
- Substation Automation Interoperability
- Analogue GOOSE messages
- IEC 61850 interoperability testing
- IEC 61850 testing

The keywords can be mixed and matched to conduct further searches and search results can be filtered as required. This gives rise to various research papers relevant to the keywords

The existing research papers are evaluated for the period from 2004 year to 2016 year. Figure 2.2 shows the distribution of papers during the said period.
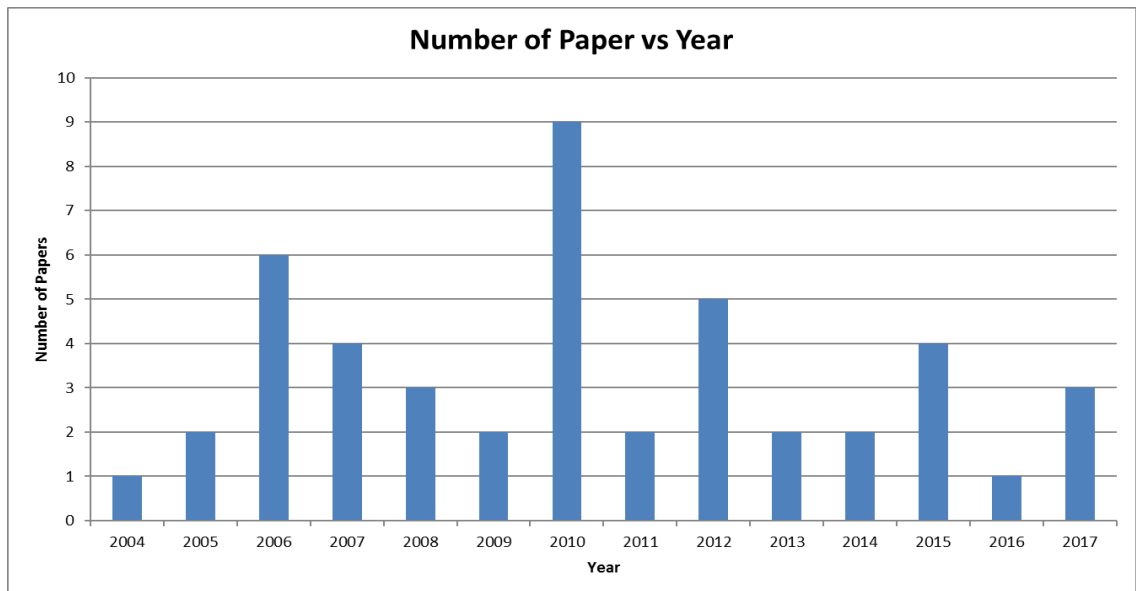
Figure 2.2:Publication reviewed rate per year

From Figure 2.2 the starting point of reviewed publication is 2004. This was done to ensure relevant research pertains to IEC 61850 standard edition 1. Vendor devices used for this research are compliant to IEC 61850 standard edition 1 which was published in 2003. The research focuses on reviews of various interoperability scenarios viz. interoperability testing, performance testing, engineering processes, conformance testing etc. As much the IEC 61850 standard champions/promotes interoperability the graph above indicates that minimal research directly deals with GOOSE message interoperability. This allows the review of literature to be moulded by various research to build/firm-up a methodology to achieve interoperability.

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2.3 Review of existing papers on IEC 61850 interoperability

The review of the papers was carried out using the following criteria.

- Statement of the problem
- Project objective
- Approach of the solution (model/method) of a Substation Automation System (SAS)
- Constraints and drawbacks experienced, and
- Findings

The developments of GOOSE message applications and interoperability applications are shown in Table 2.1. The literature review sets out to learn from previous research with regard to any shortfalls and success and to ensure the research takes the direction of successful implementation from proposed methodologies.

Table 2.1: Literature comparison table

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
Brand, Brunner, Wimmer (2004) *"Design of IEC61850 based substation automation systems according to customer requirement"*	*Communication* is the backbone of substation automation and, therefore, IEC 61850 is the most important key for designing systems since interoperability and free allocation of functions opens up	To analyze the effect of IEC61850 features in designing optimized systems.	A model of the real environment is used in order to implement the designing parameters as issued by the customer	Some boundary conditions like the topology of the substation, the interfaces to auxiliary power supply system, to the switchgear and to network control centers exist	With IEC61850, different solutions are possible. Optimized Substation Automation systems can be designed, which are not expensive and with un-maintainable solutions. Two design processes are proposed. 1. Specify, Design, Allocate LNs, Find and Configure IEDs,

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
	a vast range of possible solutions				Communication Architecture, Detailed Design 2. Specify, Select IEDs, Check LDs, Map Functions, Communication Architecture, Detailed Design
Dolezilek (2004) *"IEC 61850: What you need to know about functionality and practical implementation"*	Review IEC 61850 and analysis	To provide contemporary observations and implementation evaluation	Evaluate all IEC 61850 standard parts	No implementation was conducted.	Seamless system integration as IEC 61850 standard makes use of flexible data mapping
Apostolov (2005) *" Simplifying the configuration of multifunctional distribution protection and control IEDs"*	Modern multifunctional IED bring about complexity of setting IEDs be it protection or non-protection elements	Evaluation of a tool that will simplify configuration	Assessment of how different functions and functional hierarchy for configuration requirements in the configuration tool. Step by step guide on using S1 Studio software.	Only one tool evaluated and the tool is from Areva (S1 Studio).	Illustrated the benefits of use of a user friendly tool for configuration.
Maffezzini, Gelinas(2006) *"IEC 61850 interoperability from client/integrator point*	Description of functional and database design to validate Intelligent	Implementation of a configuration system	Design and implementation of a centralised database to	Openness of the IEC 61850 standard. Implementing	SCALCID provides the engineer or integrator with ability to check vendor device against the utility set

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
of view"	Electronic Device based on IEC 61850	prototype(SCA LCID)	assist with interpretation and interoperability	interoperability using utility specific tools does not benefit SA society at all.	requirements effortlessly. This ensures the utility procures without discrimination of any vendor and create an environment where interoperability can thrive.
Zhang et al (2006)*"Compatibility and Interoperability for All-digital Protection through Automatic Application Test"*	Lack of definition of different optical instrument transformers connected to different relays by IEC 61850	Develop methodology of compatibility and interoperability evaluation	Develop an automatic application test by evaluating compatibility and interoperability and evaluate the conformance and performance test	None	Methodologies developed by creating a referent model and evaluating performance indices
Brand, Rietmann et al (2006) *"Requirements of interoperable distributed functions and architectures in IEC 61850-based SA systems"*	Application of distributed functions in complex switchyard topologies with dynamic power flows with regard to IEC 61850 interoperability	Evaluate IEC 61850 interoperability on distributed functions.	An evaluation of distributed functions namely breaker failure protection, Interlocking, and reverse blocking protection scheme.	IEC 61850 does not clearly define distributed functions specifically the interfaces required for communication.	IEC 61850 requires improvements with regards defining more interfaces to cater for complex switchyard topologies with dynamic power flows
Brand and Wimmer (2006) *"Modeling interoperable protection and control devices for*	Interoperability modelling of different IED	A closer look of syntax and semantics.	Distance protection scheme	IED capabilities	IEC 61850 allows for expansion of functions namely allocation of Logical Nodes (LN) for

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
substation automation according to IEC 61850	vendors				various plants.
Wang and Jing, (2006) *"Research on GOOSE Configuration"*	How GOOSE messages effect engineering design	Illustrate GOOSE message configuration	Review GOOSE message configuration compared to legacy protocols and hardwiring	The shift of design work of protection systems from consultants to vendors	Improved protection and control due to the use GOOSE messaging and no requirement of signal list.
(Muschilitz, 2006) *" IEC Conformance Testing: Goals, Issues and Status"*	Review of IEC 61850 Conformance Testing	Discuss issues surrounding conformance testing	Propose IEC 61850 conformance testing requirements based on the review	Defined test methods in IEC 61850 Standard are open to interpretation	Proposed an establishment of a KEMA test lab although with its shortcomings
Schwarz (2007) *"Impact of IEC61850 on system engineering, tools, people-ware and the role of system integrator"*	To analyze the basics of IEC 61850 through the engineering of substations and IEDs application	To understand and to define the role of the system integrator for IEC 61850 based systems.	Lab tests, pilot projects, and other projects are used to train users, to gain the needed expertise	Vendors, users, and system integrators have to go through a learning curve	The knowledge of IEC61850 is still minimal within utility companies
(Charles, McDaniel, Dood 2007) *"Protection, Control and Automation system for a multi station looped distribution system"*	Development of the protection, control and automation systems for a distribution system	To upgrade the protection scheme and design a Supervisory	A one line diagram method was implemented for interface purposes on the	Product selection due to the flexibility and analogue logic availability that is required	The use of IEC 61850 IED's and SCADA is a solution to a reliable and cost effective protection system

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
		Control and Data Acquisition (SCADA) system	SCADA		
Holbach, et al (2007) *"First IEC 61850 Multivendor Project in the USA"*	Demonstration of IEC 61850 Interoperability	Implement IEC 61850 SAS using multivendor IEDs.	Multivendor IEDs implemented on a 500kV project. Proof of concept tests were conducted prior to integration.	Reliance on relay manufacturers on system configuration	Interoperability was achieved. The 500kV substation was successfully commissioned as per methods employed.
Flores, et al (2007) *"Case Study: Design and Implementation of IEC 61850 From Multiple Vendors at CFE La Venta II"*	Reduce engineering costs and commissioning time.	Implement interoperability and interchangeability with IEC 61850 devices	Implementation of a IEC 61850 substation by setting out functionality required in the substation first	The standard IEC 61850 has left a lot for vendors to interpret on their own.	Implementation was a success. The implementation was done in stages in order to attain interoperability.
Gupta (2008) *"Substation Automation using IEC 61850 Standard"*	Conceptual substation automation scheme in compliance with IEC 61850 to achieve interoperability	Review of IEC 61850 standard on defined object models	Review of measurement data model.	Reviewed only one data model. For interoperability to be realised full functionality needs to be evaluated.	The conceptualized model provides better control and monitoring of substation automation. This is due to IEC 61850 standard blocks and can allow distributed functions and interoperability possible.
(**Ito and Ohashi, 2008***)"*	Review of GOOSE	Outline basic	Evaluate	None	Test methods discussed show

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
IEC 61850 GOOSE of High Performance and Protection Relay Testing"	messaging protection based systems	testing requirements of GOOSE messaging based systems	performance of GOOSE messages in a protection system with various test methods		that GOOSE message performance can be evaluated with various methods.
(Liang & Campbell, 2008) "Understanding and Simulating the IEC 61850 Standard"	IEC 61850 Standard tends to be convoluted and complex.	To provide a new point of view to understand IEC 61850 standard	Design and implementation of a simulation tool to fully understand IEC 61850 standard	The use of proprietary software merely further complicates IEC 61850 implementation and testing	Difficult to understand and implement IEC 61850 for other than domain experts. Established own internal data representation to simulate the IEC 61850 standard protocol.
Hakala-Ranta et al (2009) *"Utilizing possibilities of IEC 61850 and Goose"*	Illustrate/Demystify IEC 61850 standard	Discuss IEC 61850 elements	Discuss installation benefits, performance and protection schemes based on IEC 61850	None	IEC 61850 is cost efficient keeping in mind the increased performance, flexible protection schemes and better reliability
(Tan, Green, & Ciufo, 2009)" Testing IEC 61850 Based Multi-vendor Substation Automation Systems for Interoperability"	Establishing Interoperability testing.	Verify interoperability prior integration	Test case to prove interoperability. Interoperability testing scenarios. Proof of concept test, Site acceptance test, Single vendor	None	Testing was a success using a transfer trip cased study. Compared hardwire trip with GOOSE trip. GOOSE message was faster than the hardwired trip. GOOSE trip proved faster even with background traffic on Local Area Network when

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
			and multi-device test, peer to peer test, Client-server test, Horizontal test and Vertical test.		compared to hardwired trip.
Carmo, et al (2010) *"Design and Automatic Testing of IEC 61850 Substation Automation Systems"*	IEC 61850 standard does not define functional and performance testing.	Proof of concept of a software tool for testing and performance testing.	SMASH(SAS Testing and Fault Diagnosis) Tool which provides functional testing	None	Various advantages when using the Smash tool. The tool provides a GOOSE message monitoring, provides benchmarked tripping times and easy comparative results.
Matsuda, et al (2010) *"IEC 61850 based Substation Automation System and Interoperability Solutions"*	IEC 61850 standard provides too many options with regard to logical nodes.	Different integration methods to achieve interoperability	System design method to achieve interoperability. The methodology steps are Definition, System design, System test, Operation and Maintenance.	Issues regarding the flexibility of the standard, Issues regarding optional parameters and generic application data and Issues regarding the detail of the standard	System configuration must be done carefully to achieve interoperability. This was achieved by the following steps: Confirmed the LNs to be applied for each function, Confirmed the essential data attributes in the LNs and define the meaning of data within the LNs, Confirmed the communication services for each LN, Confirmed the allocation of LNs to physical devices.
Dawidczak and Engelrt (2010) *"Improving IEC 61850 interoperability by*	The continuing trend of utilities relying on single	Assess interoperability.	Flexible object modelling and		Interoperability depends upon vendor implementation of IEC 61850. Interchangeability can

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
flexible object modelling and naming"	vendor for SAS although interoperability is available.		naming		be met.
Luc (2010) *"The Performance of IEC 61850 Goose Messaging"*	To investigate the protection and messaging performance of GOOSE messages between IEDs, in comparison with the performance of hard-wired protection schemes.	Compare hardwired performance of protection scheme to a GOOSE message protection scheme	Hardwired protection scheme set up in a lab and GOOSE message based protection scheme set up in a lab to evaluate performance.	No evaluation conductor on prioritising GOOSE messages in the network.	Goose messaging faster than hardwired signal but the network topology for GOOSE messaging has effects on their performance. Where additional Ethernet switches are added and background traffic added the GOOSE message becomes slower but still faster than a hardwired scheme
Steinerhauser et al. (2010) *"The Performance Measurement of IEC 61850 IEDs and Systems"*	Review performance testing of IEC 61850 IEDs and Systems	Formulate test procedures for performance testing of IEC 61850 IEDs and Systems	GOOSE message round trip test , Rally test to evaluate performance	None	Performance of an IEC 61850 IED is not only dependent on the IED. The network topology plays role in the performance of GOOSE message and network load.
Joshi (2010) *"Utilization of GOOSE in MV Substation"*	The use of legacy protocols in MV Substations	Discuss advantages of GOOSE over conventional protection and control schemes	Comparing GOOSE messaging to other protocols with regards to their functionality.	None	GOOSE messaging was found to have more advantages although capital cost is high but it is cost effective in the long run. This was compared to Modbus, Profibus and IEC 6870-5-103

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
Brunner and Apostolov (2010) *"Functional Testing of IEC 61850 based systems "*	Testing of IEC 61850 based systems	Establishing methods of testing IEC 61850 based systems	Adopted the analogy of software tools testing	None	Details concepts of Testing IEC 61850 based systems both complex and simple substation automation system
Englert and Dawidczak (2010) *"Improving IEC 61850 Interoperability: Experience and Recommendations "*	Interoperability of IEC 61850 devices	Recommend modelling methods to achieve Interoperability	Defines Interoperability and its categories	None	Flexible modelling is ousted as a major requirement for Interoperability
Aguilar and Ariza (2010) *"Testing and Configuration of IEC 61850 Multivendor Protection Schemes'*	IEC 61850 standard does not define testing procedures nor for multi-vendor protection schemes.	Discuss Multivendor testing obstacles and configuration of the system	Set up a Laboratory test bench. The case study used was a backup up protection scheme (Breaker failure). Methodology adopted was configuration of individual IEDs, configuration of the system, system verification test, comparing hardwire to GOOSE	The configuration difficulties are not illustrated but merely referred to.	Lack of knowledge of IEC 61850 leads to challenges of testing and configuration an IEC 61850 multi-vendor based system

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
			performance		
Tarlochan et al. (2011) *"Configuration and Performance Testing of IEC 61850 GOOSE"*	IEC 61850 is being widely adopted around the world and not always implemented systematically.	Illustrate a systematic approach for GOOSE configuration, verification and performance	Test case of Round trip GOOSE message to provide configuration , verification and performance insights	None	A comparison between VLAN and non-VLAN tagged GOOSE messages with varying network background traffic. VLAN tagged GOOSE messages are faster than non-VLAN GOOSE messages.
(UCA International Users Group, 2011)	Evaluation of Interoperability in a IEC 61850 system	Demonstrate interoperability using various models	Creating various test scenarios for Substation Communication Language, Sampled Values, GOOSE and Client/Server applications	Number of participants and Witnessing vendors/ companies	Various issues with regard to interoperability but can be improved by robust interoperability testing.
Chen et al.(2012) *"Using Multi-Vendor IEDs for IEC 61850 Interoperability and HMI-SCADA Application"*	Develop an interface between Multi-Vendor IEDs and HMI-SCADA Applications	Build a functional platform for the Interface	Configured lab based IEC 61850 Interoperable system interfaced to HMI-SCADA Applications	None	With Interoperability functional new IEDs can be easily integrated and GOOSE messages can be monitored on the HMI-SCADA
Tan et al.,(2012) *"The Importance of IEC 61850 Interoperability Testing"*	Discuss IEC 61850 Interoperability issues	Recommend IEC 61850 Interoperability Testing	Discuss various Interoperability testing scenarios. Proof of concept	Interoperability testing methods are not defined in the IEC 61850 and	Interoperability testing is vital before implementation on equipment in substations. It serves as proof of concept for

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
			test, Site acceptance test, Single vendor and multi-device test, peer to peer test, Client-server test, Horizontal test and Vertical test	need to be formulated	interoperability as per methods
Koshiishi et al., (2012) *"Interoperability experience with IEC 61850 Substation Automation Systems"*	Discuss IEC 61850 Interoperability implementation issues	Discuss IEC 61850 Interoperability SAS	Evaluate IEC 61850 Interoperability based on previous test scenarios	None	IEC 61850 standard does not define the implementation of a SAS.
(Netto et al., 2012) *"A Behavior Evaluation of Network Traffic in Power Substation Concerning GOOSE Messages"*	GOOSE message performance on a loaded network	Assess GOOSE message performance under different network loading	Assessment of network threshold loading before GOOSE messages performance is compromised	GOOSE message priority was not explored.	Established network loading threshold where GOOSE messages speeds are compromised. This was illustrated by generating LAN background traffic and measuring GOOSE message performance.
(Sidhu et al., 2012)"Packet Scheduling of GOOSE Messages in IEC 61850 based Substation Intelligent	Scheduling methods for GOOSE messages investigation	Analyse packet scheduling algorithms	Test various algorithms of packet scheduling	None	Packet scheduling assist GOOSE messages to retain acceptable transfer times but has its shortcomings. (Ethernet switches strip the VLAN tagging from the packet once a packet

26

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
Electronic Devices (IEDs)					passes a switch)
(Yang, Gu, Lin, Huang, & Guan, 2013)" Interoperability and Performance Analysis of IEC 61850 Based Substation Protection System**"**	KEMA IED certification insufficient to ensure interoperability of IEDs from different manufactures	Test interoperability by development of a test platform	A test platform to verify and analyse the interoperability and performance of IEC 61850 standard among IEDs.	Failure to evaluate GOOSE message interoperability communications that failed.	Interoperability was achieved on some of the devices. The evaluation was done using a CMC Omicron device and Wireshark network analyser.
(Castano, Zapata, & Garcia, 2013)" Monitoring and Checking Standard IEC 61850 Respect to Manufacturer"	Monitor and Check manufactures conformance to IEC 61850 standard	Specify the standard techniques for development of conformance testing	Compare between concepts and guidelines that define the standard IEC 61850.	Based on IEC 61850 Edition 1.	Successfully implemented conformance testing as per IEC 61850-10. This is done by repeating all tests as per conformance testing.
(Fernandes, Borkar, & Gohil, 2014)" Testing of GOOSE Protocol of IEC 61850 Standard in Protection IED"	The requirement to test high speed communication between IED to IED	Provide setup for practical testing of protection schemes	Test peer to peer communication between two IEDs. Round trip time is evaluated.	None	GOOSE message communication was confirmed using Wireshark to check status/event changes
(UCA International Users Group, 2014)	Evaluation of Interoperability in an IEC 61850 system	Demonstrate interoperability and pin pointing problems and addressing potential	Creating various test scenarios for Substation Communication Language, Sampled Values, GOOSE and	Number of participants and Witnessing vendors/ companies	Various issues with regard to interoperability but it can be improved by robust interoperability testing.

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
		source of issues	Client/Server applications		
(Amjadi & Kalam, 2015) "IEC 61850 GOOSE Performance in Real Time and Challenges Faced by Power Utilities"	IEC 61850 standard has been accepted across the world and hardwiring systems are being used less and less. Historic hardwired systems are used to benchmark IEC 61850 system performance.	To ascertain GOOSE message performance against hardwired schemes	Built an interoperable system to test GOOSE messaging using the following vendors ABB, SEL and Areva devices. The protection scheme implemented is breaker failure scheme vs a hardwired scheme.	None	GOOSE message faster than wire trip signal, at 2.4ms faster. This was measured making use of IEDScout software. The Omicron CMC 356 device is used to induce a fault.
(Carmo, et al., 2015)**" IEC 61850 Traffic Analysis in Electrical Automation Networks"**	With the rapid adoption IEC 61850 network performance becomes vital for protection functions	Diagnose failure/fault type by observing network traffic	Measurement of the process bus and station bus network traffic on a test bed using Wireshark	Only one type of fault is evaluated.	Process buss traffic yielded no results as the network traffic behaviour does not change during an event/trip event. Station bus traffic illustrates the event by an increase in the flow of data in the network. The network behaviour is modelled and rationalised with probability distribution.

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
(Noran & Shukri, 2015)**"** **Adaptive Breaker Failure Protection Scheme for Double Busbar Substation using IEC 61850 GOOSE Message Communication"**	Inter-trip signal is conventionally achieved by copper based wiring (hardwiring) to implement breaker failure protection scheme. With IEC 61850 GOOSE message is used to implement Inter-tripping.	Design an adaptive breaker failure protection scheme using IEC 61850 GOOSE message.	Define IEC 61850 Engineering process to design an adaptive breaker failure protection scheme.	None	The paper illustrated the flexibility of protection and control scheme design and configuration by using IEC 61850 standard. The design was done using multiple vendors thus also proving interoperability. The devices used are Schneider, SEL and ABB devices.
(Tsang & Ng, 2015)**"** **GOOSE Interlock Overcurrent Protection for 11kV Double Busbar Substation"**	The use of GOOSE message in protection functions raises the issue of reliability of GOOSE message transmission regardless of improved tripping times	Evaluate GOOSE message reliability technology in a 11kV busbar protection.	A supervision scheme was formulated to monitor interlocking scheme.	No actual timing between IEC 61850 scheme and hardwired scheme were assed.	The monitoring scheme provides significant advantages over the hardwired scheme due to the interlocking scheme being monitored.
(UCA Internetional Users Group, 2016)	Evaluation of Interoperability in a IEC 61850 system	Demonstrate interoperability and pin pointing problems and addressing potential	Creating various test scenarios for Substation Communication Language, Sampled Values, GOOSE and	Number of participants and Witnessing vendors/ companies	Various issues with regard to interoperability, but can be improved by robust interoperability testing.

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
		source of issues	Client/Server applications		
(Adhikary, et al., 2016) **"Implementation Aspects of Substation Automation Systmes based on IEC 61850"**	The Power industry called for a universal communication standard to enable interoperability and integration between different manufactures and different types of IEDs for Substation Automation.	Review IEC 61850 standard in a Substation Automation environment.	Review IEC 61850 in the following aspects, GOOSE message, SCL, Ethernet Topologies, Implementation issues of IEC 61850 and Migration aspects	Interoperability is not discussed in the paper but the findings praise IEC 6180 interoperability.	The paper concludes that IEC 61850 is the perfect tool to achieve interoperability between different manufacture IEDs.
(Sathyadevan, et al., 2016) **"Digitised Copper - Advantages, Disadvantages and Outlook of a Power and Process Intergrated Control System using IEC 61850"**	The unification of Power and Process Automation via the Ethernet standard	Compare common based IEC 61850 to traditional Power and Process Automation.	Set up two model projects for a traditional Power and Process Automation and a common based IEC 61850 Automation. Review Modbus RTU, Profibus and IEC 61850.	Process Automation not evaluated in conjunction with Power Automation.	The paper highlights the advantages of IEC 61850 standard with regards to its architecture.
(Singh, et al., 2016) **"Procedures for Testing Control and Protection**	Due to the adoption of IEC 61850 testing of	Illustrate requirements of testing	Build an interlocking and inter-trip	IED IEC 61850 testing equipment gave limitations with	Testing methodology established for certain protection schemes or

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
Scheme based on GOOSE Messages - Methodology and Constraints from Engineering Perspective"	protection schemes have drastically changed.	methodology for GOOSE message schemes.	protection scheme to troubleshoot/trace GOOSE message communication.	regards to SCL file identification and GOOSE message publication and subscription capability	scenarios basically using IEDscout software to interrogate GOOSE message communication
(Peng, et al., 2017)**"Implementing Automatic Transfer Scheme in Main-Tie-Main Configuration Using IEC 61850"**	How to ensure continuity of supply in a radial distribution network.	To ensure a single fault does not debilitate the entire distribution network	Formulation of an Automatic Transfer Scheme (ATS) and Retransfer Scheme (RTS) on a Main-Tie-Main (MTM) configuration using GOOSE messages.	None	Makes use of three IEDs to do the ATS and RTS. These are named Main 1, 2 and Tie relay (IED). GOOSE messages provide logic sequence for the switching.
(Amulya, et al., 2017)**"Experimenting with IEC 61850 and GOOSE message"**	Review GOOSE message application	Study the performance of GOOSE messaging	Two SEL IEDs with a multilink switch with application of an overcurrent protection application. To compare transmission time between push button and	The analogy/comparison between the push button and GOOSE message is not fully explained.	GOOSE message transmission is faster than pushbutton transmission to the IED LED.

PAPER	PROBLEM STATEMENT	OBJECTIVE	MODEL	CONSTRAINTS	FINDINGS
			GOOSE message		
(Ingalali, et al., 2017) **"SCD based IEC 61850 Traffic Estimation for Substation Automation Networks"**	Ethernet network of Substation Automation network can easily be overloaded and thus efficacy becomes a necessity.	Determination/ Estimation of traffic in the network to inform optimal segmentation of the network	Determine bandwidth using SCD file by prioritising GOOSE messages with the use of VLANs	None	Makes use of SCD file to ensure the network gets segmented in accordance with application in the network. Grouping GOOSE messages in accordance with priority of the application to ensure an efficient network and not delay critical applications.

2.4   Findings from the literature comparison

2.4.1 GOOSE configuration

It is abundantly transparent that the configuration of a substation automation system based on IEC 61850 standard plays a huge role to achieve interoperability. This is due to the fact that IEC 61850 is based on object modelling. (IEC 61850-1, 2003)

Dolezilek (2005) states that the majority of LN content described within the IEC 61850 are optional. IEC 61850 does not standardise which LN must be in an IED. This causes IEDs from different vendors to have different LN collections which may have different data attributes within them. Interoperability is achievable but due to the optional data defined in the standard some vendors may include the data, some may not, which may lead to a reduced functionality in an interoperable SAS. The optional data attributes that are included by other vendors can actually impede interoperability which is squarely dependent on how the vendors interpret or process incoming GOOSE messages.

Bay level interoperability allows users/designers to choose bay level Local Area Network (LAN) designs from multiple vendors based on functionality, performance, reliability and communication acceptance criteria. Interoperability can become complex when complex switchyard topologies are implemented on an IEC 61850. According to **Maffezzini and Gelinas(2006)** the narrower the application domain the easier it is to implement interoperability. Interoperability can be achieved in many ways but **Maffezzini and Gelinas(2006)** research focus is on an interoperable configuration tool. Development of the configuration tool had to meet certain requirement for the developers namely:

- Facilitation of functional requirements elicitation, specification and validation.
- Design and implementation of centralised database, called SCALCID
- Storage of the IEC and Hydro-Quebec (HQ) substation control standards in the SCALCID (Configuration System Prototype) database

SCALCID is a configuration tool designed to perform the above. SCALCID is adaptable to any IEC 61850 configuration tool. The standard defines LNs and their mandatory attributes and some optional attributes. Due to this, vendors include these optional attributes because the attribute might be required for functionality. Some vendors might just define only the mandatory attributes and thus the issues of interoperability arise.

Although an interoperable configuration tool adds value to the whole interoperability mission it also brings new challenges with regard to achieving proficiency on the configuration whilst the same proficiency is required for the proprietary vendor configurations tools.

Gupta (2008) achieves interoperability by making use of object models defined by IEC 61850 standard. Conceptual data class model provides better control and monitoring of substation automation. Evaluation was conducted on a defined model and the data within defined model was evaluated and the functions performed by the data evaluated. Utilities have often criticised IEC 61850 interoperability capability because undefined object models in IEC61850 poses challenges to achieve interoperability. Although not impossible to achieve it requires in depth studies and Substation Configuration Language (SCL) file manipulations to be achieved.

According to **Apostolov (2005)** the configuration of advanced multifunctional relays is a critical step in the protection system. A selection of a configuration tool requires a criterion to perform the selection. A configuration tool must be user friendly, reduce configuration time and reduce human errors. The configuration tool should be able to enable and disable protection functions and visibility control. The research points out an improvement and a reduction of the number of settings that need to be entered. Configuration tools should have a graphical user interface to develop a programmable scheme logic diagram. Although **Apostolov (2005)** views are correct and provide insight on an ideal configuration tool. If user utilises various vendors the user still requires the vendor proprietary configuration tool to load the necessary files onto the device.

According **Flores, et al (2007)** the IEC 61850 standard has left the implementation details to the discretion of vendors, just to name a few issues which are not standardised:

- *"Quantity of client/server associations to the device*
- *Quantity of peer to peer messages the device will publish or transmit*
- *Quantity of peer to peer messages the device will subscribe to or receive*
- *Number of characters allowed in the device name*
- *Run time diagnostics*
- *Configuration of the device via SCL Extensible Markup Language (XML) files instead of settings"*

Implementation was a success although there were a few drawbacks as detailed above. Even though the IEC 61850 has not defined the items above, this should not be a hindrance for interoperability. One requirement to achieve interoperability is that a naming convention needs to be adopted thus all IED's need to be evaluated to this regard in order to achieve interoperability

Brand and Wimmer (2006) state that interoperability can be achieved by careful modelling of the substation automation system. This requires an extensive understanding of IEC 61850 standard. The research looked at vertical function structures and horizontal function structures. IEC 61850 has extensive mapping for defined object models and also allows for definition of object models by the user in accordance to a certain set of rules. This allowed vendors freedom of what functionality to incorporate with in an IED. Free allocation, combination and connection of LNs allow vendors to optimise their particular IED but this freedom can also hamper interoperability. Thus in-depth evaluations of IED's is required prior an interoperable substation automation systems is implemented.

Carmo, et al (2010) state that functionality and performance testing is not defined by IEC 61850 standard. Working Group (WG) B5.32 proceedings were adopted for the research in the paper. B5.35 defines a script language and is used in conjunction with a configuration tool called Smash. Smash is a syntax driven editor which builds test scripts for various protection schemes. Proof of concept implementation of the tool was demonstrated.

Matsuda, et al (2010) developed four steps procedure on how to achieve interoperability which are:

1. *"Confirm the logical nodes to be applied to each function*
2. *Confirm the essential data attributes in the logical nodes and define the meaning of data in the logical nodes.*
3. *Confirm communication services for each logical node*
4. *Confirm the allocation of the logical nodes to the physical devices"*

Dawidczak and Engelrt (2010) state that flexible object modelling and naming enables interchangeability and interoperability. **Dawidczak and Engelrt (2010)** paper established interchangeability and interoperability requirements. This was to show the efficiency of flexible modelling and naming. Established flexible modelling and naming requirements are:

- Ensure that the set of IEDs, which are selected for replacement, provides the comparable functionality (e.g. protection and control) and physical compatibility (terminals and auxiliary voltage level)
- Ensure that the set of IEDs supports a common set of data classes and communication services. This includes the ability for flexible object modelling and naming

UCA International Users Group (2011) details products used for GOOSE testing and findings thereof. The products used for testing are given in as follows:

Table 2.2: Interoperability testing device (UCA International Users Group, 2011)

Vendor	Product Name	
	Publisher	**Subscriber**
Alstom	Micom P545 Relay	Micom P545 Relay
Efacec Automation	BCU 500 Bay Controller v2	BCU 500 Bay Controller v2
Prosoft Systems	F650 Relay, SR3 Relay	F650 Relay, SR3 Relay
RTDS	GTNET-GSE	GTNET-GSE
Schneider electric - Energy	P139 Relay	P139 Relay

Vendor	Product Name	
	Publisher	**Subscriber**
Siemens	SIPROTEC 4 7SJ64 Relay	SIPROTEC 4 7SJ64 Relay
SISCO	Unified Analytic Platform (UAP)	Unified Analytic Platform (UAP)
Schweitzer Engineering Laboratories	421 Relay	421 Relay
Toshiba	GRZ100 Relay	GRZ100 Relay
Traingle Microworks	Hammer	Hammer
ZIV	TPU-1 7IDV Relay	TPU-1 7IDV Relay

The following aspect of GOOSE messaging where tested namely:

- Substation Configuration Language (SCL) Exchange
- Functional Constraint Data (FCD) Dataset
- Functional Constraint Data Attribute (FCDA) Dataset
- Test Bit
- Time Allowed to Live Detection
- Control Block Enable/Disable

The various participants where pitted together to test interoperability. The tabulation of the results on the report where not discussed properly and are difficult to interpret. The tables provided in the report are ambiguous due to spaces left on tables provided and abbreviations that where left undefined. An example of the table is shown below, Table 2.3.

Table 2.3:Interoperability Test Participants

Company (Publisher)		Alstom	Efacec Automation	GE	GE	Prosoft-System	RTDS	Schneider Electric	Schweitzer Engineering Laboratories	Siemens	SISCO	Triangle	Toshiba	ZIV	ZIV
Company (Publisher)	Product	P545	BCU500	F650	SR350	MC ECA	GTNET	P139	421	SIPROTEC-4-7SJ64	UAP	HAMMER	GRZ 100	TPU-1	7IDV
Alstom	P545					P					P				
Efacec Automation	BCU500														
GE	F650														
GE	SR350					P		P							
Prosoft-Systems	MC ECA	P					P	P			P		P		P
RTDS	GTNET														
Schneider Electric	P139				F - N2	P	P		P		P	P			
Schweitzer Engineering Laboratories	421		P					P							
Siemens	SIPROTEC 4-7SJ64														

	Company (Subscriber)	Alstom	Efacec Automation	GE	GE	Prosoft-System	RTDS	Schneider Electric	Schweitzer Engineering Laboratories	Siemens	SISCO	Triangle	Toshiba	ZIV	ZIV
	PAS														
SISCO	UAP	? - N1				P		P							
Toshiba	GRZ 100														
Triangle Microworks	ANVIL														
ZIV	TPU-1														
ZIV	7IDV					P	P						P		

UCA International Users Group (2014) discusses various issues found during their sponsored interoperability tests. The areas of interest to this study are the findings/issues with regards to the GOOSE messages. The Table 2.4 below provides a summary of the:

- Category: What is the root cause of the problem (e.g. standard, implementation, non-issue, not identified).
- Issue: What was the problem/issue that was encountered.
- Diagnosis: What is the impact of the issue.
- Action: This indicates the action(s) that are intended to be taken to resolve the issue.

GOOSE message issues encountered:

Table 2.4:GOOSE Message Issues

Issue No	Category	Issue Description	Diagnosis	Action
1.	61850-8-1 Standard Interoperability	During GOOSE testing, GOOSE messages were being transmitted and received. However, some of the DataSet member data could not be processed or displayed.	There is no mechanism to declare what data types are supported within SCL file. A subset of mandatory supported data types needs to be defined or all data types need to be supported. See SCL issue 32 UCA International Users Group (2014) .	Submit to WG10 through User Feedback Task Force.
2.	Interoperability Implementation	An ICT could load and process an appropriately configured Instantiated IED Description (IID). However, the IED that the ICT configured could not subscribe to a GOOSE message.	There were a couple of instances of this problem during the Interoperability (IOP). One instance was the failure of a general laptop Ethernet port that caused a need for the computer to be restarted. The other instance was investigated, but no final diagnosis was determined.	Further diagnosis is required.
3.	Implementation of Interoperability Tests	A subscriber could not subscribe to a Functionally Constrained Data (FCD) that had more than one floating point value in it.	There are many FCDs where this is going to occur (vector, etc.). It is expected that FCD support is provided by subscribers in Edition 2 (ED.2) and any Edition 1 (ED.1) subscriber claiming FCD support should also behave appropriately.	Fix Implementation.
4.	Question	A question arose about if a GOOSE message stNum should update if a value is "updated" but the value does not change.	GOOSE is a state changed based protocol. Therefore, if a value in the DataSet does not change, there is no requirement for stNum to increment. However, if the Timestamp is part of the DataSet, an "update" would typically	Submit through User Feedback Task Force. Target would be for a system design document within UCA IUG.

Issue No	Category	Issue Description	Diagnosis	Action
			change the value of the Timestamp and the GOOSE must be sent with a different stNum. Is it allowed to send a GOOSE and increment stNum on a value "update"? The standard does not prohibit this and subscribers should be capable of receiving such information.	
5.	Interoperability	A GOOSE publisher sent a DataSet member value that was a 2-bit bitstring. However, the unused bits were set to values of True. The bitstring was received by a subscriber and discarded since the unused bits were True.	ASN.1 implies that the unused bits should be set to False. The publisher should be sending False. It is suggested that the subscriber be more tolerant and ignore the values of unused bits.	Fix Implementation

UCA Internetional Users Group (2016) compare fndings on interoperability tests done previously. The Figure 2.3 below illustrates the number of issues encountered. .
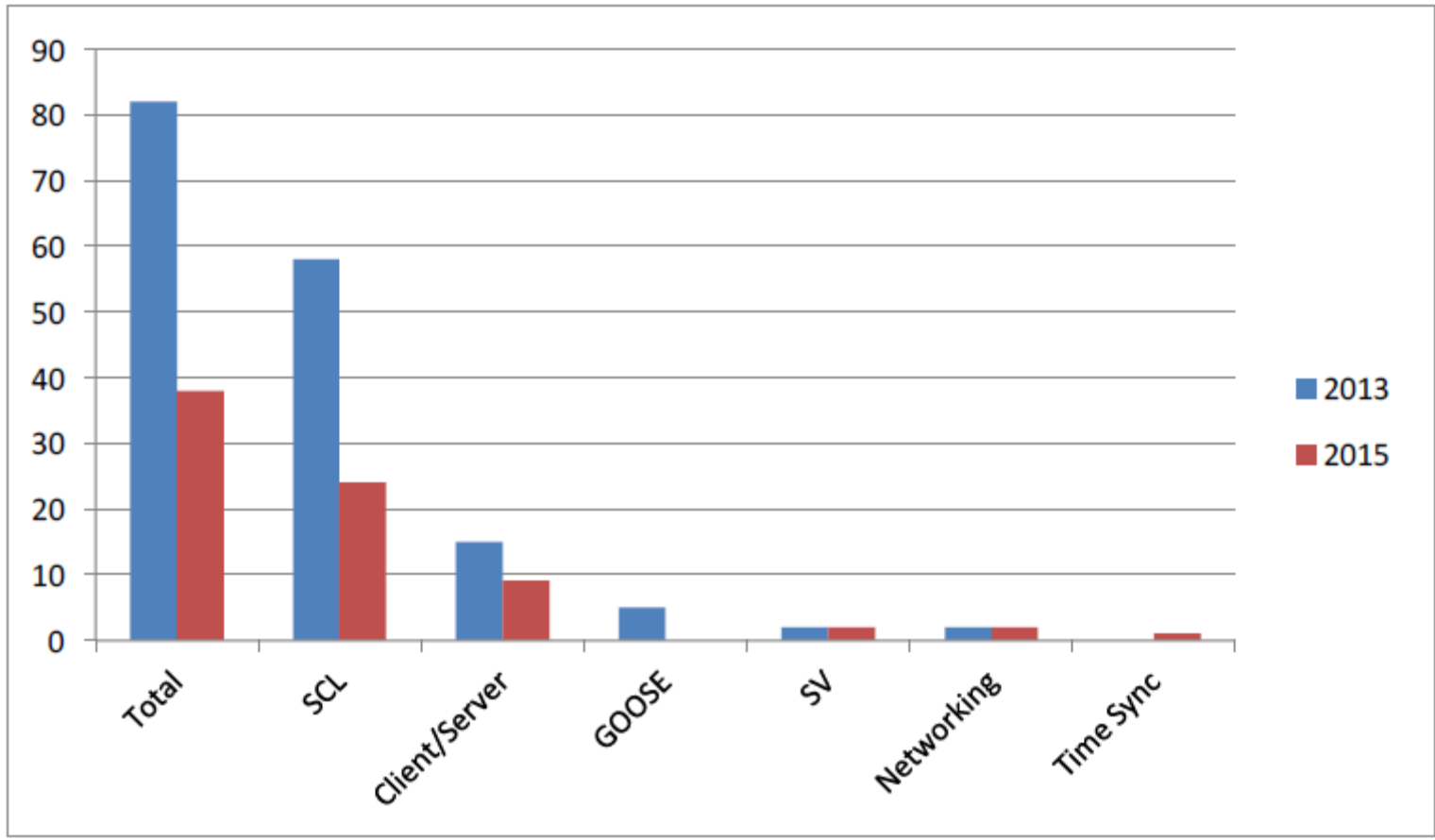
Figure 2.3: Interoperability Test Findings

Note on the above figure that no GOOSE messages errors encountered for all test scenarios for the test in 2015. The various interoperability tests done by UCA International Users Group (UCAIug) do not evaluate the various configuration tools used by the vendors. The reason for this is because this is not a factor for the study as the configuration is done by the vendors themselves. To promote IEC 61850 interoperability it is important to evaluate configurations tools independently in order to show seamless integration to provide confidence to various utilities and municipalities.

Tarlochan et al. (2011) discusses the configuration of GOOSE messages in a more generic manner. Generic pertaining is that the discussion does not refer to particular software packages. Although the research is relevant to configuration problems it fails to mention if that configuration of GOOSE messages is vendor independent or not.

It is clear that Interoperability is influenced by various factors. Interoperability configuration of IEC61850 is influenced by the following:

- Configuration tools
- Naming conventions
- IED selection for appropriate application

Tan et.al, (2009) provides a generic integration procedure for SCL files as follows:

1. *"Generate IED Capability Description (ICD) or Configured IED Description (CID) files*
   Each IED produces a self-description IED Capability Description (ICD or CID) file with the information required for exchange already configured for GSSE/GOOSE publication. The file extension, which can be ICD or CID, must contain the following specific IED configurations:

   - *IED name*

   - *IP address*

   - *Multicast MAC*

   - *VLAN ID*

   - *Ethertype, AppID*

   - *Publishing GOOSE dataset information*

This part remains as proprietary, must be performed by the vendor-specific IED configuration tool

2. *Configuring the data flow between IEDs*
    Import ICD/CID files generated from (1) into a System Configurator such as Digsi 4.8. The information published for each IED will be auto-displayed in the source window ready to be configured.

    Configure the data flow between IEDs by subscribing to the published GSSE/GOOSE messages. Once all configuration is done, export the project configuration to create the Substation Configuration Description (SCD) file.

3. *Send Back the CID files*
    Feedback the SCD file to the IED configurator, where the specific CID file will be extracted and downloaded into the IED. The data flow information should not be changed by the IED Configurator."

Configuration of the substation automation system is the first step to achieve interoperability as the application success is dependent on configuration of the system. Usually IEC 61850 standard interoperability is rubbished due to configuration complications rather than application failures. Utilities need to learn all the naming conventions have been established, they need to expand or narrow their conventions to achieve interoperability or vendors need to apply a more flexible naming convention.

2.4.2 GOOSE applications

GOOSE applications can only be achieved once the system is configured correctly. Interoperability for GOOSE applications is dependent on how different vendors interpret or process incoming communication. The GOOSE message structure for each vendor is critical as this portion is defined by the IEC 61850 standard and has flexibility to some extent for additional data to be transmitted or received.

Applications are an integral part of interoperability as this makes or breaks the possibility of interoperability. **Brand, et al (2006)** evaluate breaker failure, reverse

blocking and interlocking. They were evaluated on a basis of distributed functions on certain criteria. The research was looking at interoperability on the distributed functions. These functions for complex switchyard topologies with dynamic power flows proved to be challenging for implementation. This was because the IEC 61850 standard did not provide a model for those complex topologies.

Holbach, et al (2007) state that Tennessee Valley Authority (TVA) Bradley 500kV multivendor project was successfully implemented. Interoperability was achieved between the following vendors ABB, GE and Siemens. The project provided a learning curve for interoperability in the following fields of Substation Automation Systems which are:

- *"VLAN issues with Ethernet switch*
- *Logical device names*
- *GOOSE ID names*
- *Supporting attributes in GOOSE*
- *Adherence to name case sensitivity*
- *Length of names of GOOSE control blocks"*

All of the above could have been avoided had there been a proper study of the IED's and an evaluation of ancillary equipment capabilities.

Joshi (2010) describes benefits of implementing IEC 61850 and also addresses concerns with such SAS. **Joshi (2010**) tabulates functionality of the different protocols as way of showing the benefits of IEC 61850 as follows, Table 2.5.

Table 2.5: Different Protocol Tabulation (Josh, 2010)

Functionality	Modbus (Standard)	IEC 60870-5-103 (Standard)	Profibus	IEC 61850
Speed of Communication	9.6kBPS 19.2Kbps Maximum	9.6kBPS 19.2Kbps Maximum	9.6kBPS to 12MBPS Maximum	100MBPS
Circuit Breaker Control	Not Supported	Not Supported	Not Supported	Supported
Disturbance Record Uploading	Not Supported	Not Supported	Not Supported	Supported

Functionality	Modbus (Standard)	IEC 60870-5-103 (Standard)	Profibus	IEC 61850
Remote Relay Parametization	Not Supported	Not Supported	Not Supported	Supported
Time Synchronization Accuracy	Not Supported	±1msec	Not Supported	±1msec
Peer to Peer Communication	Not Supported	Not Supported	Not Supported	Supported
Interoperability	Not Supported	Not Supported	Not Supported	Supported
Multi Master Capability	Master Slave	Master Slave	Master Slave	Master Master
Level of Standardization	De Facto	Most implementations using proprietary extensions	De Facto	Full application coverage defined in standard, including engineering

Concerns and resolutions of IEC 61850 are described by **Joshi (2010)** as the following:

- "Expert staff for advanced technology is needed
- Signal transfer time hardwired scheme and GOOSE messaging comparison the latter is faster
- Network traffic can impact GOOSE message speed
- Failure of Ethernet network is a concern and this poses as a network vulnerability
- GOOSE message and IED's CPU loading can be resolved by management of GOOSE messages
- Loss or corruption of GOOSE message in transit is addressed by the GOOSE message repletion cycle.
- Testing of GOOSE based substation is a concern as new methods need to be developed."

Hakala-Ranta et al (2009) discuss the benefits of implementing IEC 61850 on medium voltage substation. The discussion is around horizontal communication and vertical communication. At best **Hakala-Ranta et al (2009)** illustrates performance superiority compared to hard wired systems and further shows a protection application which demonstrates the performance of the system.

The success of the implementation of protection applications proves that interoperability is possible when compared to the same vendor protection applications which must be compared with reference to the performance of the system. **Hakala-Ranta et al (2009)** show the connection between protection application and performance requirements regardless which protocol/hardwired is being used.

Englert and Dawidczak (2010) discuss various interoperability implementations that have occurred previously and give their recommendations on shortcomings of these implementations. **Englert and Dawidczak (2010)** also categorise the interoperable systems as follows:

- "Category A: station controller, bay controllers and protection devices are from a single vendor. IEDs for special purposes like voltage controllers, power quality meters or equipment monitoring are provided by different vendors.
- Category B: bay controllers and protection devices are from the same vendor, the station controllers and special purpose IEDs are from a different vendor
- Category C: station controller, bay controllers," main 1" protection, "main 2" or backup protection device are from different vendors, respectively as well a special purpose IEDs.
- Category D: devices from different vendors are mixes with no distinct preference"

Chen et al. (2012) review interoperability and Human Machine Interface (HMI) and Supervisory Control and Data Acquisition (SCADA) applications. Also point out shortfalls of vendors with regard to GOOSE message configurations. But they fail to name the vendors although hints at what the solution is. Interoperability seems to be achievable only if some kind of reconfiguration is done on certain devices **(Chen et al., 2012).**

(Koshiishi et al., 2012) outline interoperability issues for IEC 61850 Substation Automation Systems. The review provided reveals that Interoperability is mostly defined by the applications in a particular substation rather than random devices being plugged in a system. One of the solutions that is put forward is to define the system prior the implementation in order to ensure selected devices will be interoperable for the applications at hand.

2.4.3 GOOSE speed and performance

Speed and performance of an IEC 61850 protection application serves as the measure of the system whether it is a viable solution. **Zhang et al (2006)** evaluate the criteria and methodology of compatibility and interoperability for digital protection systems. The criterion is rendered around the following:

- Referent Models
- Performance indices
- Compatibility indices

Automatic testing was not possible on conventional protection systems and the introduction of IEC 61850 standard has brought about a big possibility for automatic testing. By following a few steps automatic testing is possible.

GOOSE message performance is not entirely dependent on a specific vendor IEDs. Performance of GOOSE messages was investigated by **Luc (2010). Luc (2010)** illustrates that different network conditions can influence GOOSE message performance. And **Luc (2010)** also states that GOOSE message are quicker than hardwired wired provided traffic on the network is moderate. Moderate traffic on the network refers to the network capacity not being fully utilised e.g. below 50% network utilisation. The addition of switches in a network system also degrades GOOSE message performance according to **Luc (2010).**

Steinerhauser et al. (2010) describe different types of tests to ascertain performance for IEC 61850 standard compliant IEDs and systems. Types of test/influences are as follows:

- "*Round Trip Test*
- *Rally Test*
- *Influence of Network Load*
- *Definition of Network Load*
- *Network Load Scenarios*
- *Sampled Values as Network Load*"

Substation Automation system performance is dependent on all the elements that make up the SAS according to **Steinerhauser et al. (2010).**

Tarlochan et al. (2011) propose performance test methods which assist with testing an IEC 61850 substation automation system. The performance test methods are listed as follows:

- *"GOOSE integration verification test*
- *Communication network configuration verification test*
- *Testing performance between hardwire and GOOSE messages*
- *Testing round trip delay of GOOSE over the network"*

Aguilar & Ariza (2010) discussed different test methods for multivendor systems. The test methods are no different from test methods discussed by **Tarlochan et al. (2011)** and **Steinerhauser et al. (2010).** This is a clear sign that multivendor systems need not to tested/treated differently from single vendor systems.

Currently testing interoperability/single-vendor systems are not defined on the IEC 61850 standard and this has brought about different methods of testing for functionality and performance of the system as seen in the literature review.

Brunner and Apostolov (2010) established test methodologies for full implementation and partial implementation of the IEC 61850 standard. Test methodologies of various substation automation systems based on IEC 61850 standard including different test equipment are discussed. **Brunner and Apostolov (2010)** proposed test methods which are:

- "*Testing of IEC 61850 protocol compliance for the individual components of the system*
- *Testing of merging units*
- *Testing of IEC 61850 compliant IEDs*
- *Testing of bay level distributed applications*
- *Testing of substation level distributed application*"

The above test methods provide above chronological testing for an IEC 61850 system

Sidhu et al. (2012) put forward packet scheduling algorithms to ensure GOOSE messages are not delayed in an IEC 61850 system. The proposed algorithms are as follows:

- "*Strict Prioty*
- *Round Robin*
- *Weighted Round Robin*"

Netto et al. (2012) review GOOSE message transmission with regard to traffic on the network. A test bench was used to illustrate GOOSE message transmission. GOOSE message transmission test conducted under low traffic and high traffic volumes to assess the effects on GOOSE message transmission.

2.5 Discussion

The literature review shows that in order to achieve interoperability certain requirements must be taken into account when configuring an SAS. The issue ultimate lies on how vendors interpret IEC 61850. When implementing interoperable systems IEDs must be selected according to application functionality. The existing research fails to point out how different vendors interpret IEC 61850 standard. Utilities should not compromise their protection philosophy because of being stagnated to one vendor. This research will serve to shed some light on interoperability success.

Englert and Dawidczak (2010) categorise interoperability by means of the levels in a substation automation system with different vendors utilised. Although this is good practice to achieve interoperability it opens an avenue for vendors to categorise their devices and this would be defeating the purpose of IEC 61850 standard to achieve interoperability. IEC 61850 standard protocol was purely developed to achieve interoperability at all levels of a substation automation system without any restrictions at all system levels provided that the devices used conform to IEC 61850 standard.

The literature review shows that previous research is mostly focused on the shortcoming of the IEC 61850 when it comes to interoperability. This should not be the case because IEC 61850 defines the medium of communication and the data for transmission/publishing. The basis of interoperability lies with how different vendors process the data when received. The interconnecting medium between devices should be evaluated as the processes within different vendors will differ. IEC 61850 interoperability should be assessed on the user requirements being analysed rather than seeking to reuse previous applications requirements with IEDs that may not offer the desired interoperability. What this means is that IED from different vendors need to be assessed against the user's interoperability requirements rather than simple plug and play on the basis that the device conforms to IEC 61850.

Tan et.al, (2009) illustrate or describe various interoperability tests namely:

- *"Proof of concept interoperability tests*
- *Site acceptance interoperability tests*
- *Single vendor multi-device interoperability tests*
- *Multi-vendor multi-device interoperability tests*
- *Peer to peer profile based interoperability tests*
- *Client server profile based interoperability tests"*

This is essentially horizontal and vertical interoperability testing. The location of devices which have to be interoperable can either be at the process level, bay level or at the station level. The basis of interoperability is to establish a communication framework and implement the communication framework. This is done via testing and analysing the system under various conditions.

The research in the thesis is to investigate interoperability and protection functionality of an interoperable protection scheme. The interoperability investigation is to assess how generic GOOSE messages are interpreted by different vendors. Timing of GOOSE messages between different and same vendor devices are also investigated in order to assess if any discrepancies may occur in an interoperable substation automation system. A protection scheme shall be implemented on to show that interoperability is functional in the protection scheme rather than assessing timing issues. Then evaluation of system configuration tools is conducted for different vendor tools. An evaluation of the vendor independent system configuration tools to assess functionality of such tools is provided.

Interoperability is the corner stone of the foundation of IEC 61850 and it is paramount that interoperability becomes seamless to implement. Interoperability is achievable but at what cost? Utilities and municipalities are reluctant to implement interoperability namely because of:

- Different configuration software tools from different vendors (not limited to IEC 61850 configurators but protection settings as well are needed.)
- The steep learning curve due to the various different software tools is difficult and complex.
- Third party tools are limited to IEC 61850 tools (including the capital cost of the software tool). All IED settings configuration tools are proprietary.
- File management becomes a big administration exercise due to the software tools being incompatible.

The research is aimed at assessing the impact of the scenarios mentioned above. Specially to assess whether the fears of utilities and municipalities are legitimate and to recommend some solutions. All interoperability research conducted till now has heavily relied on vendors to achieve interoperability. This thesis research will take the point of view of the user doing the implementation rather than vendors conducting the implementation. The interoperability research will develop a methodology to obtain interoperability. Various proof of concept tests will be conducted. The evaluation of configuration tools form part of the research as these are lacking on the past research as the implementation was done by vendors.

2.6 Conclusion

This chapter takes a look at research of GOOSE message interoperability since the birth of IEC 61850 standard. Various scenarios have been developed by various researchers and those scenarios are evaluated. The research review revealed that utilities or municipalities only obtained interoperability if implementation was conducted by vendors in corroboration. This practice rather disadvantages the user which is tasked with maintaining the system although integrated by vendors. This becomes complex when interoperable systems are implemented by vendors rather than users. The research is to ensure users are made aware of interoperability integration requirements.

Chapter Three reviews IEC 61850 standard holistically including network topology. It also interprets the IEC 61850 standard and shall provide insights for how vendors would interpret the standard.

CHAPTER THREE
IEC 61850 DESCRIPTION

3.1 Introduction

This chapter delves and reviews into the various parts of the IEC 61850 standard. In section 3.2 of the chapter the history of IEC 61850 standard is discussed including the major building blocks of the standard. Section 3.3 discusses the data model as this is a major object in the standard. 3.4 reviews the Substation Configuration Language (SCL). In 3.5 the system configuration tool is described. In section 3.6 the IEC 61850 communication stack is described. 3.7 describes Generic Object Oriented Event (GOOSE) message. Section 3.8 discusses Sampled Measured Values (SMV). 3.9 describes message performance within an IEC 61850 standard. Section 3.10 describes various network topologies in an IEC 61850 standard network. 3.11 presents the discussion and 3.12 provides the conclusion.

3.2 IEC 61850 Introduction

IEC 61850 standard defines/describes the communication between Intelligent Electronic Devices (IEDs) in a substation and related system requirements. This is achieved by virtually defining all components of the substation. The defined components are utilised in combination meaning a substation design is built with the defined components in accordance to specific requirements. IEC 61850 also defines the requirements of such a system with regards to communication and quality systems. In essence IEC 61850 provides syntax and semantics to be followed to allow for interoperability.

IEC 61850 was launched by the Electric Power Research Institute (EPRI) and IEEE with a project called Utility Communication Architecture (UCA). **(Jukka, 2010)** A standard was developed from that project which was called IEC 60870-6-TASE.2. Both organisations embarked on further research with an objective of station bus communication in 1994. IEC Technical Committee 57 (IEC TC 57) began formulation of IEC 61850 in 1996. **(Jukka, 2010)** Now there was a case where two committees where working on solving the same problem implanting different methods. Since EPRI and IEEE had begun earlier on a project called UCA2 and IEC TC 57 had also begun formulation of IEC 61850, the two decided to make it a joint effort in 1997. UCA2 advancement in its research was recognised and the basis of IEC 61850 was

based on UCA2. The outcome of the joint venture is the IEC 61850 standard published in 2003.

The vision of IEC 61850 is extremely broad in the sense that defining a communication standard that will not constrict improvements on other communication platforms but will allow future integration with ease. IEC 61850 promotes and aids complex applications in protection and control to the point of combination of non-conventional CTs and VTs into the protection scheme under the guise for a standardised way of exchanging information digitally between the producers and recipients of this information. IEC 61850 ensures less capital costs, greater flexibility, hard-wired connections get improved by communication networks, plug-and-play functionality, reduced construction and commissioning time. **(Kasztenny, et al., 2008)**

The 61850 standard makes a sweeping utilization of the idea of virtualization. IEDs introduce information utilizing a uniform/standardised organization. Along these lines IED capacities end up non-specific from the perspective of the substation planner yet the basic capacities hold merchant particular attributes that might be remarkable and restrictive in nature **(Kasztenny, et al 2008**). The accessible information is likewise sensibly apportioned by groupings that ought to be well-known to protection engineers (protection, metering, supervisory control, and so forth.). This would permit simple usage for interoperability and compatibility. Introduced information have characteristics that are regular crosswise over seller stages**. (Kasztenny, et al 2008)**

IEC 61850 arrangement standardises the components by which information is shared inside the substation. The IEC 61850 idea standardises information and services, and in addition urges peer to peer communication of data between the IEDs: Included are systems for revealing and logging of data, instruments for passing basic messages, for example, tripping signals amongst IEDs, and components for exchange of voltage and current samples from process-level devices to IEDs. The plan of computerisation capacities requires a lot of design of the constituent IEDs. At present, when building multi-vendor SASs, the user is gone up against with at least more than one configuration tool. **(Kasztenny, et al 2008)**

IEC 61850 helps the execution of capacities to be achieve specific protection and control methodologies not to reside in one IED but a few IEDs even from various vendors, this particular does not endeavour to standardise the function capabilities

themselves. It is left to the end client to force his or her own particular building practices and rationalities to the specific application. Correspondingly, the IEC 61850 standard makes couple of necessities as to which information models and information things are to be made accessible in a specific IED. The assignment of information models and also a great part of the information that makes up the models is left to the IED vendor. This makes a potential gap between the seller and the end-client. It is essential for the substation designer to precisely check details/specifications while choosing IEDs. **(Kasztenny, et al 2008)**

The IEC 61850 standard details the traits of the information traded between IEDs. These traits incorporate data on the nature of the information and data on the working condition of the origin of the information (for instance, typical versus test). (Kasztenny, et al 2008)

IEC 61850 standard characterises the portrayal language Substation Configuration Language (SCL) to be utilised by configuration tools, while the usefulness of the configuration tools themselves is outside the extent of the standard. All the more significantly the general building forms are not characterized and are probably going to be unique in relation to those of the past. A significant part of the IED settings will stay in the space of the vendor in particular IED setup settings. Without a doubt, designing procedures and the relating configuration tools should advance as one and guaranteeing that past IEDs to ensure compatibility. **(Kasztenny, et al 2008)**

According to **IEC 61850-1, (2003)** communication interfaces can be illustrated as per the Figure 3.1 below. **(IEC61850-1, 2003)**
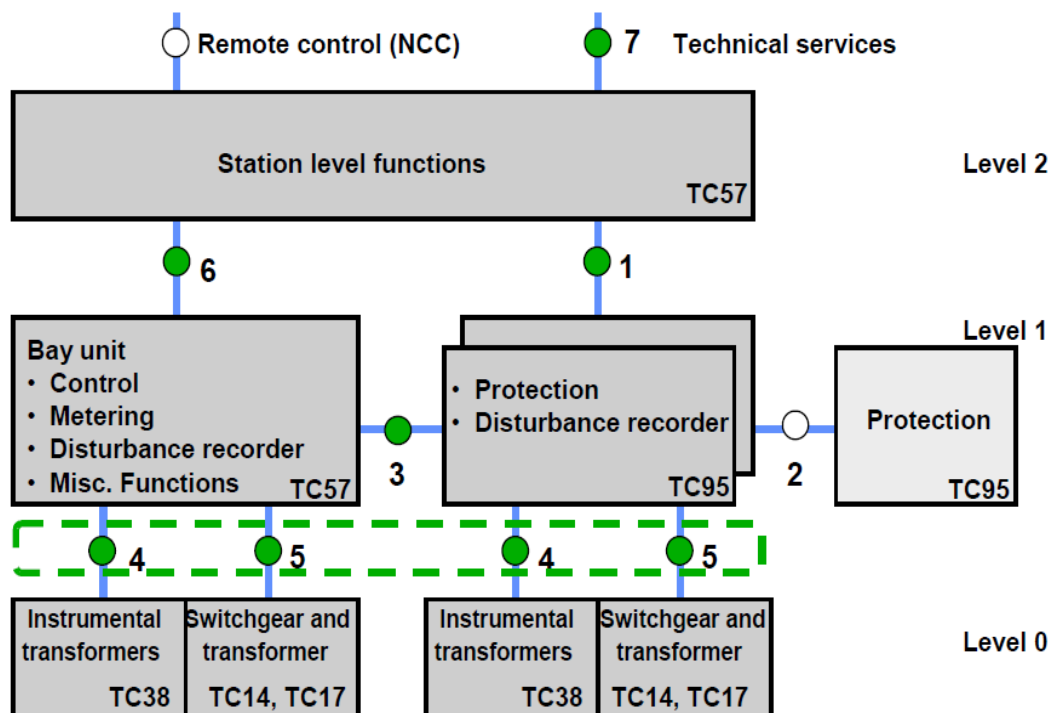
Figure 3.1: Communication Interfaces **(IEC61850-1, 2003)**

The Figure 3.1 above further shows the different Technical Committees responsible for the formulation of standards with reference to the relevant equipment. **IEC 61850-1, (2003** defines the communication interfaces as follows:

"1: protection-data exchange between bay and station level.

2: protection-data exchange between bay level and remote protection (beyond the scope of this standard).

3: data exchange within bay level.

4: CT and VT instantaneous data exchange (especially samples) between process and bay level.

5: control-data exchange between process and bay level.

6: control-data exchange between bay and station level.

7: data exchange between substation (level) and a remote engineer's workplace.

8: direct data exchange between the bays especially for fast functions such as interlocking.

9: data exchange within station level.

10: control-data exchange between substation (devices) and a remote control centre (beyond the scope of this standard)."

IEC 61850 standard is divided into different parts which address all aspects for substation automation namely: **(IEC 61850-1, 2003)**

- "*IEC 61850-1 Introduction and overview:*

- *IEC 61850-2 Glossary: Explains terms and abbreviations used throughout the standard*

- *IEC 61850-3 General requirements: Specifies system requirements with emphasis on the quality requirements of the communication network.*

- *IEC 61850-4 System and project management: Specifies system and project management with respect to the engineering process, life cycle of overall system and IEDs, and the quality assurance.*

- *IEC 61850-5 Communication requirements for function and device models: Describes all required functions in order to identify communication requirements between technical services and the substation, and between IEDs within the substation. The goal is interoperability for all interactions.*

- *IEC 61850-6 Substation automation system configuration description language: Specifies the SCL file format for describing communication related IED configurations, IED parameters, communication system configurations, function structures, and the relations between them. The purpose is to exchange IED capability description, and SA system descriptions between IED engineering tools and different system engineering tools.*

- *IEC 61850-7 Basic communication structure for substation and feeder equipment*

- *IEC 61850-7-1 Principles and models: Introduces modelling methods, communication principles and information models used in IEC 61850-7. Also, detailed requirements and explanations are given regarding the relation between IEC 61850-7-x and the requirements from IEC 61850-5.*

- *IEC 61850-7-2 Abstract Communication Service Interface (ACSI): Presents the ACSI providing abstract interfaces describing the communications between a client and a remote server, such as interfaces for data access and retrieval, device control, event reporting and logging.*

- *IEC 61850-7-3 Common data classes: Specifies common attribute types and common data classes related to substation applications. The common data classes specified, are for instance, classes for status information, measured information, controllable status information, controllable analogue set point information, status settings and analogue settings.*

- *IEC 61850-7-4 Compatible logical node classes and data classes: Specifies the compatible logical node names and data names for communication between IEDs.*
- *IEC 61850-8 Specific Communication Service Mapping (SCSM)*
- *IEC 61850-8-1 Mapping to MMS (ISO/IEC 9506 Part 1 and Part 2): Specifies how time-critical and non-time-critical data may be exchanged through local area networks by mapping ACSI to MMS.*
- *IEC 61850-9 Specific Communication Service Mapping (SCSM)*
- *IEC 61850-9-1 Serial unidirectional multi-drop point to point link: Specifies the specific communication service mappings for the communication between bay and process level and a mapping of the abstract service for the transmission of sampled values. These are specified on a serial unidirectional multi-drop point to point link.*
- *IEC 61850-9-2 Mapping on a IEEE 802.3 based process: Defines the SCSM for the transmission of sampled values according to the abstract specification in IEC 61850-7-2.*
- *IEC 61850-10 Conformance testing: Specifies how a SAS should be tested to ensure conformance with the IEC 61850 standard.*"

3.2.1 IEC 61850 System Overview

IEC 61850 defines a substation automation system with three different levels as per Figure 3.2 which are: **(IEC 61850-1, 2003)**

- *"Station Level - station computer with a database, the operator's workplace, interfaces for remote communication*
- *Bay Level - control, protection or monitoring units per bay*
- *Process Level - remote I/Os, intelligent sensors and actuators"*
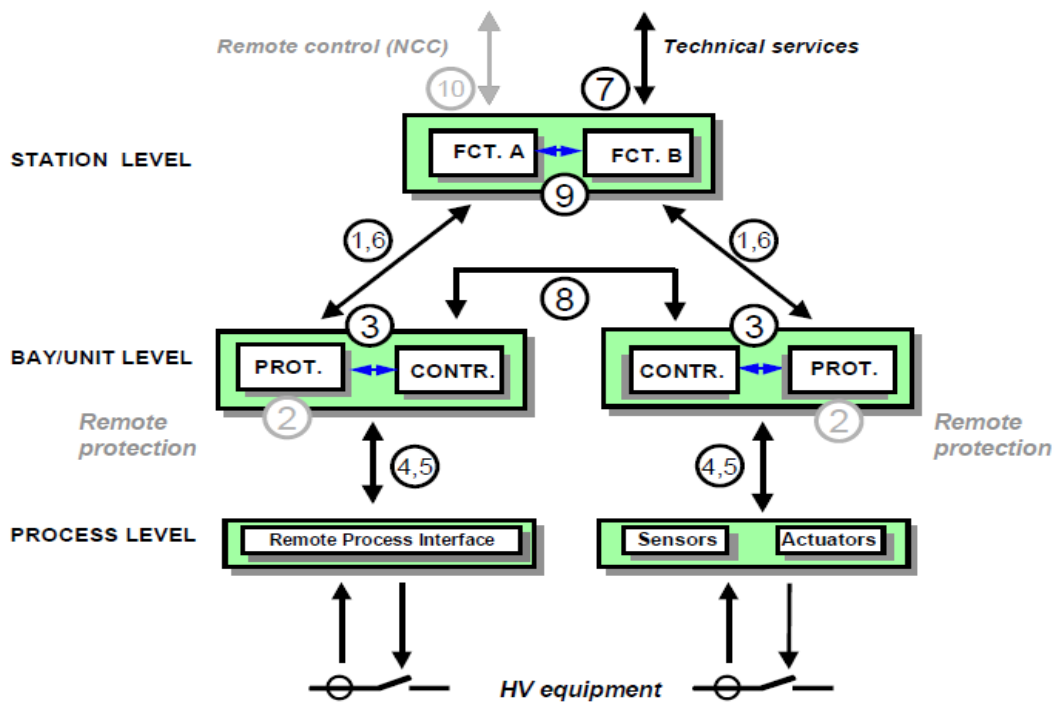
Figure 3.2: Interface model of a substation automation system **(IEC 61850-1, 2003)**

1. "Protection-data exchange between bay and station level.
2. Protection-data exchange between bay level and remote protection (beyond the scope of this IEC 61850 standard Edition 1).
3. Data exchange within the bay level.
4. CT and VT instantaneous data exchange (especially samples) between the process and bay levels.
5. Control-data exchange between the process and bay levels.
6. Control-data exchange between the bay and station levels.
7. Data exchange between the substation (level) and a remote engineer's workplace.
8. Direct data exchange between the bays especially for fast functions such as interlocking.
9. Data exchange within station level.
10. Control-data exchange between the substation (devices) and a remote control centre (beyond the scope of the IEC 61850 standard Edition 1)."

IEC 61850 standard defines the building blocks in order to simplify and allow further flexibility to a substation automation communication system. IEC 61850 defines data

models which house the various building blocks to provide substation automation communication.

3.3   Data Model

This is one of the fundamental parts of the standard 61850 (standardised data), and assumes a critical part in empowering interoperability between the IEDs and funtions. The standard is devoted to characterizing these information models that enable the IEDs from various vendors to impart. The data indicates that is isolated from the innovation to empower a future proof the communication protocol. Later on the standard can be extended or remapped concerning innovation if necessary, without meddling with the data model.

The models are to characterize the syntax and semantics (structure and significance) of the language. These models separate all data accessible in a substation automation system to the smallest parts. This disintegration is completed by separating all functions into miniature functions segments called Logical Nodes (LN). Here each LN contains standardised information. The Figure 3.3 below shows the logical node MMXU (refers to measurement logical node) contains the measured phase currents in a data class A. **(Gupta, 2008)**
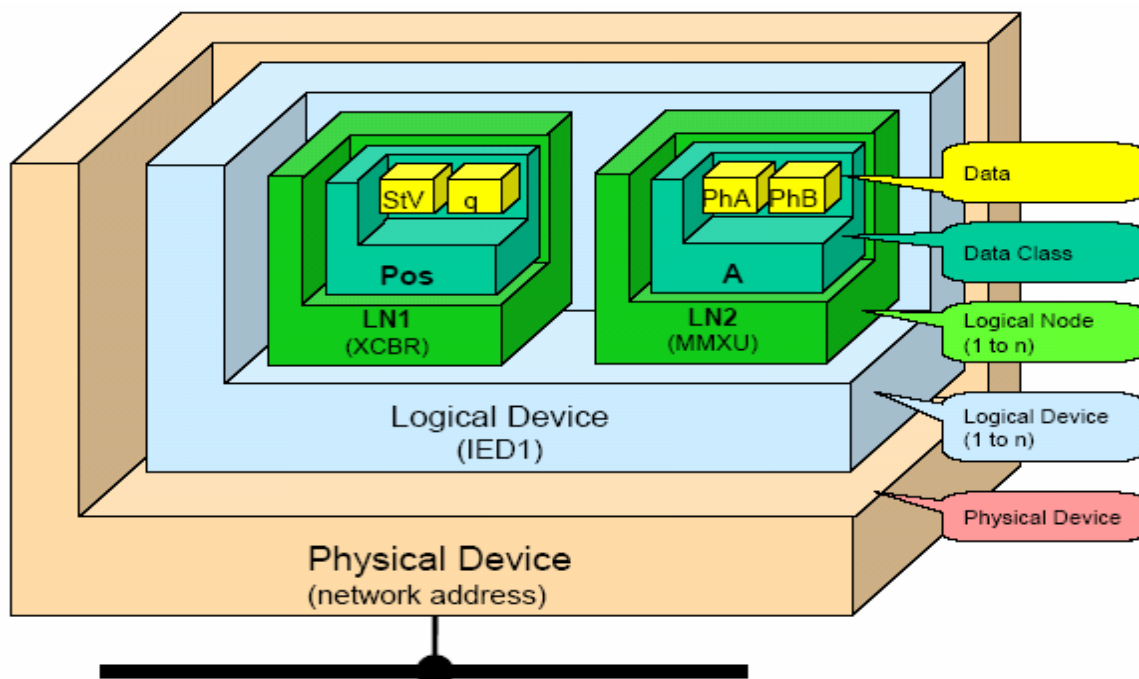
Figure 3.3: Data Model **(Gupta, 2008)**

The Figure 3.3 above shows how the ideas of Logical Device (LD), Logical Node (LN) and Data are connected. These are on the whole virtual terms and can't be deciphered physically, despite the fact that they have physical applications. The main physical substance is the Physical Device (normally an IED) and is a device conceivably containing various LD, which thus can contain numerous LN etc. Usage is the seller's obligation and determinations from the client to be clung to. The LNs are one of the more focal ideas in the information models as they speak to the essential elements of a substation automation system.

The hierarchy of the data model is shown in Figure 3.4 **(Zhang and Gunter, 2011)**
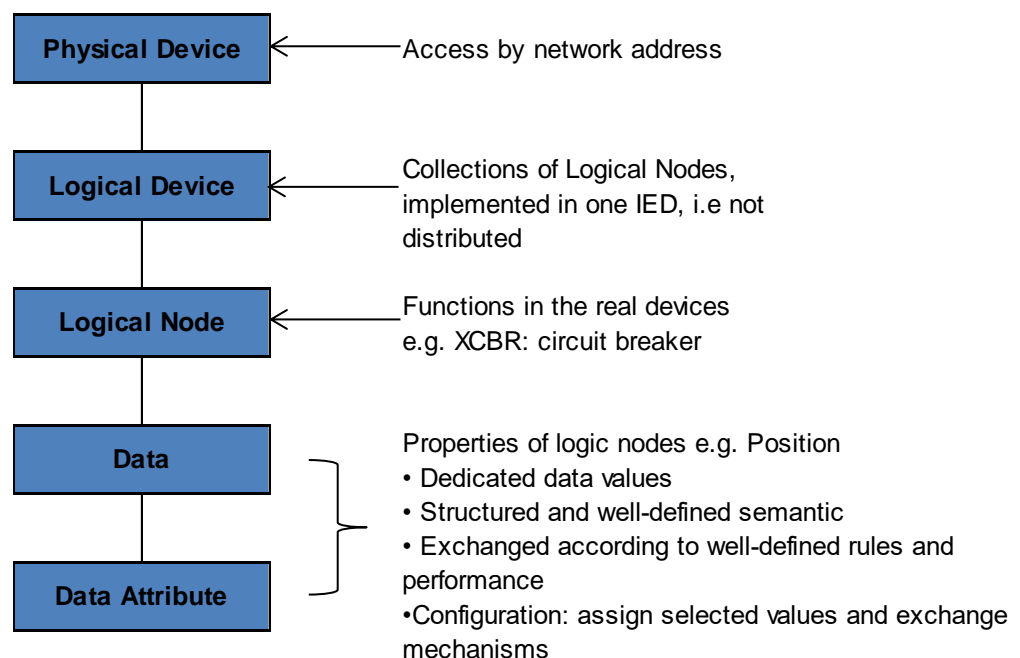
Figure 3.4: Hierarchy of the data model of IEC61850 **(Zhang and Gunter, 2011)**

As mentioned IEC 61850 defines substation automation system communication virtually, this is achieved by the Substation Configuration Language (SCL).

3.4   Substation Configuration Language

IEC 61850 also defines the Substation Configuration Language (SCL). It can be seen as the system specification of the substation interconnections of IEDs and all connected equipment. It also contains the allocation of Logical Nodes (LNs) of each IED connected to associated equipment. This language allows for interoperability between vendors and an easy integration process. SCL defines standard data formats that are used by the system configuration tool. The system configuration tool

is an engineering tool used to configure the IEC 61850 logic. The defined file formats are: (Zhang and Gunter, 2011)

- *"ICD: IED Capability Description*
  - *Data exchange from the IED configuration tool to the system configuration tool.*
  - *Describes the capabilities of an IED.*
- *CID: Configured IED Description*
  - *Data exchange from the IED configuration tool to the IED.*
  - *Describes an instantiated IED within a project.*
- *SSD: System Specification Description*
  - *Data exchange from a system specification tool to the system configuration tool.*
  - *Describes the single line diagram of the substation and the required logical nodes.*
- *SCD: Substation Configuration Description*
  - *Data exchange from the system configuration tool to IED configuration tools.*
  - *Describes all IEDs, a communication configuration section and a substation description section."*

The SCL language is made up of four file types, each with a specific purpose. Any SCL file is structured with Extensible Markup Language (XML) format and is made up of some of the following five parts, depending upon its purpose:

- Header
- Substation description
- IED description
- Communication system description
- Data type templates

Keeping in mind the end goal to be completely consistent with the IEC61850 standard, an IED might have an ICD document containing essential data about the IED, for example, which logical nodes and services it underpins, the IP address etc. A configuration tool would then be able to peruse such records and create or adjust a SCD document which depicts the full substation design. This record ought to be construct in light of the ICD documents, as well as on data entered by a system integrator about the substation preceding including the IEDs, or on the other hand a SSD record portraying the SAS itself

All CID, ICD, SSD and SCD files are written in XML format. The XML files can be edited and the various files be created from the ICD files. This would require extensive knowledge of XML language and a vendor insight on IEC 61850 interpretation of the standard. Manufacturers provide system configuration tools to avoid XML programming. System configurations tools provide a platform to configure

a substation automation system on a Windows platform thus ensuring that the learning curve is reduced significantly.

3.5   System Configuration Tool

The introduction of IEC 61850 opened up a new market for configuration tools. The vendors developed their own configuration tools. A configuration tools address various tasks required in designing and implementing a substation automation system. The standard does not define which tools should be used. This standardized file format is used for the exchange of information between the various engineering software. These files have the potential to replace the schematics, wiring diagrams and point lists currently used to develop and document the substation. **(Kasztenny, et al., 2008)**

Configuration tools are used to parameterize the various IEDs to produce a working system. This task may be further broken down into the configuration of substation level functions and parameters (system configurator) and the configuration of autonomous IED parameters (IED configurator). The system configurator makes use of the specifications developed in the project design tool. The system configurator also utilizes standardized files that describe the capabilities of the IEDs. These tools also are responsible for the transfer of the configuration to the IED and for management and archiving of IED configurations. **(Kasztenny, et al 2008)**

IEC 61850 standard defines the structures of a substation automation system and involves all aspects of the communication system.

3.6   IEC61850 Communication

The communication profile of IEC 61850 standard is of significance. The communication profile is a set of different protocols working together. Part 8-1 of IEC61850 explains the mapping technique of this standard onto Manufacturing Message Specifications (MMS) and the Ethernet. Following Figure 3.5 gives a view of a protocol profile defined in IEC61850:
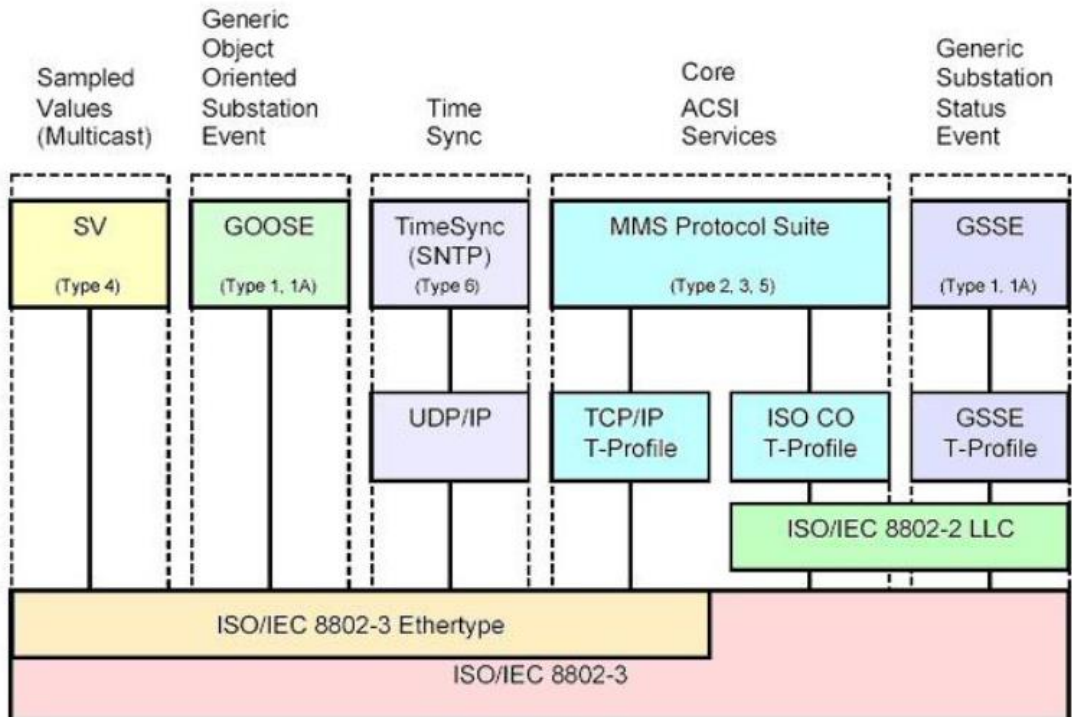
Figure 3.5: Overview of functionality and profiles **(Zhang and Gunter, 2011)**

In IEC 61850-8-X and IEC 61850-9-X these abstract communication services and items are mapped to real conventions. All interchanges utilize Ethernet (ISO/IEC 8802-3) as the essential communication innovation. Services generally utilised for exchange inside the entire substation are mapped in IEC 61850-8-1 to MMS. MMS is an application layer standard intended to help informing interchanges between IEDs in an appropriated framework condition. It was picked on the grounds that it is the main open standard convention that can bolster effectively the ACSI mapping and data models characterised in IEC 61850-7-X arrangement. Extra conventions are characterised for those ACSI services that are not mapped to MMS, for example, SNTP (Simple Network Time Protocol) for time synchronization messages, or GOOSE (Generic Object Oriented Substation Event) and GSSE (Generic Substation Status Event) for trips and fast messages. On the other hand, services utilised for the transmission of tested qualities are mapped over serial unidirectional multi sloping edge to point connect in IEC 61850-9-1 or mapped specifically finished Ethernet in IEC 61850-9-2/LE (Light Edition). An outline of every one of these mappings utilised for the standard IEC 61850 is it appears in Figure 3.5
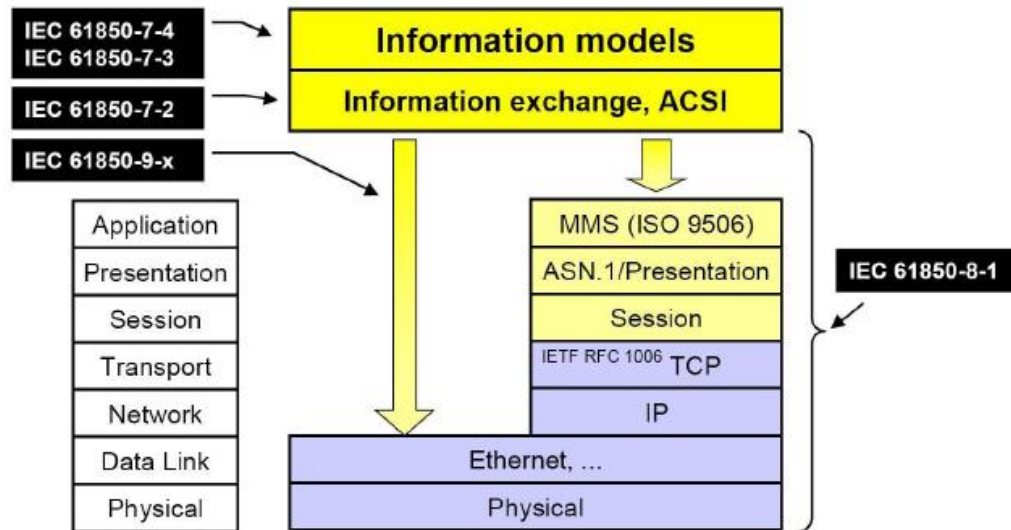
Figure 3.6: The SCSMs of IEC61850 placed according to the OSI layers **(Hammer and Sivertsen, 2008)**

Figure 3.6 delineates the three Specific Communication Service Mappings (SCSMs) proposed in the IEC61850 standard and spots them as indicated by the OSI show. In the figure, the SCSMs are named by their part numbers in the standard, IEC61850-8-1 and IEC61850-9-x for IEC61850-9-1 and IEC61850-9-2. The SCSM of IEC61850-8-1 maps most ACSI services to the Manufacturing Message (MMS). It likewise gives mappings to Sampled Values, GOOSE, Time Synchronization and GSSE to Ethernet. MMS is set in the application layer of the OSI show while TCP/IP and Ethernet are set in the supposed T-profile, involved the transport layer and those underneath it. Ethernet is additionally a worldwide standard (IEEE 802.3). **(Mackiewicz, 2004)**

Ethernet is additionally the reason for the SCSMs proposed in IEC61850-9-1 and IEC61850-9-2. IEC61850-9-1 is named "Inspected esteems over serial unidirectional multi-slanted edge to point connect". IEC61850-9-2 is named "Sampled values over ISO/IEC 8802-3" and is planned as a supplement to IEC61850-9-1 to give a total mapping to sampled measured values. **(Mackiewicz, 2004)**

The Generic Object Oriented Substation Event (GOOSE) is defined by IEC 61850 as the core crust of the standard as this can provide fast applications within protection performance requirements.

3.7 Generic Object Oriented Substation Event (GOOSE)

GOOSE messages are vital to getting or accomplishing interoperability. IEC 61850 presents a particular data transmission benefit for time critical trade of data between functions situated inside a bay or in various bays, called Generic Object Oriented Substation Event (GOOSE). It depends on the publisher subscriber idea and it is utilized for fast transmission of substation events, for example, commands, alerts and signs. Messages are sent as multicast messages over the communication system and they are unverified. The publisher has no chance to get of knowing whether the subscriber has gotten the message. Along these lines, the publisher should ceaselessly transmit messages to the Local Area Network (LAN). The activating occasion for GOOSE messages might be a difference in value, an intersection of a limit, and so on. (Fiorenza, 2008)

A GOOSE message is continuously transmitted across a LAN. GOOSE messages work on peer to peer communication in order to meet protection requirements. GOOSE messages as mentioned are continuously transmitted in accordance with a repetition strategy. The Figure 3.7 below illustrates the GOOSE message repetition strategy. **(IEC 61850-8-1, 2004)**
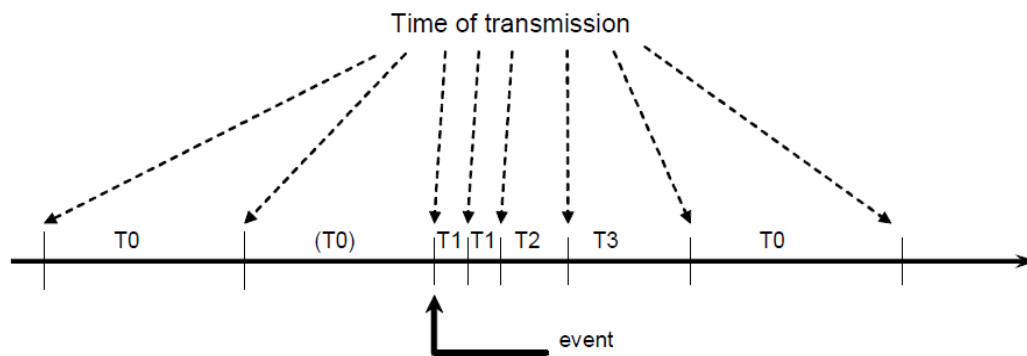
Figure 3.7: GOOSE message repetition strategy **(IEC 61850-8-1, 2004)**

The occurrence of an event causes the GOOSE transmission interval to decrease substantially as illustrate in the above figure. The transmission settles to a certain interval after the event and the intervals become constant until the occurrence of an event.

The content of messages is defined with a dataset. The GOOSE message is encapsulated in an Ethernet frame. The Figure 3.8 below illustrates a typical Ethernet frame.
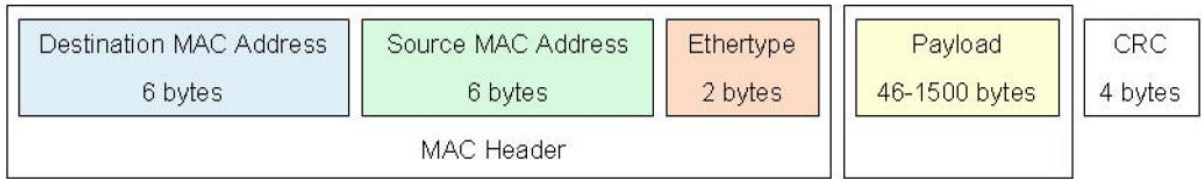
Figure 3.8: Typical Ethernet frame **(Fiorenza, 2008)**

The above figure shows that the frame contains destination, source, ethertype and the payload information. The payload structure is defined by IEC 61850.

The GOOSE message structure is as illustrated by the Table 3.1 below:

Table 3.1: GOOSE message structure **(IEC 61850-5, 2003)**

GOOSE MESSAGE		
Parameter Name	**Parameter Type**	**Value/Value Range/Explanation**
DataSet	ObjectReference	Value from the instance of GoCB
AppID	VISIBLE STRING65	Value from the instance of GoCB
GoCBRef	ObjectReference	Value from the instance of GoCB
T	EntryTime	
StNum	INT32U	
SqNum	INT32U	
Test	BOOLEAN	(TRUE) test I (False) no-test
ConfRev	INT32U	Value from the instance of GoCB
NdsCom	BOOLEAN	Value from the instance of GoCB
GOOSEData [1..n]		
Value	(*)	(*) type depends on the common data classes defined in IEC 61850-7-3. The parameter shall be derived from GOOSE control

The structure of the GOOSE message will be discussed further with practical applications in order to compare it between different vendors. Although conformance tests may have been conducted, previous research suggests that message structures are of importance to accomplish interoperability.

Typical applications that resort to the utilization of GOOSE service are exchange of information between devices inside the bay or between devices placed in different bays.

Fernandes, Borkar, & Gohil, (2014) state advantages of GOOSE message namely:

- *"GOOSE protocol uses the standard Ethernet for communication. As Ethernet is evolving, the progress in its development will be reflected on GOOSE communication and enhance its advantages.*

- *Ethernet replaces point to point hardwired copper connection between different IEDs.*
- *GOOSE does not use a handshake mechanism hence speed performance requirements of substation automation functions is improved*
- *To ensure highest level of reliability, GOOSE messages are repeated as long as the state persists. These heartbeat messages are sent continuously in the network with long cycle time which ensures that the devices which have been activated recently, will know the current status values of their peer devices in the network. Each packet has a fixed Time Allowed to Live (TAL) in the network.*
- *The GOOSE is directly mapped to the Ethernet layer hence the processing time is also very less which is best suited for very time critical protection function in the substation.*
- *To maximise dependability and security, GOOSE message has a "hold time" parameter which defines the time for which the message will live and afterwards will expire unless the same status is repeated or new message is received prior to the expiration of the hold time.*
- *One single GOOSE message of an individual IED, can contain all the required data related to the protection scheme, whereas the hard-wired approach requires function specific connection, and hence reduces the network traffic during fault conditions.*
- *GOOSE message is not a command in the sense that it does not tell any receiving device what to do, rather just indicates that a new event has occurred, what that event is and time when it happened.*
- *GOOSE messages also use advanced configuration of Ethernet frames like Virtual Local Area Network (VLAN) and priority tagging. This priority helps to filter out the message especially when there is high traffic, which can occur when a fault occurs.*
- *GOOSE protocol uses multicast mode of communication which enables multiple IEDs to receive the same data at the same time."*

The advantages of GOOSE messages are fundamentally important in interoperability implementation as these advantages need to be realised using various vendors in substation automation system.

3.8   Sampled Measured Values (SMV) transmission

IEC 61850 defines a service for the exchange of information between the substation automation system and the high voltage equipment. Information is sampled measured values like voltage and current waveforms, position and open/close controls. The exchange may be done using copper wiring or using serial communication. SMV supports two transmission methods: a Multi-cast service over Ethernet and a Unicast (point-to-point) service over serial links. Messages are shared among IEDs and they are unconfirmed.

As for the GOOSE message, the content of the message is defined with a dataset. Losses of some samples are handled without problems by the receiving functions,

e.g. by a protection algorithm. The trigger event of sending these values is a clock event. An important aspect while using sampled values in a power system is the phase relationship between the different measured signals, in particular between current and voltage. **(Fiorenza, 2008)**

IEC 61850 is using the concept of synchronized sampling. All units performing sampling are globally synchronized with the required accuracy. The samples are taken all at the same time. A typical application for the process connection is the information transfer between instrument transformers, protection devices and circuit breakers. This information transfer is time critical. It has a direct impact on the response time of the protection function. **(Fiorenza, 2008)**

3.9   Message Performance

All messages defined by IEC 61850 are categorised with regards to performance or application. Performance of messages is normally adjudicated against time. This opens up an avenue where certain messages have time requirements to execute an application. IEC 61850 provides a definition for transfer time. Transfer time is defined as the time taken to complete a transmission from a publisher/sender to a subscriber/receiver. The Figure 3.9 below illustrates the transfer time mechanism. **(IEC 61850-5, 2003)**
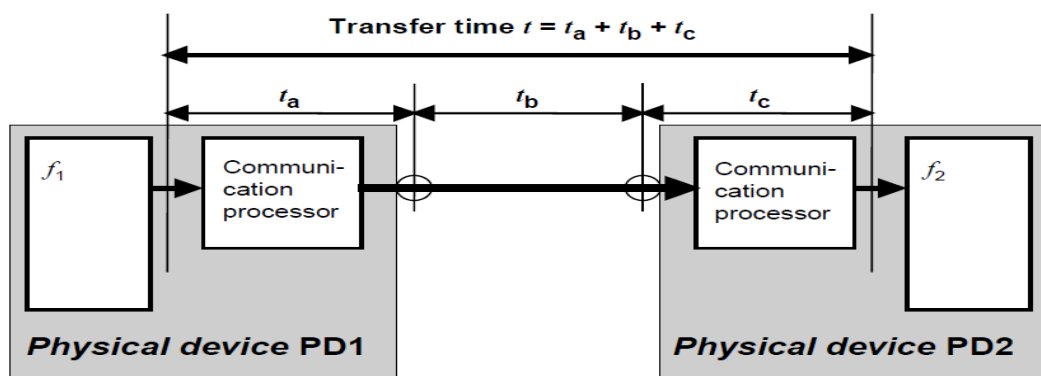
Figure 3.9: Transfer Time Definition **(IEC 61850-5, 2003)**

As illustrated above a transmission time requirement is measured from point where PD1 passes the data to the communication processor. The end of the transfer time is only triggered once the data is passed on to the application from PD2 communication processer. The notation 't' is the total time taken to transfer the data from PD1 to PD2. The following notations:

- ta – time taken by the data to pass through the communication processor
- tb – transmission time through the communication medium
- tc - time taken by the data to pass through the communication processor

The transfer times may vary from vendor to vendor, thus testing an interoperable system is very critical. Message performance is measured and illustrated as per Table 3.2. The performance of the message is measured against the type of the message utilised.

Message performance is categorised into different performance classes in relation to applications as follows:
- Control and protection, or
- Metering and power quality

Table 3.2: Message Performance **(IEC 61850-5, 2003)**

Protection and Control	
Performance Class	**Use**
P1	Distribution environment
P2	Transmission environment
P3	Transmission environment
Metering and Power Quality	
Performance Class	**Use**
M1	Revenue metering for accuracies of 0.5 and 0.2
M2	Revenue metering for accuracies of 0.2 and 0.1
M3	Quality metering for up to the 40th harmonic

Performances of the messages are dictated by their application in a Substation Automation System (SAS). The messages are apportioned in accordance to the type of message as follows: **(IEC 61850-5, 2003)**
- *"Type 1 – Fast messages*
- *Type 2 – Medium messages*
- *Type 3 – Low speed messages*
- *Type 4 – Raw data messages*
- *Type 5 – File transfer functions*
- *Type 6 - Time synchronization messages*

- *Type 7 – Command messages with access control"*

It should be noted that the above message types are directly linked to applications and applications have performance requirements.

Type 1 messages are divided into two messages namely:
- Type 1A "Trip"
- Type 1B "Others"

Type 1A messages are utilised for tripping, interlocking and intertripping. Type 1B messages are for messages with less performance requirements with reference to trip messages in essence Type 1A messages. The performance of the message is squarely dependant on the application as illustrated on the Table 3.3 below:

Table 3.3: Type 1 Fast Message **(IEC 61850-5, 2003)**

Type 1- Fast Messages		
Message Type	**Performance Class**	**Transmission time**
Type 1A	Class P1	10ms
	Class P2/3	3ms
Type 1B	Class P1	≥100ms
	Class P2/3	20ms

Type 2 messages are typically used for transmissions which are less critical compared to Type 1. The transmission time requirement is less than 100ms for Type 2 messages. Type 3 messages are low speed messages with a less than 500ms transmission time requirement. Type 4 message requirements are as due to different applications that utilise Type 4 messages. The time requirement for Type 4 messages are shown in Table 3.4 as follows: (IEC 61850-5, 2003)

Table 3.4: Type 4 Raw data message **(IEC 61850-5, 2003)**

Type4- Raw data messages		
Message Type	**Performance Class**	**Transmission time**
Type 4	Class P1	10ms
	Class P2/3	3ms

Type 5 messages are used for file transfer functions and the time transmission requirement is less than or equal to 1000ms. Type 6 messages are used for time

synchronisation messages. Type 7 messages are used for command messages no time requirement is set for these messages.

It should be noted that the different types of messages and performance classes should be defined by vendors and imbedded in applications. This simply means the user shall not allocate a certain type of message to an application and this ensures or removes any error from occurring. So all IEC 61850 engineering configuration tools do not have an interface for the selection of different types of messages. Since IEC 61850 makes use of Ethernet infrastructure which can be implemented in various topologies to provide security and redundancy.

3.10 Network topology

IED 61850 is based on Ethernet infrastructure; thus the network in a substation defines the reliability and speed of the communications. Ethernet technology is deemed efficient and flexible among all global users of the technology. Ethernet technology provides four data rates namely:

- 10Base-T-Ethernet
- Gigabit Ethernet
- 10 Gigabit Ethernet

10Base-T-Ethernet can deliver up to 10Mbps data rate. Gigabit Ethernet can provide up to 1000Mbps data rate. 10 Gigabit Ethernet can provide 10Gbps data rate. Ethernet technology can provide the above mentioned bandwidth, which also indicates that it is essential to ensure IEDs in an automation system are compatible to the data rate and to avoid congestion in the network.

The Local Area Network (LAN) can be configured in many different ways to create a system that can be either quite simple providing minimal redundancy or very complex creating a fully redundant network. It should be noted that complex networks may provide redundancy but may also give rise to challenges with regards to transmission time. It is imperative that a substation LAN topology is considered carefully prior to implementation.

Network topologies are defined by the following:

- Recovery time
- Redundancy
- Deterministic
- Robustness
- Fault tolerance
- Economical aspects

71

Network topologies provide various advantages and disadvantages thus substation applications drive the choice of topology to be used. The advantages and disadvantages of topologies may affect substation automation applications, thus rigorous testing is required before choosing a topology to implement in a substation automation application. There are various LAN topologies used in the substation automation system namely:

- Star topology
- Ring topology
- Duplicated ring topology
- Hybrid topology

3.10.1 Star topology

The star topology is the simplest where IEDs are interconnected via a single Ethernet switch. The star topology provides the following features:

- High speed
- Very Flexible
- High Reliability
- High Maintainability

The star topology has its advantages and disadvantages. The advantages of the star topology are as follows:

- The failure of a single device or a cable doesn't bring down the entire network
- The centralized networking equipment can reduce costs in the long run by making network management much easier
- It allows several cable types in the same network where the centralized device can accommodate multiple cable type

The disadvantages of the star topology are as follows:

- Failure of the central device causes the whole network to fail

The star topology has its focal points and impediments. The upsides of the star topology are as per the following:

- The failure of a solitary device or a link doesn't bring the whole system down.
- The unified systems administration hardware can diminish costs over the long run by making system administration substantially simpler
- It permits a few link composes in a similar system where the concentrated device can suit various link write

The hindrances of the star topology are as per the following:

- Failure of the focal device makes the entire system fall flat

This topology is illustrated in Figure 3.10.
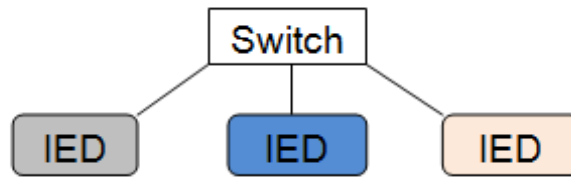
Figure 3.10: Star Communication Topology

An adaptation of the star topology is to create redundancy using two network switches. With each switch connected to an IED and associated equipment. The disadvantage of this topology is that all the IEDs must support two communications channels. This topology is illustrated in Figure 3.11
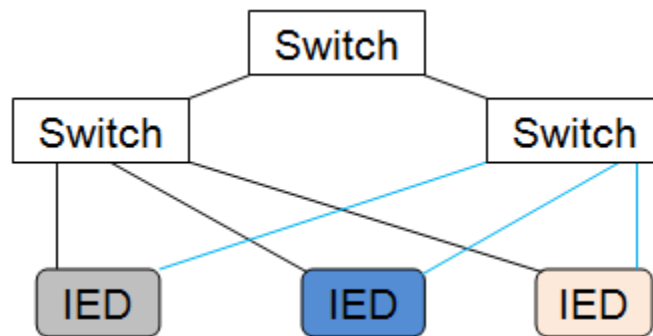
Figure 3.11: Modified Star Topology

3.10.2 Ring topology

With the ring topology, redundancy is created with the ring connection between network switches with each IED having a dedicated network switch. When a communication channel between network switches fails, an alternative communications path exists. The disadvantage of the topology is that it does not cater for individual network switch failure. This topology is illustrated in Figure 3.12
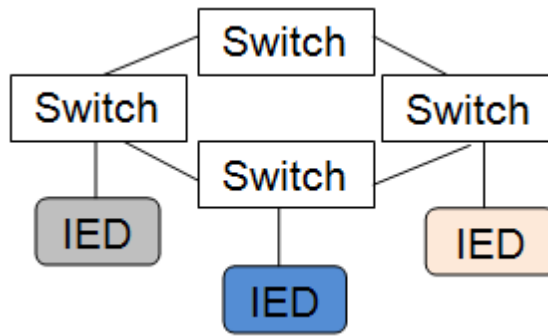
Figure 3.12: Ring Topology

An adaptation of the ring topology is to create redundancy using two network switches per IED. The disadvantages of this topology are that all the IEDs must support two communications channels and it does dramatically increase the cost of the network especially in larger substations with many IEDs. This topology is illustrated in Figure 3.13
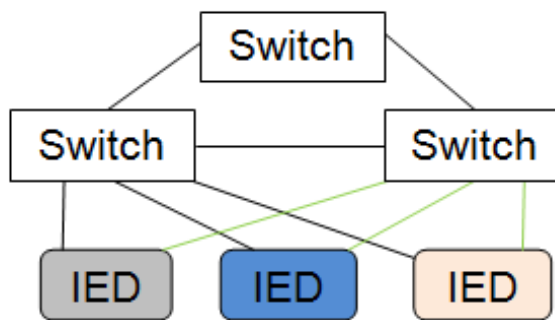
Figure 3.13: Duplicated Ring Topology

3.10.3 Hybrid topology

This topology is a combination of the star and ring topologies. A network switch is placed in each bay and the IEDs associated with that bay are connected in a star while the network switches are connected in a ring. A bay would typically consist of at least two IEDs. This topology is illustrated in Figure 3.14.
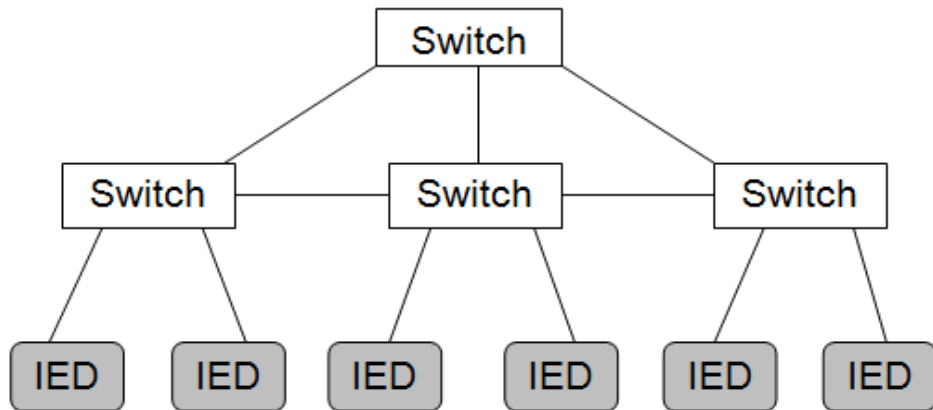
Figure 3.14: Hybrid topology

The different topologies listed above are not the only ones that exist, as they can be adapted to fit the requirements of the specific application.

3.11 Discussion

To achieve interoperability a methodology needs to be formulated and this methodology will be derived from the IEC 61850-10 part of the standard.

3.12 Conclusion

The establishment of IEC 61850 has brought about the use of a single protocol for a complete substation. This has allowed for the Implementation to occur on a common format to describe the substation and facilitate object modelling of data required in the substation. IEC 61850 achieves all of the above by defining the basic services required to transfer data using different communication protocols. Thus this allows for interoperability between products from different vendors.

Although IEC 61850 provides interoperability vendors can interpret the standard differently. This is why interoperability needs to be investigated first to ensure interoperability is possible thus providing proof of interoperability. This is to identify pit falls and shortcomings of vendors and to allow improvement of products from different vendors to allow seamless interoperability integration.

Chapter Four proposes the methodology to achieve interoperability. The GOOSE message structure is discussed. This also includes the review of vendor specific documentation. The evaluation of the methodology proposed is also discussed.

CHAPTER FOUR
PROPOSED INTEROPERABILITY EVALUATION METHODOLOGY

4.1 Introduction

GOOSE message interoperability needs to be evaluated systematically to ensure IEDs are thoroughly vetted. The vetting or evaluation of GOOSE message interoperability does not stray away from test methodologies formulated over the years for IEC 61850 compliant devices. This is to ensure no new test devices are required for GOOSE message interoperability as test devices in the market are increasing by the day.

A methodology of evaluation of GOOSE message interoperability is a necessity to ensure evaluation is thorough.

The material of the chapter is presented as follows:
The GOOSE message structure is introduced in part 4.2. The formulation of an interoperability evaluation method is proposed in part 4.3. Discussion of the proposed interoperability evaluation methodology is presented in part 4.4 and part 4.5 presents the conclusion.

4.2 GOOSE Message Structure

The IEC 61850 is an extensive standard and the conformity of the protection device according to this standard does not necessary imply the interoperability with devices from other vendors. The challenge is how these IEC 61850 devices from different vendors can be deemed interoperable. Vendors do not provide information on interoperability in relation to other vendors. The challenge of interoperability is multi-faceted as interoperability of the vendors differs from each other. There are different levels/categories of interoperability. GOOSE messaging interoperability is one of those levels/categories. GOOSE messaging interoperability provides various applications in an automation substation. Essentially GOOSE messaging is peer to peer messaging to implement whichever application is required of the message. The application of GOOSE message has been reported as reducing fault clearing time when compared with hardwired solutions. GOOSE messaging has the following advantages:

- No handshake mechanism required
- High reliability as the message is repeated periodically

- Message is mapped directly to the Ethernet thus speeding up processing times.
- Message has an attribute Time Allowed to Alive (TAL) which ensures dependability and security. Should the message be delayed it will be disregarded.
- VLAN priority tagging used to expedite messages in a network.

The GOOSE message frame consists of the following :**(IEC 61850-8-1, 2003)**

- *"Header Media Access Control (MAC)*
  - *Destination address*
  - *Source address*
- *Priority tagged field*
  - *Tag Protocol Identifier (TPID)*
  - *Tag Control Information (TCI)*
  - *Virtual LAN Identifier (VID)*
- *Ethernet Protocol Data Unit (PDU)*
  - *Application Identifier (APPID)*
  - *Length*
  - *GOOSE Application Protocol Data Unit (APDU)"*

The Header MAC consists of destination address and source destination. The destination address is defined as a multicast address. The source address defines the MAC address of the sending device. The Priority tagged field consists of three fields namely: **(IEC 61850-8-1, 2003)**

- *"Tag Protocol Identifier (TPID)*
- *Tag Control Information (TCI)*
- *Virtual LAN Identifier (VID)"*

The message frame also consists of Ethernet PDU. The Ethernet PDU consists of four fields namely: **(IEC 61850-8-1, 2003)**

- *"Application Identifier (APPID)*
- *Ethernet type*
- *Length*
- *GOOSE Application Protocol Data Unit (APDU)"*

Figure 4.1 illustrates the GOOSE message frame.
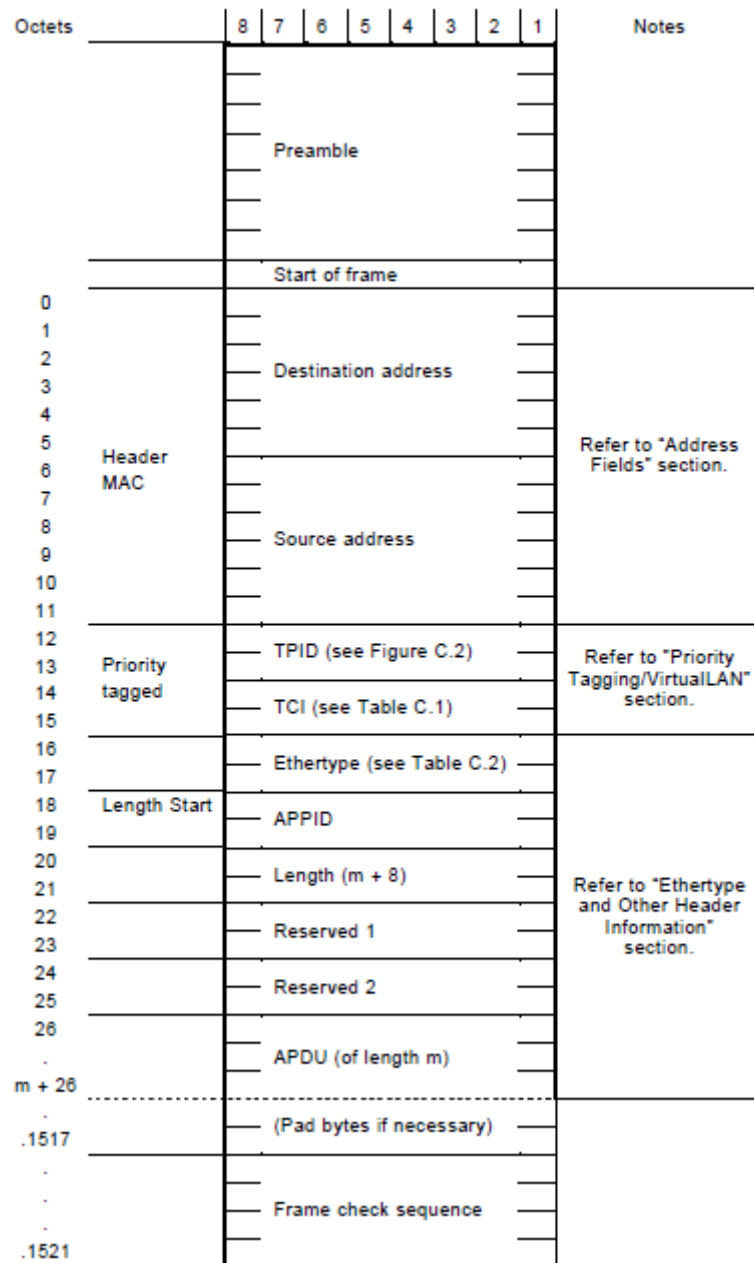
Figure 4.1: GOOSE message frame structure **(IEC 61850-8-1, 2003)**

Note on Figure 4.1 on the TPID, TCI and Ethertype fields refer to Table C1, C2 and Figure C2 which refer to IEC 61850-8-1 standard. The Ethernet type field is defined as 0x88B8 as per IEC 61850. The Length field indicates the number of octets. The GOOSE APDU houses the GOOSE message data and has numerous fields. The GOOSE APDU consists of the fields namely: **(IEC 61850-8-1, 2003)**

- *"State number (stNum)*
  - *Field provides a number to identify when an event has occurred namely when a GOOSE message changes state or an event occurs.*
- *Sequence number (sqNum)*
  - *Field provides an incrementing number for every GOOSE message transmitted on the network.*

78

- *Test*
  - *Field provides insights whether the device is under test or live scenario.*
- *Time allowed to live (TAL)*
  - *Field provides information with regard to the maximum time allowed for the packet to reach its destination.*
- *Need to commission (NdsCom)*
  - *Field indicates the validity of the GOOSE message*
- *Configuration revision (confRev)*
  - *Field indicates the revision of the configuration file*
- *Number of dataset entries (numDatSetEntries)*
  - *Field indicates the number of data sets in the GOOSE message*
- *GOOSE control block reference (gocbRef)*
  - *Field indicates the name of the GOOSE control block*
- *Data set (dataset)*
  - *Field indicates the name of the GOOSE dataset*
- *GOOSE ID (goID)*
  - *Field indicates GOOSE block ID*
- *Timestamp (t)*
  - *Field indicates the time when GOOSE message is generated*
- *Data*
  - *Field indicates the information of the GOOSE message"*

4.3   Proposed Interoperability Evaluation Method

The proposed method for investigation of GOOSE message interoperability is founded on the conformance testing as defined in **IEC 61850-10(2005**).Although conformance testing is being used as benchmark for interoperability the following differences need to be observed as per Table 4.1:

Table 4.1: Conformance testing vs Interoperability testing **(Mulder, 2011)**

Conformance	Interoperability
Needs a reference system	Needs two systems
Both positive and negative testing	Positive testing and limited negative testing
Can test all supported functions	Cant test matching functions
Certificate	Test report
Each system is tested once	Each combination of systems to be tested
All errors are detected	Matching errors are not detected

IEC 61850-10 (2005) makes use of the following vendor documentation to test the veracity of vendor's device is in accordance to IEC 61850 standard:

- *"Protocol Implementation Conformance Statement (PICS);*
  - o *Summarizes the communication capabilities of the system or device to be tested.*
- *Protocol Implementation eXtra Information for Testing (PIXIT) statement and*
  - o *Contains device specific information regarding the communication capabilities of the system or device to be tested and which are outside the scope of the IEC 61850 series*
- *Model Implementation Conformance Statement (MICS);*
  - o *Details the standard data object model elements supported by the device. It shall include definitions of the specific logical nodes, common data classes and data attribute types in the same format as IEC 61850-7-3 and IEC 61850-7-4 parts of the standard.*
  - o *Instruction manuals detailing IED hardware/software versions."*

IEC 61850-10 (2005) sets the requirements of conformance testing into two categories as follows:

- *"Static conformance requirements (refers to the IEC 61850 standard documentation which set requirements for a device to be deemed compliant to the standard)*
- *Dynamic conformance requirements (refers to the requirements that arise from the protocol used for a certain implementation)."*

The Figure 4.2 illustrates the conformance testing process
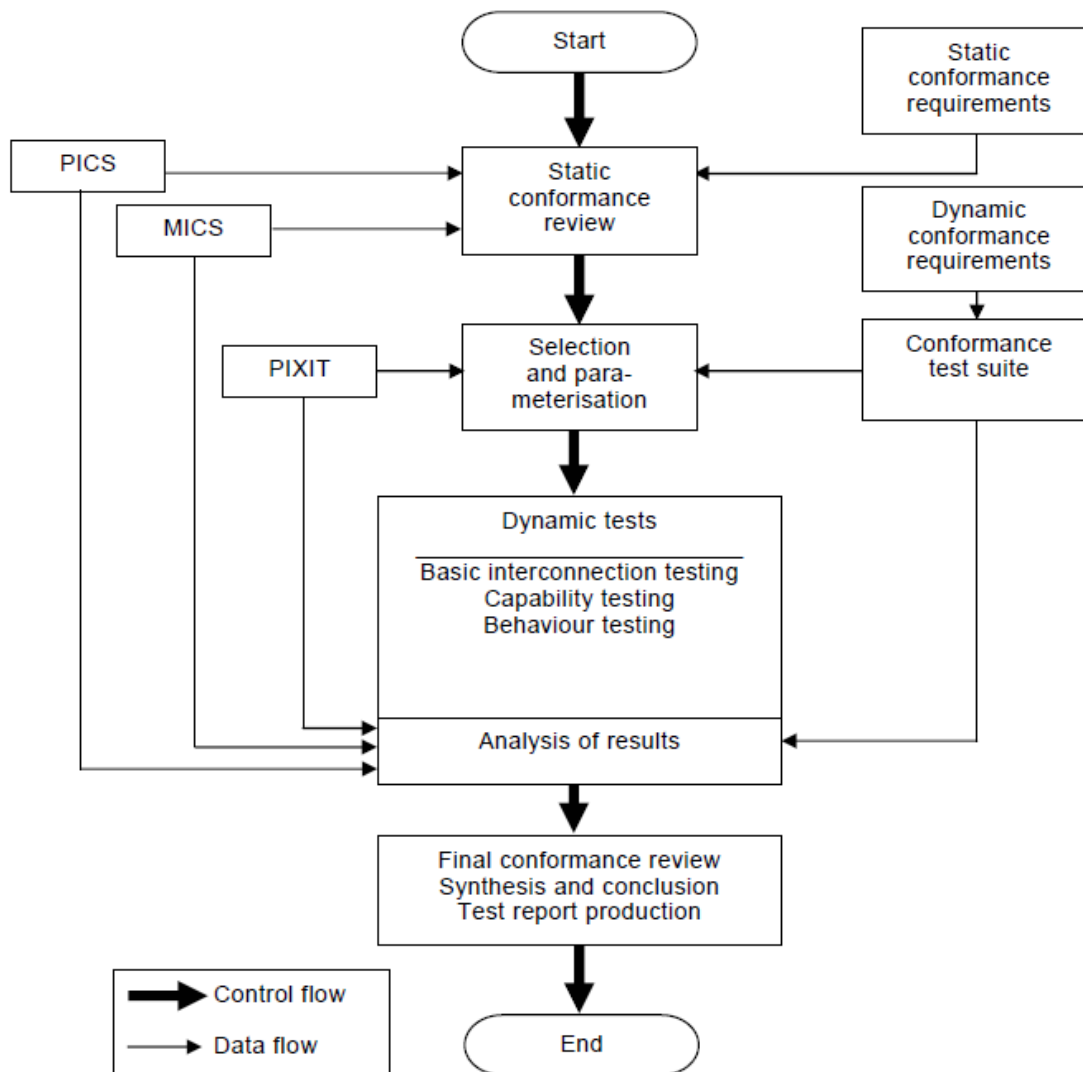
Figure 4.2: Conceptual conformance assessment process **(IEC 61850-10, 2005)**

The interoperability evaluation methodology is based on conformance testing. The methodology consists of two phases namely:

- Preliminary Evaluation – Evaluation of IED capabilities based on IED documentation/manuals
- IED configuration and testing – Configuration, integration and testing of interoperability capability of IEDs

Note the phases are illustrated as steps totalling 5 steps. The steps are categorised per phases as follows:

- Preliminary Evaluation – Step 1 and 2
- IED configuration and testing – Step 3, 4 and 5

The proposed GOOSE message interoperability investigation method is as illustrated in Figure 4.3
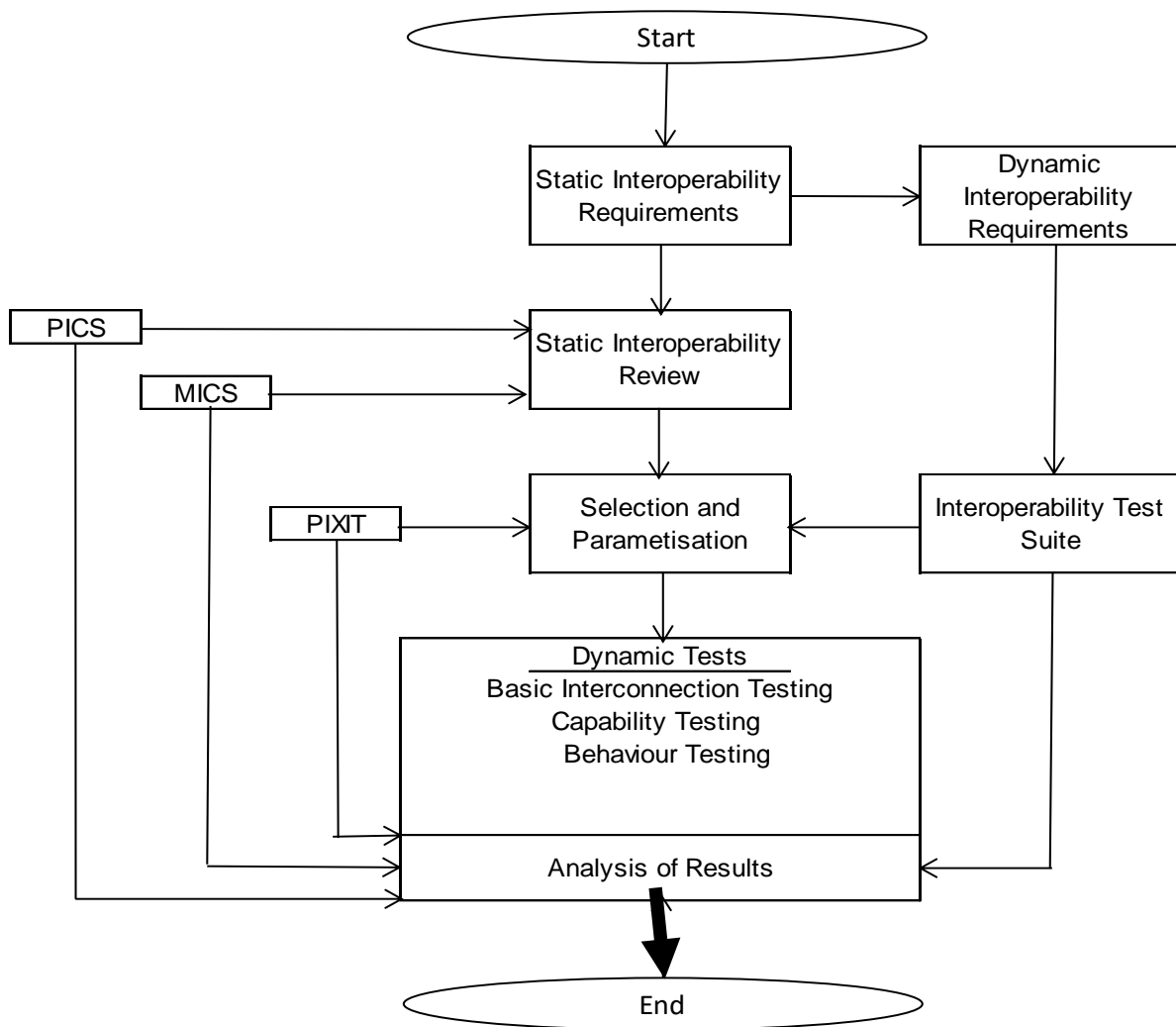
Figure 4.3: Proposed Interoperability assessment method

The method illustrated by Figure 4.3 can also be defined as follows:

- Step 1 Static Interoperability Requirements (include Dynamic Interoperability Requirements)
    - o Static Interoperability Requirements includes the evaluation of IEC 61850 conformance statement.
    - o Static Interoperability Requirements involves reviewing PICS and MICS documentation with regards to the protocols and object models implemented in an IED that allow for GOOSE messaging.
    - o Dynamic Interoperability refers to the protocol or object model used in an IED and in this research its GOOSE messaging. This step reviews GOOSE message applications.
- Step 2 Static Interoperability Review
    - o Static Interoperability Review refers to comparing protocols and object models implemented in two or more different vendor IED's. This involves PICS and MICS documentation review/comparison.
- Step 3 Selection and Parametisation (including Interoperability Test Suite)
    - o Selection and Parametisation refers to the selection IED's that are deemed to be possibly interoperable with each other with regards to GOOSE messaging

82

and configuration of IED's. The configuration of IEDs includes the evaluation of IED manuals and engineering process required to achieve interoperability.
- o Interoperability Test Suite refers to tests to provide proof of concept with regards to GOOSE messaging interoperability.
- Step 4 Dynamic Tests
  - o Dynamic Tests refers to implementation of tests with regards to GOOSE messaging and recording results.
- Step5 Analysis of Results
  - o Analysis of results refers to benchmarking them against PICS, MICS and PIXIT documents and for positive test of GOOSE messaging interoperability.

Step 1 and Step 2 involve the review and comparison of documentation thus is desktop exercise. Step 1 and Step 2 are elaborated on in section **Error! Reference source not found.**, 4.3.2 and 4.3.3. Step 3, Step 4 and Step 5 are progressive steps which are unique to a certain   application being implemented within the IED's. Step 3, Step 4 and Step 5 are repetitive steps with all case studies implemented to assess GOOSE message interoperability/any interoperability assessment being conducted.

4.3.1 PICS documentation review

Protocol Implementation Conformance Statement (PICS) provides details with regards to:

- Abstract Common Services Interface (ACSI) basic conformance statement
- ACSI models conformance statement
- ACSI service conformance statement

The PICS provide self-description models/services to allow communication in an IEC 61850 system. PICS provide information that is required for conformance testing. IEC 61850-7 stipulates which ACSI models/services are mandatory and optional. This is to ensure IEC 61850 complaint IED manufactures are provided with clear and concise information to model compliant IED's. PICS are compiled with objective that they assist with interoperability. ACSI models/services allow for client to server interfaces and peer to peer interfaces. Table 4.2 illustrates ACSI basic conformance statement tabulated against three vendors.

Table 4.2: ACSI Basic conformance statement

IEC 61850					SEL	Schneider			SIEMENS		
		Client/ subscriber	Server/ publisher	Value/ comments	SEL-421 Support	Client/ subscriber	Server/ publisher	Value/ comments	Client/ subscriber	Server/ publisher	Value/ comments
Client-server roles											
B11	**Server** side (of TWO-PARTY- APPLICATION-ASSOCIATION)	–	c1		Yes		Y			Y	
B12	**Client** side of (TWO-PARTY-APPLICATION-ASSOCIATION)	c1	–						N		
SCSMs supported											
B21	**SCSM**: IEC 61850-8-1 used				Yes		Y		Y	Y	
B22	**SCSM**: IEC 61850-9-1 used										
B23	**SCSM**: IEC 61850-9-2 used										
B24	**SCSM**: other										
Generic substation event model (GSE)											
B31	**Publisher** side	–	O		Yes		Y			Y	
B32	**Subscriber** side	O	–		Yes	Y			Y		
Transmission of sampled value model (SVC)											
B41	**Publisher** side	–	O							N	
B42	**Subscriber** side	O	–						N		
c1 – shall be 'M' if support for **LOGICAL-DEVICE** model has been declared. O – Optional M – Mandatory											

IEC 61850				SEL	Schneider			SIEMENS		
	Client/ subscriber	Server/ publisher	Value/ comments	SEL-421 Support	Client/ subscriber	Server/ publisher	Value/ comments	Client/ subscriber	Server/ publisher	Value/ comments
Yes/Y – Supported No/N – Not Supported										

IEC 61850 pegs Generic Substation Event (GSE) model as optional and all three vendors indicate that the model has been implemented. Note the vendors implement the model for both publisher and subscriber side indicated on Table 4.2 (B31 and B32). This is an indication that GOOSE messaging has been implemented in the different vendor devices.

IEC 61850 is defined by a client server model of which the model is built up by building blocks. The building blocks are referred to as models which constitute the client-server model. The models have been defined in IEC 61850-7-2 conditionally and mandatory models required in the IED. The models are as follows:

- Logical Device
- Logical Node
- Data
- Dataset
- Substitution
- Setting group control
- Reporting
- Logging
- Control
- GOOSE
- GSSE
- File Transfer

The **Table 4.3** illustrates IEC 61850 ACSI model requirements including various vendors

Table 4.3: ACSI models conformance statement

	IEC 61850			SEL	Schneider			SIEMENS		
		Client/ subscriber	Server/ publisher	Value/ comments	SEL-421 Support	Client/ subscriber	Server/ publisher	Value/ comments	Client/ subscriber	Server/ publisher	Value/ comments
If **Server** side (B11) supported											
M1	**Logical device**	c2	c2		Yes		Y			Y	
M2	**Logical node**	c3	c3		Yes		Y			Y	
M3	**Data**	c4	c4		Yes		Y			Y	
M4	**Data set**	c5	c5		Yes		Y			Y	
M5	**Substitution**	O	O							N	
M6	**Setting group control**	O	O				Y			Y	
	Reporting										
M7	**Buffered report control**	O	O		Yes		Y			Y	
M7-1	sequence-number				Yes		Y			Y	
M7-2	report-time-stamp				Yes		Y			Y	
M7-3	reason-for-inclusion				Yes		Y			Y	
M7-4	data-set-name				Yes		Y			Y	
M7-5	data-reference				Yes		Y			Y	
M7-6	buffer-overflow				Yes		Y			Y	
M7-7	entryID				Yes		Y			Y	
M7-8	BufTm				Yes		Y			Y	

IEC 61850		Client/ subscriber	Server/ publisher	Value/ comments	SEL SEL-421 Support	Schneider Client/ subscriber	Server/ publisher	Value/ comments	SIEMENS Client/ subscriber	Server/ publisher	Value/ comments
M7-9	IntgPd				Yes		Y			Y	
M7-10	GI				Yes		Y			Y	
M8	**Unbuffered report control**	O	O		Yes		Y			Y	
M8-1	sequence-number				Yes		Y			Y	
M8-2	report-time-stamp				Yes		Y			Y	
M8-3	reason-for-inclusion				Yes		Y			Y	
M8-4	data-set-name				Yes		Y			Y	
M8-5	data-reference				Yes		Y			Y	
M8-6	BufTm				Yes		Y			Y	
M8-7	IntgPd				Yes		Y			Y	
M8-8	GI						Y			Y	
	Logging	O	O				Y			N	
M9	**Log control**	O	O							N	
M9-1	IntgPd									N	
M10	**Log**	O	O							N	
M11	**Control**	M	M		Yes		Y			Y	
If **GSE** (B31/B32) is supported											
	GOOSE	O	O		Yes	Y	Y		Y	Y	
M12-1	entryID				Yes						
M12-2	DataRefInc				Yes						
M13	**GSSE**	O	O						N	N	
If **SVC** (B41/B42) is supported											

IEC 61850		Client/ subscriber	Server/ publisher	Value/ comments	SEL SEL-421 Support	Schneider Client/ subscriber	Server/ publisher	Value/ comments	SIEMENS Client/ subscriber	Server/ publisher	Value/ comments
M14	Multicast SVC	O	O						N	N	
M15	Unicast SVC	O	O						N	N	
M16	**Time**	M	M	Time source with required accuracy shall be available		Y	Y	Time source with required accuracy shall be available	Y	N	
M17	**File Transfer**	O	O				Y		N	Y	

c2 – shall be 'M' if support for **LOGICAL-NODE** model has been declared.

c3 – shall be 'M' if support for DATA model has been declared.

c4 – shall be 'M' if support for **DATA-SET**, Substitution, Report, Log Control, or Time model has been declared.

c5 – shall be 'M' if support for Report, GSE, or SV models has been declared.

M – Mandatory

Yes/Y - Supported

No/N – Not Supported

Since the objective is GOOSE message interoperability the GSE model is critical thus assurance in reviewing all its enablers is essential. The Data set model is due to the vendors implementing/supporting the GSE model as per **Table 4.3** (M4). The requirements intertwine because the Data set model cannot exist without the Data model and subsequent models which house the mention models as illustrated in **Table 4.3** (c3, c4 and c5). The GSE model is supported/implemented by all the vendors as per **Table 4.3** (M12-1 and M12-2).

PICS provide communication models/services required for communication in an IEC61850 system. Table 4.4 illustrates IEC 61850 requirements for services for models listed in **Table 4.3**. The Table 4.4 further list implemented/supported services on various vendors.

Table 4.4: ACSI service conformance statement

	IEC 61850					SEL	Schneider			Siemens		
	Services	*AA: TP/MC*	*Client/ subscriber*	*Server/ publisher*	*Comments*	**SEL-421 Support**	*Client/ subscriber*	*Server/ publisher*	*Comments*	*Client/ subscriber*	*Server/ publisher*	*Comments*
Server (Clause 6)												
S1	*ServerDirectory*	*TP*		*M*		*Yes*		*Y*		*N*	*Y*	
Application association (Clause 7)												
S2	Associate		M	M		Yes		Y		N	Y	
S3	Abort		M	M		Yes		Y		N	Y	
S4	Release		M	M		Yes		Y		N	Y	
Logical device (Clause 8)												
S5	LogicalDeviceDirectory	TP	M	M		Yes		Y		N	Y	
Logical node (Clause 9)												
S6	LogicalNodeDirectory	TP	M	M		Yes		Y		N	Y	
S7	GetAllDataValues	TP	O	M		Yes		Y		N	Y	
Data (Clause 10)												
S8	GetDataValues	TP	M	M		Yes		Y		N	Y	
S9	SetDataValues	TP	O	O		Yes		Y		N	Y	
S10	GetDataDirectory	TP	O	M		Yes		Y		N	Y	
S11	GetDataDefinition	TP	O	M		Yes		Y		N	Y	

	IEC 61850					SEL	Schneider			Siemens		
	Services	*AA: TP/MC*	*Client/ subscriber*	*Server/ publisher*	*Comments*	**SEL-421 Support**	*Client/ subscriber*	*Server/ publisher*	*Comments*	*Client/ subscriber*	*Server/ publisher*	*Comments*
Data set (Clause 11)												
S12	GetDataSetValues	TP	O	M		*Yes*		Y		N	Y	
S13	SetDataSetValues	TP	O	O		*Yes*				N	N	
S14	CreateDataSet	TP	O	O						N	Y	
S15	DeleteDataSet	TP	O	O						N	Y	
S16	GetDataSetDirectory	TP	O	O		*Yes*		Y		N	Y	
Substitution (Clause 12)												
S17	SetDataValues	TP	M	M						N	N	
Setting group control (Clause 13)												
S18	SelectActiveSG	TP	O	O				Y		N	Y	
S19	SelectEditSG	TP	O	O						N	N	
S20	SetSGValues	TP	O	O						N	N	
S21	ConfirmEditSGValues	TP	O	O						N	N	
S22	GetSGValues	TP	O	O				Y		N	*N*	
S23	GetSGCBValues	TP	O	O				Y		N	Y	
Reporting (Clause 14) Buffered report control block (BRCB)												
S24	Report	TP	c6	c6		*Yes*		Y		N	Y	
S24-1	data-change (dchg)					*Yes*		Y		N	Y	
S24-2	qchg-change (qchg)					*Yes*				N	Y	
S24-3	data-update (dupd)									N	Y	
S25	GetBRCBValues	TP	c6	c6		*Yes*		Y		N	Y	
S26	SetBRCBValues	TP	c6	c6		*Yes*		Y		N	Y	

IEC 61850						SEL	Schneider			Siemens		
	Services	*AA: TP/MC*	*Client/ subscriber*	*Server/ publisher*	*Comments*	*SEL-421 Support*	*Client/ subscriber*	*Server/ publisher*	*Comments*	*Client/ subscriber*	*Server/ publisher*	*Comments*
Unbuffered report control block (URCB)												
S27	Report	TP	c6	c6		*Yes*		Y		N	Y	
S27-1	data-change (dchg)					*Yes*		Y		N	Y	
S27-2	qchg-change (qchg)					*Yes*				N	Y	
S27-3	data-update (dupd)									N	Y	
S28	GetURCBValues	TP	c6	c6		*Yes*		Y		N	Y	
S29	SetURCBValues	TP	c6	c6		*Yes*		Y		N	Y	
Logging (Clause 14)												
Log control block												
S30	GetLCBValues	TP	M	M						N	N	
S31	SetLCBValues	TP	O	M						N	N	
Log												
S32	QueryLogByTime	TP	c7	M						N	N	
S33	QueryLogAfter	TP	c7	M						N	N	
S34	GetLogStatusValues	TP	M	M						N	N	
Generic substation event model (GSE) (14.3.5.3.4) GOOSE-CONTROL-BLOCK												
S35	SendGOOSEMessage	MC	c8	c8		*Yes*		Y	*IED supports GOOSE publish and subscription*	Y	Y	
S36	GetGoReference	TP	O	c9						N	N	
S37	GetGOOSEElementNumber	TP	O	c9						N	N	

	IEC 61850					SEL	Schneider			Siemens		
	Services	*AA: TP/MC*	*Client/ subscriber*	*Server/ publisher*	*Comments*	**SEL-421 Support**	*Client/ subscriber*	*Server/ publisher*	*Comments*	*Client/ subscriber*	*Server/ publisher*	*Comments*
S38	GetGoCBValues	TP	O	O		*Yes*		Y		N	Y	
S39	SetGoCBValues	TP	O	O		*Client/Sub ONLY*		Y		N	Y	
GSSE-CONTROL-BLOCK												
S40	SendGSSEMessage	MC	c8	c8						N	N	
S41	GetGsReference	TP	O	c9						N	N	
S42	GetGSSEElementNumber	TP	O	c9						N	N	
S43	GetGsCBValues	TP	O	O						N	N	
S44	SetGsCBValues	TP	O	O						N	N	
Transmission of sampled value model (SVC) (Clause 16) Multicast SVC												
S45	SendMSVMessage	MC	c10	c10						N	N	
S46	GetMSVCBValues	TP	O	O						N	N	
S47	SetMSVCBValues	TP	O	O						N	N	
Unicast SVC												
S48	SendUSVMessage	TP	c10	c10						N	N	
S49	GetUSVCBValues	TP	O	O						N	N	
S50	SetUSVCBValues	TP	O	O						N	N	
Control (17.5.1)												
S51	Select		M	O				Y		N	*N*	
S52	SelectWithValue	TP	M	O				Y		N	Y	
S53	Cancel	TP	O	O		*Yes*		Y		N	Y	

	Services	AA: TP/MC	Client/ subscriber	Server/ publisher	Comments	SEL-421 Support	Client/ subscriber	Server/ publisher	Comments	Client/ subscriber	Server/ publisher	Comments
	IEC 61850					**SEL**	**Schneider**			**Siemens**		
S54	Operate	TP	M	M		*Yes*		Y		N	Y	
S55	Command- Termination	TP	M	O				Y		N	Y	
S56	TimeActivated-Operate	TP	O	O						N	N	
File transfer (Clause 20)												
S57	GetFile	TP	O	M				Y		N	Y	
S58	SetFile	TP	O	O						N	*N*	
S59	DeleteFile	TP	O	O				Y	*Only from /dr_unextracted/ Operation performed on .cfg files.*	N	N	
S60	GetFileAttributeValues	TP	O	M				Y		N	Y	
Time (5.5)												
T1	Time resolution of internal clock				Nearest negative power of 2 in seconds	T1		*1ms*	Nearest negative power of 2 in seconds		*10(1ms)*	Nearest negative power of 2 in seconds
T2	Time accuracy of internal clock				T0	10/9		*1ms*	T0			T0
					T1	*Yes*			T1		*Class T1*	T1
					T2	*Yes*			T2			T2
					T3	*Yes*			T3			T3
					T4	*Yes*			T4			T4
					T5	*Yes*			T5			T5

IEC 61850					SEL	Schneider			Siemens		
	Services	*AA: TP/MC*	*Client/ subscriber*	*Server/ publisher*	*Comments*	**SEL-421 Support**	*Client/ subscriber*	*Server/ publisher*	*Comments*	*Client/ subscriber*	*Server/ publisher*	*Comments*
T3	Supported TimeStamp resolution				Nearest value of 2**-n in seconds	*10*		*1ms*	Nearest value of 2**-n in seconds		*10(approx. 0.9ms)*	nearest negative power 2 in seconds
c6 - shall declare support for at least one (BRCB or URCB) c7 – shall declare support for at least one (QueryLogByTime or QueryLogAfter). c8 - shall declare support for at least one (SendGOOSE or SendGSSEMessage). c9 - shall declare support if TP association is available c10 – shall declare support for at least one (SendMSVMessage or SendUSVMessage). Yes/Y – Supported No/N – Not Supported												

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The GSE model GOOSE control block ACSI services in Table 4.4 (S35, S36, S37, S38 and S39) illustrate that vendors interpret the implementation different to IEC 61850 standards stipulates. The GOOSE control block services determined in the standard are:

- SendGOOSEmessage – Send a GOOSE message
- GetGoReference – Retrieve Functional Constrained Data (FCD)/Functional Constrained Data Attribute (FCDA) of a specific member of Data Set associated with the GOOSE message
- GetGOOSEElementNumber – Retrieve the position of the member in the Data Set associated
- GetGoCBValues – Retrieve the attributes of a GoCB (GOOSE Control Block)
- SetGoCBValues – Write the attributes of GoCB

The GetGoReference and GetGOOSEElementNumber services are stipulated as mandatory by the IEC 61850 standard. The vendors indicated in Table 4.4 all ignore the two above mention mandatory services and instead implemented two optional services GetGoCBValues and SetGoCBValues services.

ACSI services are crucial to GOOSE message communication as these services underpin GOOSE messaging functionality. The attribute GOOSE control block holds the GOOSE messages and is situated in the LLNO (Logical Node Zero). Note Application Association (AA) model refers to the Two Party Application Association (TP) is mandatory in a Table 4.4 (S2, S3 and S4) due to Table 4.2 (B11). Basically Table 4.4 illustrates all the model services and indicates which are mandatory with regards to information in Table 4.2 and Table 4.3 . This is indicative of the description of IEC 61850 as building blocks as some features are mandatory or optional to the vendor thus allowing vendors flexibility with regards to additional features and not straying away from IEC 61850 conformances. The IEC 61850 conformance requires the bare minimum to achieve functionality.

4.3.2 MICS documentation review

MICS documentation illustrates modelling extensions in comparison to IEC 6850 standardised models. It should be noted that unlike PICS the MICS documentation does not have a standardised documentation format thus documentation from various vendors is presented in various ways. The PICS documentation is not standardised but all vendors make use of the table illustrated in IEC 61850-7-2. The evaluation of MICS has disparity due to the different information provided on the document by various vendors.

For the purposes of the study this does not cripple the study as MICS merely provide models for the functionality/feature of the device. The evaluation of MICS documentation does proved insight to the device but other vendor MICS documentation is either unnecessary cumbersome or basic. Instead manuals are used to determine the ability of different vendor devices.

4.3.3 PIXIT (Protocol Implementation eXtra Information for Testing) Documentation review

4.3.3.1 Generic substation events model

The Table 4.5 below illustrates the GOOSE message structure elements that are checked by the vendors when processing GOOSE messages. IEC 61850 standard does not dictate how GOOSE messages are validated. The elements being checked are defined in IEC 61850 thus what is required is to ensure interoperability will be realised among these devices.

Table 4.5: GOOSE validity check

Goose Header Items	Siemens	SEL	Schneider
Destination MAC address	Not Checked	Checked	Checked
Source MAC address	Not Checked	Not Checked	Not Checked
AppID	Not Checked	Not Checked	Checked
Ethertype	Not Checked	Checked	Checked
goCBRef	Checked	Checked	Not Checked
TAL	Checked	Not Checked	Checked
DataSet	Checked	Checked	Checked
T	Not Checked	Not Checked	Not Checked
goID	Checked	Checked	Checked
stNum	Not Checked	Checked	Not Checked
sqNum	Not Checked	Checked	Not Checked
Test	Not Checked	Checked	Not Checked
confRev	Checked	Checked	Checked
ndsCom	Not Checked	Checked	Not Checked
numDatSetEntries	Checked	Checked	Checked
VLAN tag	Not Checked	Not Checked	Not Checked
VLAN Priority	Not Checked	Not Checked	Not Checked
Q	Checked	Not Checked	Not Checked

4.4 Discussion

While a single set of communication interoperability tests applied to all products might seem an ideal approach to test power system devices, the wide range of products required for substation automation precludes the application of a blanket test set. However, there are sets of services required for all products and those services have to be tested in all cases. Beyond the required services, interoperability testing should be customized for each product based on the services identified in the Protocol Implementation Conformance Statement (PICS), Protocol Implementation Extra Information for Testing (PIXIT), and Model Implementation Conformance Specification (MICS) provided by the vendor.

True interoperability testing requires that each vendor's product be tested with complementary and /or competitive products from all other vendors. The problem is that complementary or competitive products will not always be available for testing. Therefore, the test concept must provide a test environment simulating the target environment using products from the vendors of the communications software. Given these initial conditions, products developed to operate in the role of a Client will be tested with simulated servers to verify that they perform the required messaging functions in that role.

The proposed methodology for the evaluation of interoperability is based on the conformance test methodology described in IEC 61850-10. This illustrates that conformance testing and interoperability testing are similar. The notion of having interoperability tests conducted as part of conformance testing is far-fetched due the number of combinations of various interoperability scenarios being endless. Then this makes interoperability testing the responsibility of the end user i.e. Utility, Municipality or consumer.

The proposed methodology for evaluation of interoperability can assist in implementing interoperable substation automation systems. Step 1 and Step 2 can be used to formulate the specifications (for procurement) of IEDs/devices for a certain application in substation. Step 3, Step 4 and Step 5 are dependent on applications that are implemented in the IEDs and make use of tried and tested testing methods. These tests can be incorporated into Factory Acceptance Test (FAT) and Site Acceptance Test (SAT).

97

4.5 Conclusion

This chapter proposes a methodology to achieve interoperability. The GOOSE message structure is discussed. This also includes the review of vendor specific documentation. The evaluation of the methodology proposed is also discussed. Part of the methodology illustrated with regards to the evaluation of the PICS, MICS and PIXIT documentation is reviewed for the three IED vendors.

Chapter Five presents the implementation of a lab scale protection application which implements interoperable GOOSE messaging. The different configuration will be discussed in brief.

CHAPTER FIVE

DESIGN AND IMPLEMENTATION OF A LAB SCALE APPLICATION OF A PROTECTION AND CONTROL SYSTEM FOR INTEROPERABILITY EVALUATION

5.1   Introduction

A protection application is formulated to provide a proof of concept for GOOSE message interoperability. A case study is formulated using a GOOSE message application in conjunction with the protection application. Overcurrent protection application is selected for the case study. The GOOSE message application selected for the case study is Transfer Trip. The physical network of the case study is illustrated in Figure 5.1.
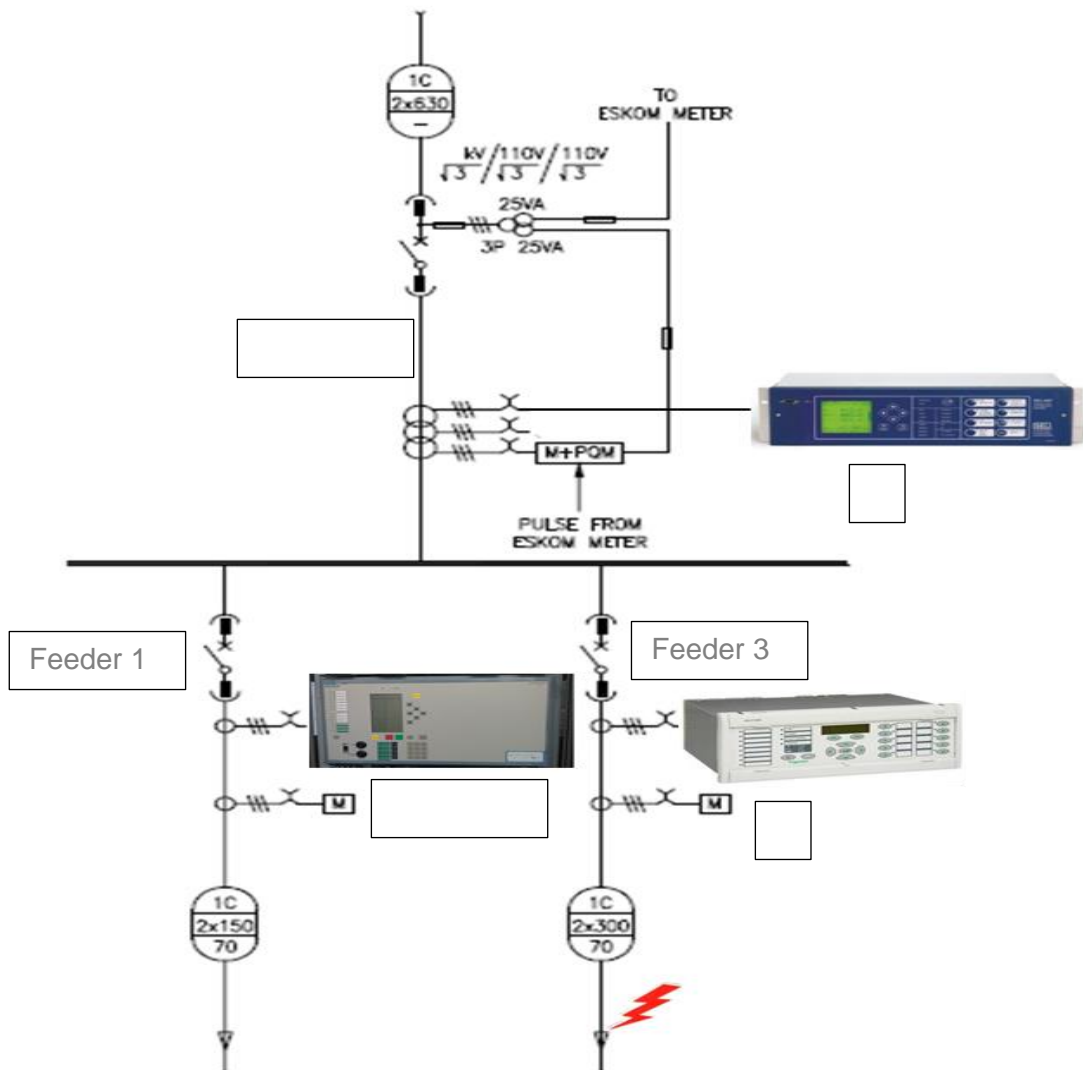
Figure 5.1: Overcurrent Protection Application

When the downstream Feeder 1 or 2 IED detects an ongoing fault on its feeder the IED clears the fault by sending a signal to the circuit breaker. Ideally the circuit breaker should respond and clear the fault but a failure of the circuit breaker is a reality. This is where the breaker failure protection or back up protection is initiated. The trip gets transferred to the next logical isolation point to isolate the fault. For the case study it is the Incomer 1 IED is the logical point of isolation and the downstream Feeder 1 or 2 IED is the origin where the fault takes place. Note the trip on the secondary protection is dependent on time set on the device to lapse prior to isolation. The case study does not implement time lapsed for the fault as the interest is the GOOSE message application. Once a trip is experienced in the Feeder 2 IED (Schneider) the trip is transferred to the Feeder 1 IED (Siemens) and Incomer 1 IED (SEL) immediately to enable a trip condition. The trip is transferred using GOOSE messages.

The case study functions to be performed can be summarised as per Table 5.1.

Table 5.1: Case Study Functions Summary

IED	Function
Schneider P145 (Feeder 2 IED)	1. Discovers and reacts to a fault 2. Generates GOOSE message to be sent to SEL device and Siemens device 3. Transfers the trip signal to output contact to be monitored by the Omicron device 4. Monitoring the trip on the device by switching LED 2 and LED 3
SEL 121 (Incomer 1 IED)	1. Receives a GOOSE message from P145 (Schneider device) 2. GOOSE messages triggers SEL device to trip 3. Generates GOOSE message to be broadcasted on the network 4. Monitors the trip on the Schneider device by switching LED 1 on, on SEL device
Siemens 7SD5 (Feeder 1 IED)	1. Receives a GOOSE message from P145 (Schneider device) 2. GOOSE messages triggers Siemens device to trip 3. Generates GOOSE message to be broadcasted on the network 4. Monitoring the Schneider device GOOSE message on device by switching LED14 on, on Siemens device

The material of the chapter is presented as follows:

The aim of the case study and protection is discussed in part 5.2. The configuration of IEDs setting and GOOSE message is presented in part 5.3. Discussion of the results is presented in part 5.4and part 5.5. The conclusion is presented in part 5.6.

5.2 Design of a lab scale application for protection and control

The electrical power system consists of various elements, used to generate or supply electricity to the consumers. The various elements/equipment need to closely be monitored and protected from any damage. Electrical protection limits or mitigates any possible damage/stress to power system elements/equipment by disconnecting/isolating them from the rest of the system thus interrupting supply to consumers. It should be noted that although the equipment needs to be protected the consumer's needs have to be considered by ensuring supply continuity and avoiding nuisance tripping. This is why the electrical protection is built on the following facets:

- Reliability
- Selectivity
- Stability
- Speed
- Sensitivity

Electrical protection is a mechanism which minimizes/ prevents damage to equipment.

5.2.1 Protection Equipment

Protection equipment is made of CT's and VT's, protection relays, circuit breakers and a communication channel. A brief discussion of each protection equipment is as follows: **(Leelaruji & Vanfretti, 2011)**

- *"Current & Voltage Transformer: also called instrument transformers. Their purpose is to step down the current or voltage of a device to measurable values, within the instrumentation measurement range 5A or 1A in the case of a current transformers (CTs), and 110V or 100V in the case of a voltage (or potential) transformers (VTs/ PTs). Hence, protective equipment inputs are standardized within the ranges above.*
- *Protective relays: are Intelligent Electronic Devices (IEDs) which receive measured signals from the secondary side of CTs and VTs and detect whether the protected unit is in a stressed condition (based on their type and configuration) or not. A trip signal is sent by the protective relays to the circuit breakers to disconnect the faulty components from the power system if necessary.*
- *Circuit Breakers: Circuit Breakers act upon open commands sent by protective relays when faults are detected and close commands when faults are cleared. They can also be manually opened, for example, to isolate a component for maintenance.*

- *Communication Channels: are the paths that deliver information and measurements from an initiating relay at one location to a receiving relay (or substation) at another location."*

5.2.2 Overcurrent Protection

Overcurrent protection acts against excess current in the power system to avoid damage and protect the capital investment. Merely protecting a power system from excess current is not sufficient thus overcurrent has the ability to discriminate. Discriminating protection ensures selectivity, speed, stability, reliability and selectivity. It should be noted that overcurrent protection encompasses all the protection facets.

The following has to be considered when applying overcurrent protection:

- Various types of high and low overcurrents
- How overcurrents occur in a typical system and
- How often the overcurrents occur

Overcurrent faults cause damage to equipment which can be classified as:

- Thermal damage
- Mechanical damage

Thermal Damage is caused by heat produced by the abnormal condition of the network. Mechanical damage is caused by abnormal state of magnetic forces created amid a system fault. This is communicated as peak current.

Overcurrent protection is implemented in an IED. The function of the IED is to detect abnormal conditions in the system and to initiate through appropriate circuit breakers the disconnection of faulty circuits so that interference with the continuity of the supply is minimized. The relay responds to a rise in current flowing through the protected system element. The element has a predetermined value where the element can operate safely without damage. The predetermined value is called overcurrent protection and it only operates when this value is exceeded. Overcurrent protection needs to be time graded to ensure that selectivity is achieved.

Overcurrent protection has various curve types used to grade a protection system. The working time of all overcurrent transfers has a tendency to end up asymptotic to a positive least incentive with the expansion in the estimation of the current. This is an inborn property of the electromagnetic transfers because of immersion of the magnetic circuit. By shifting the purpose of immersion, diverse time attributes can be obtained and are as per the following Table 5.2: **(Alstom, 2011)**

- Definite Time
- Standard Inverse
- Very Inverse
- Extremely Inverse

Table 5.2: Relay Characteristics **(Alstom, 2011)**

Relay Characteristics	Equation (IEC 60255)
Standard Inverse (SI)	$t = TMS \times \dfrac{0.14}{I_r^{0.02} - 1}$
Very Inverse (VI)	$t = TMS \times \dfrac{135}{I_r - 1}$
Extreme Inverse (EI)	$t = TMS \times \dfrac{80}{I_r^2 - 1}$
Long-time standard earth fault	$t = TMS \times \dfrac{120}{I_r - 1}$

The difference between the operating characteristics of overcurrent protection is the rate at which the relay operating time decreases as the current increases. The tripping curves behaviour is shown in Figure 5.2.
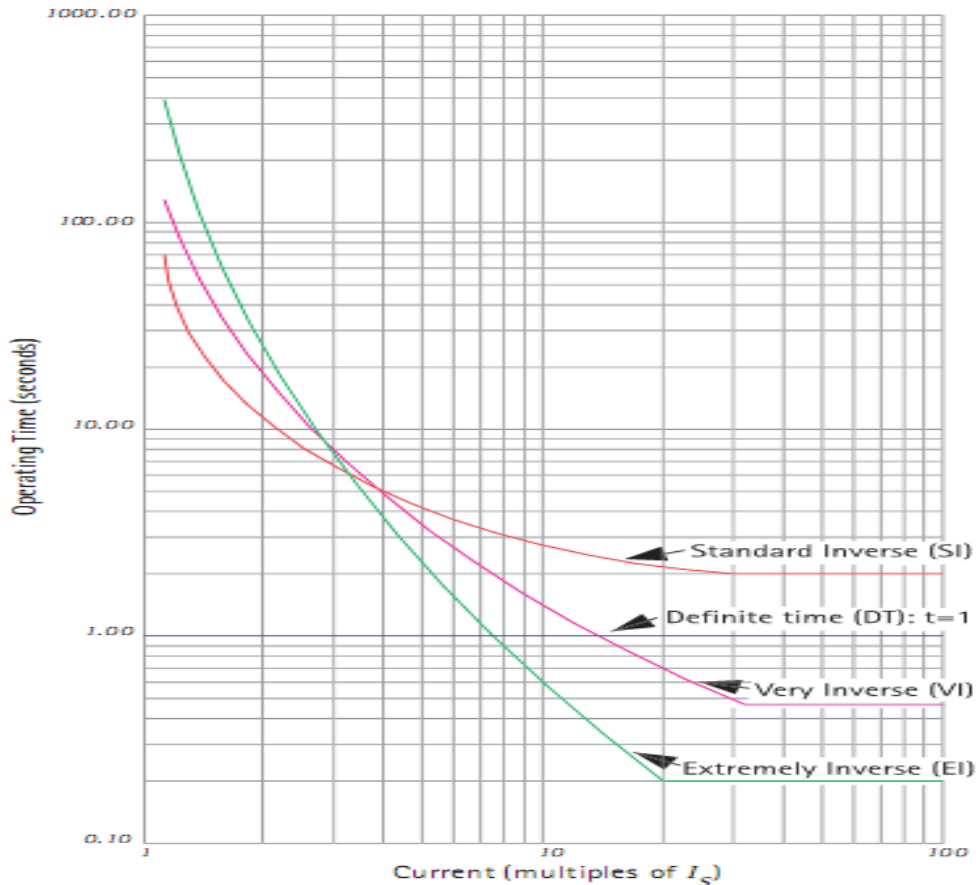
Figure 5.2: Tripping Curves **(Alstom, 2011)**

Definite Time characteristic is mainly used in the power system where tripping is required to trip according to the current value. This means the higher the fault current is the faster the tripping time and the lower the fault current is the slower the tripping time.

Very Inverse characteristic is used mainly for distant faults thus ensuring tripping is not instantaneous. This is also an indication that the fault current is low and fault clearing time is high/longer.

Extremely Inverse operation time is approximately inversely proportional to the square of the applied current. This characteristic is mainly used in areas where there is high switching on currents. This characteristic ensures that no nuisance tripping occurs.

5.2.3 Case Study Aim

The purpose of the case study is namely to:

- Provide proof of GOOSE message interoperability on the basis of implementation of the protection functions following the methodology proposed in Chapter 4.

The measurement of the transfer time between two devices is not possible with devices available for the research. The case study is not setup to enable the measure of transfer time. This is because the three IEDs do not support the same technology with regards to time definition for the devices (SNTP (Simple Network Time Protocol) and IRIG-B (Inter-range Instrumentation Group time code B)). The case study merely illustrates the interoperability of some devices in the system and the set up/configuration of multivendor systems.

5.3 Configuration of IEDs

The configuration flow of the case study is as follows:

- Configure IED settings

- GOOSE message configuration

The implementation of a test bench is used to verify and analyse an IEC 61850 based protection function among various vendors. To analyse or implement a test bench there are set of requirements that need to be met prior implementation namely:

- Understand the IEC 61850 standard thoroughly
- Review all relevant device manuals.
- Review the PICS, MICS and PIXIT documents of the relevant IEDs
- Learn all relevant configuration software tools

For this case study the idea is to implement an overcurrent protection on an IED from one and transfer the trip to other IEDs from other vendors.

Equipment used:

- Omicron CMC 356
- SEL 421
- Schneider Electric P145
- Siemens 7SD5
- MOXA Switch

Software used:

- Wireshark
- Digsi 4
- Ascelarator Quickset
- Ascelarator Architect
- Micom S1 Studio
- Omicron Test Universe

The proposed IED configuration flow chart is shown in Figure 5.3
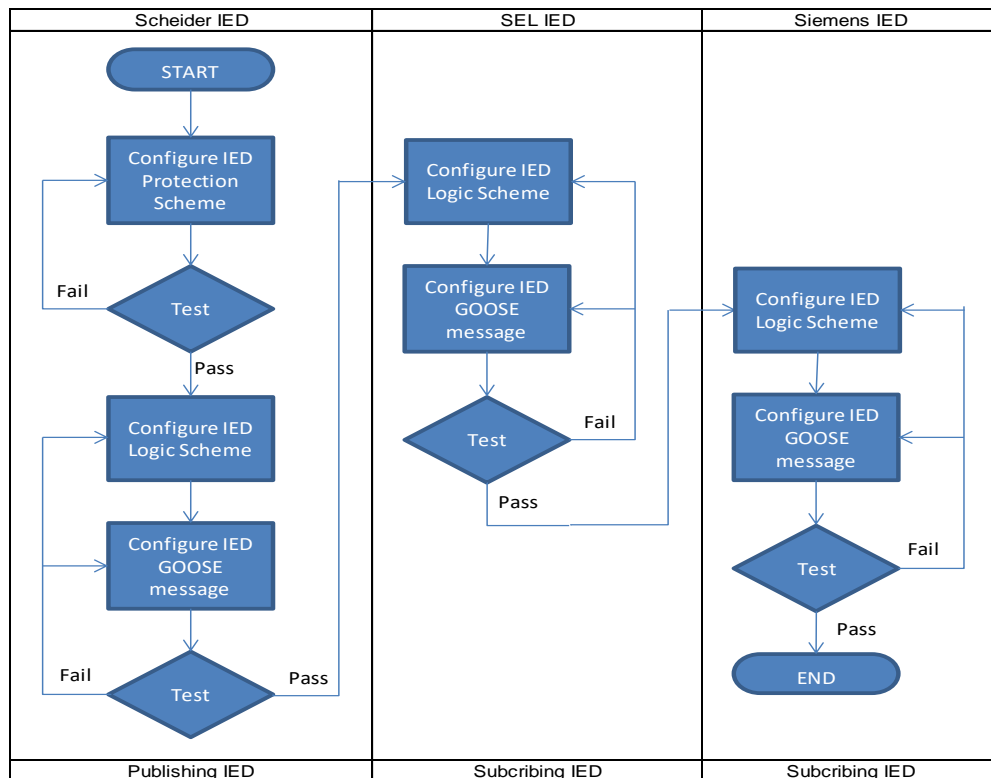
Figure 5.3: IED Configuration Flow Chart

This section illustrates Step 3(Selection and Parametisation) of the proposed methodology of interoperability assessment. Note Step 1 is conducted in section 4.3 in the previous chapter. This section is essential parametisation step and partially includes Step 4 where compulsory tests need to be conducted for integration purposes as per Figure 5.3.

5.3.1 IED Settings

This section defines/illustrates how IED settings configured across the three different vendor IED's on their proprietary configuration tools. The section 5.3.1.1 details the Schneider device details, 5.3.1.2 illustrates SEL device settings and 5.3.1.3 presents the Siemens device settings.

5.3.1.1 Micom S1 Studio - Schneider Device

This is to illustrate the configuration of IED settings and any logic scheme settings required to realize the case study's objective. The Schneider Electric P145 is the device that transfers the trip to the other two devices. The Table 5.3 below illustrates the protection settings for P145 (Schneider Electric) device.

Table 5.3: Protection Settings for P145 IED

Element 1	I>
Characteristics type I>	IEC Very Inverse
I>	1.4 A
Time Multiplier I>	0.2 s
Element 2	I>>
Characteristics type I>>	3.5 A
Time Multiplier	0.2 s
Directional Behaviour	Non Directional

The protection device settings are inserted in the device as illustrated in the Figure 5.4 below. Note the use of two elements of overcurrent which are critical to protection coordination. On completion of inserting the parameters the next step is to configure the logic required for the case study.

Figure 5.4: Schneider Device Settings

The device logic settings are as illustrated in Figure 5.5 for the device. Note that the pickup current is mapped to the Omicron CMC 356 for monitoring via output contacts from the device.. The trip signal is mapped to an output contact to be monitored on the Omicron CMC 356. Further indications are used to depict a trip on the device namely LED 2 and LED 3 on the Schneider device. On completion of the logic settings the next step is to deal with SEL device logic settings.
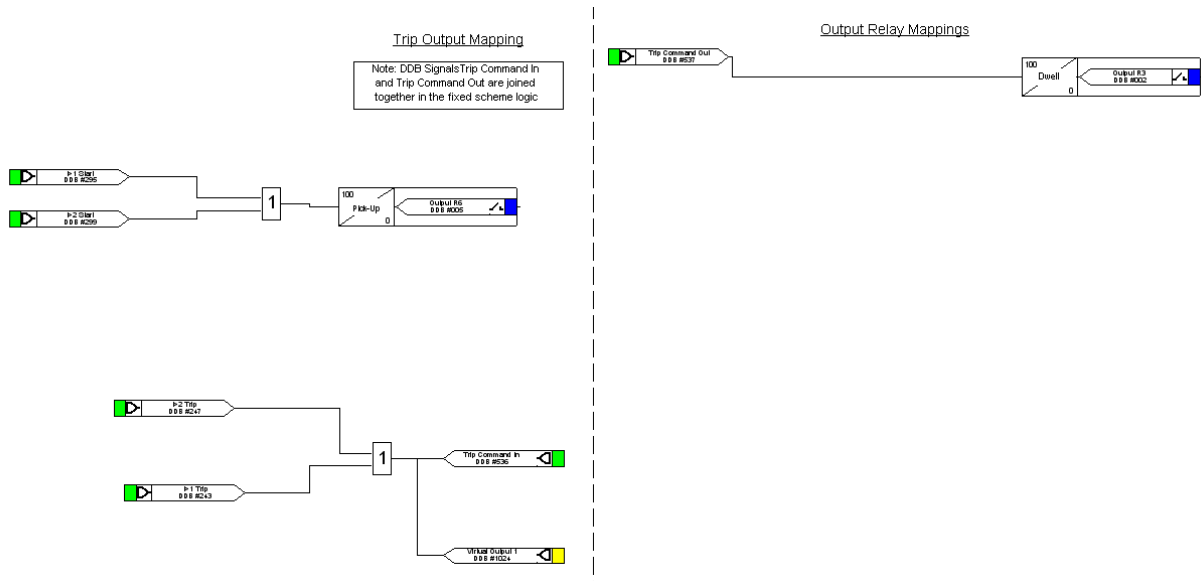
Figure 5.5: Schneider Device Logic Settings

Figure 5.6 illustrates the protection elements one and two mapping to LED 2 and LED 3.
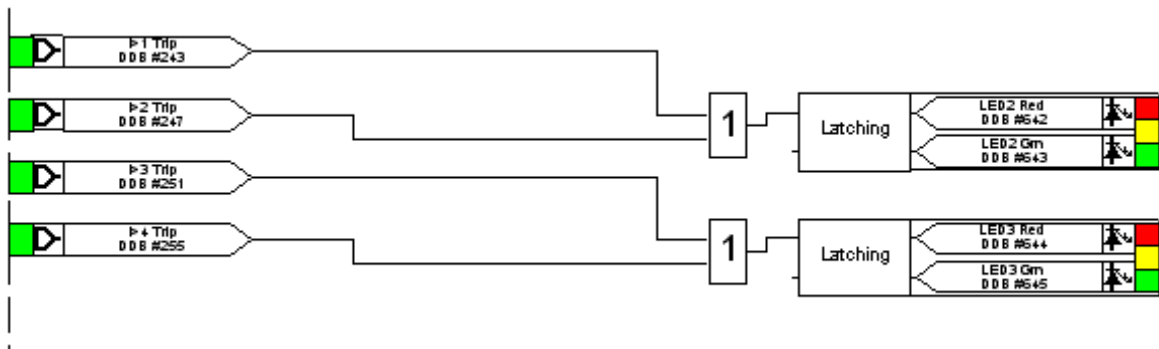
Figure 5.6: Protection Element Mapping

5.3.1.2 Acselerator Quickset - SEL Device

SEL device logic settings are illustrated on the Figure 5.7 below. The logic settings for the SEL device are fairly simple because the SEL device needs to receive a GOOSE message from the Schneider device and trip.
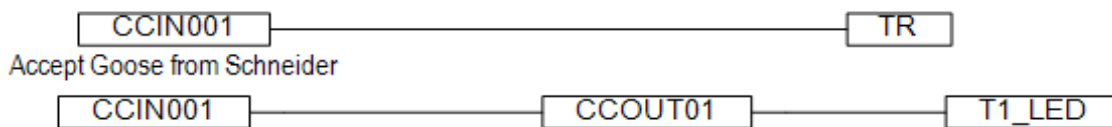
Figure 5.7: SEL Device Logic Settings

In the Figure 5.7 "CCIN001" is the virtual input used to accept the GOOSE message subscription and trigger the trip command in the device. The GOOSE message is relayed to "CCOUT01", the virtual output for GOOSE message publishing. The

"T1_LED" is just an indication on LED one on the device. The settings are loaded on to the IED device and then the next device for configurations is the Siemens device.

5.3.1.3 Digsi 4 - Siemens Device

The Siemens logic settings are shown on the Figure 5.8 below. The SEL and Siemens logic settings are the same as the Siemens device has to receive a GOOSE message from The Schneider device to trip. Further the configuration is required on the Continuous Function Chart (CFC) programming platform to complete the matrix mapping.

Figure 5.8: Siemens Device Configuration Matrix

The CFC platform is merely used to map the GOOSE message to enable tripping the Siemens device as illustrated on the Figure 5.9 below. On completion of the logic settings of the Siemens device the next step is GOOSE configuration for the devices in the system.
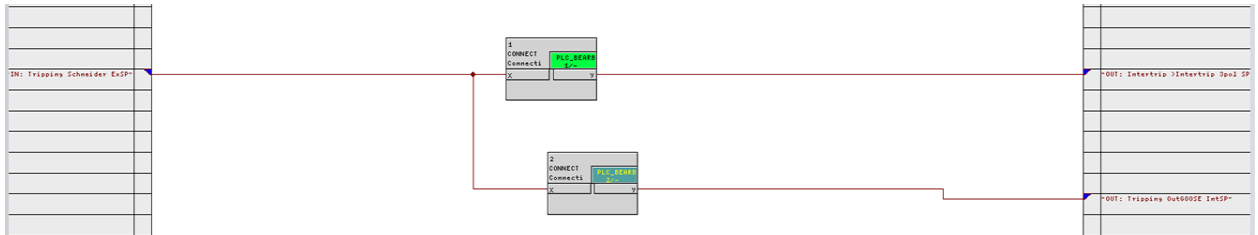
Figure 5.9: Siemens Device CFC Settings

Essentially the settings are that the Siemens device subscribes to Schneider device GOOSE message which is relayed to trip the Siemens device. The Schneider GOOSE message is also relayed to publish a GOOSE message. On completion the settings need to be uploaded to the IED device.

5.3.2 GOOSE message configuration

This section defines/illustrates how the GOOSE messages are configured across the three different vendor IED's on their proprietary configuration tool. The section 5.3.2.1 details the Schneider device details, 5.3.2.2 illustrates SEL device settings and 5.3.2.3 presents the Siemens device settings.

5.3.2.1 Micom S1 Studio - Schneider Device

The basis of GOOSE messaging virtual mapping and the medium of connectivity is Ethernet. GOOSE messaging configuration begins with the device which will publish it. Figure 5.10 below presents the virtual mapping showing the origin(trip elements) of the data that will be contained in the GOOSE message. The GOOSE message will contain or respond in accordance with the logic settings as shown in the Figure 5.10 below. On ensuring the virtual mapping is complete the next step is to configure the GOOSE message dataset.
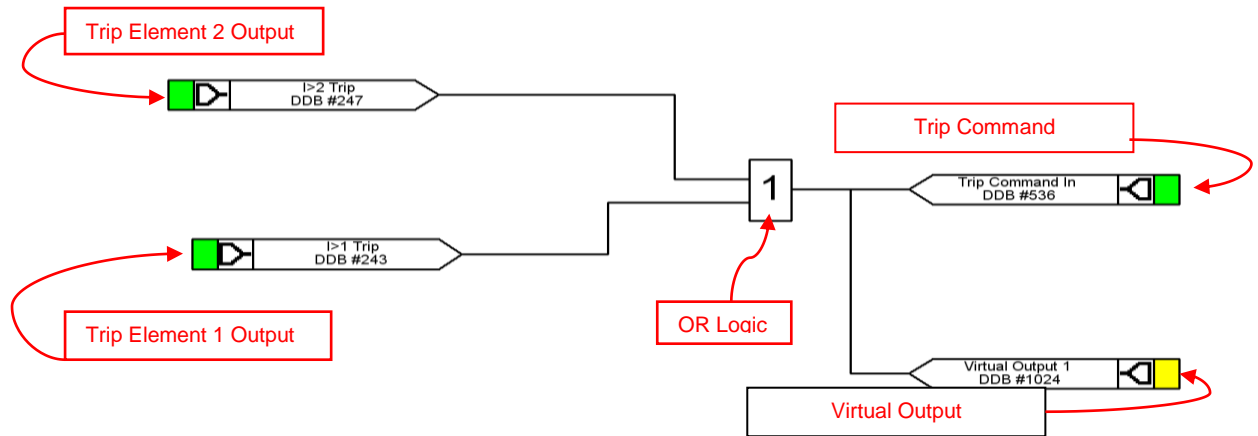
Figure 5.10: Schneider Device GOOSE Mapping

The Figure 5.10 trip element 1 and 2 outputs instigate a trip command and publish a GOOSE message. On completion of the configuration the settings are loaded on to the device. This is to illustrate the virtual output for GOOSE message publication.

Figure 5.11 below illustrates the completion of GOOSE message datasets which are mapped to the virtual output of the GOOSE message publication.
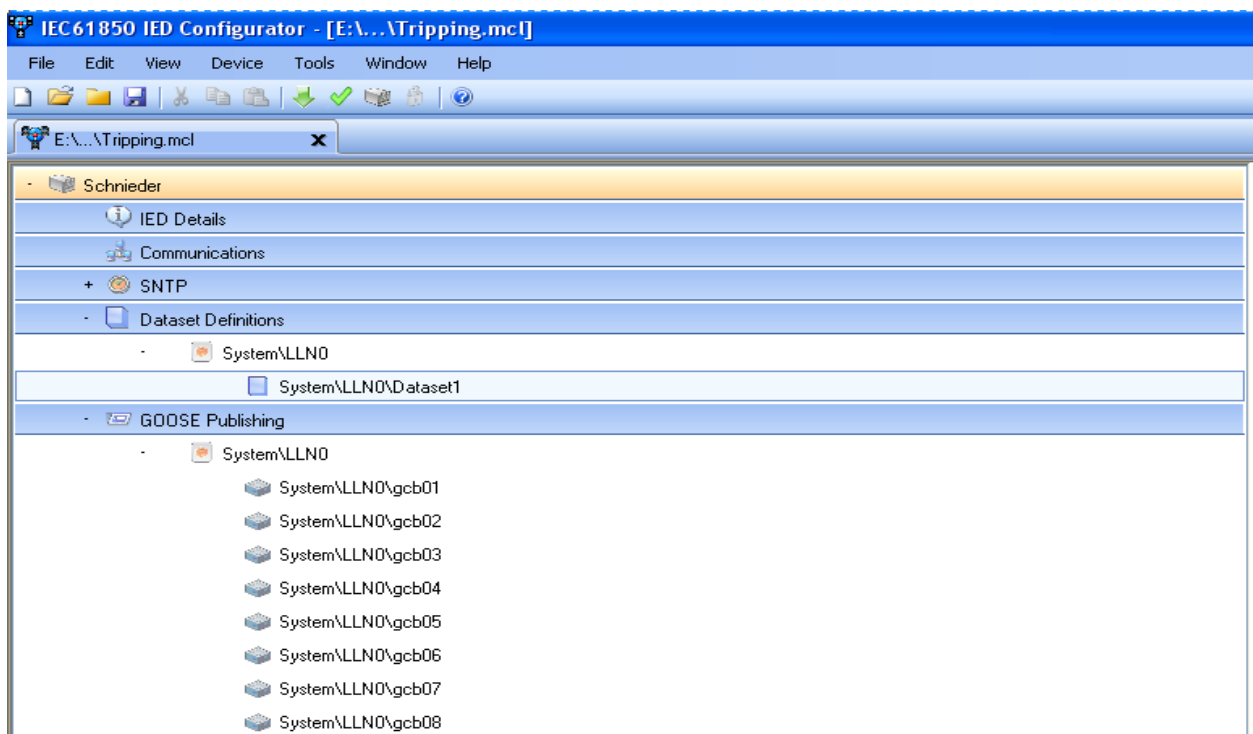
Figure 5.11: Schneider Device GOOSE Configuration

Figure 5.11 shows the configuration of the GOOSE message dataset as per the Dataset Definitions subsidiary .The next step is to define the data that is needed to

be published in the GOOSE message. Figure 5.12 illustrates dataset in the form of FCDA (Functional Constrained Data Attribute).
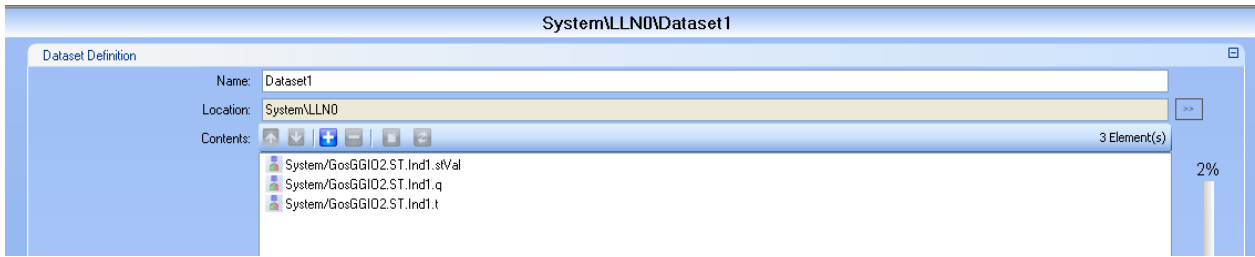
Figure 5.12: Schneider Dataset Configuration

Note GoGGIO2 in Figure 5.12 is the GOOSE message publish virtual output which is linked to the virtual output in Figure 5.10. Once the dataset is configured the next step is to configure the GOOSE control block. Figure 5.13 presents the GOOSE control block settings.
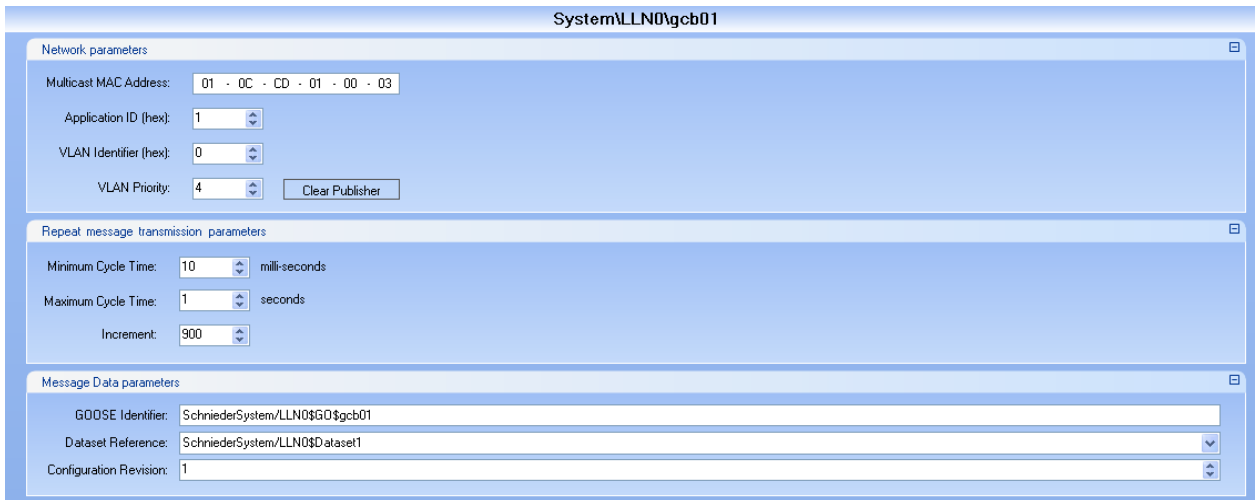
Figure 5.13: Schneider Device GOOSE Control Block Configuration

On completion of the GOOSE control block configuration the setting needs to be loaded to the device. The next step is to configure the SEL device GOOSE message

5.3.2.2 Acselerator Architect - SEL Device

SEL device GOOSE message settings are illustrated on the Figure 5.14 below. The GOOSE message settings are to map/subscribe to the GOOSE message.
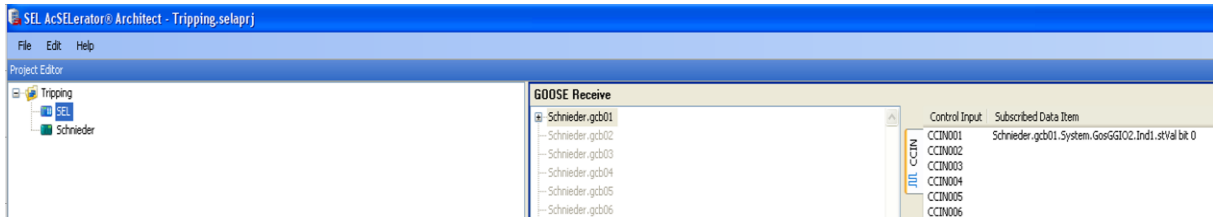
Figure 5.14: SEL Device GOOSE Mapping

In Figure 5.14 note "CCIN001" is the virtual input for a GOOSE subscription input as per Figure 5.7. On completion of mapping the GOOSE message subscription, the next step is to configure the GOOSE message publication by defining the dataset. Figure 5.15 shows the virtual output for GOOSE message publication.
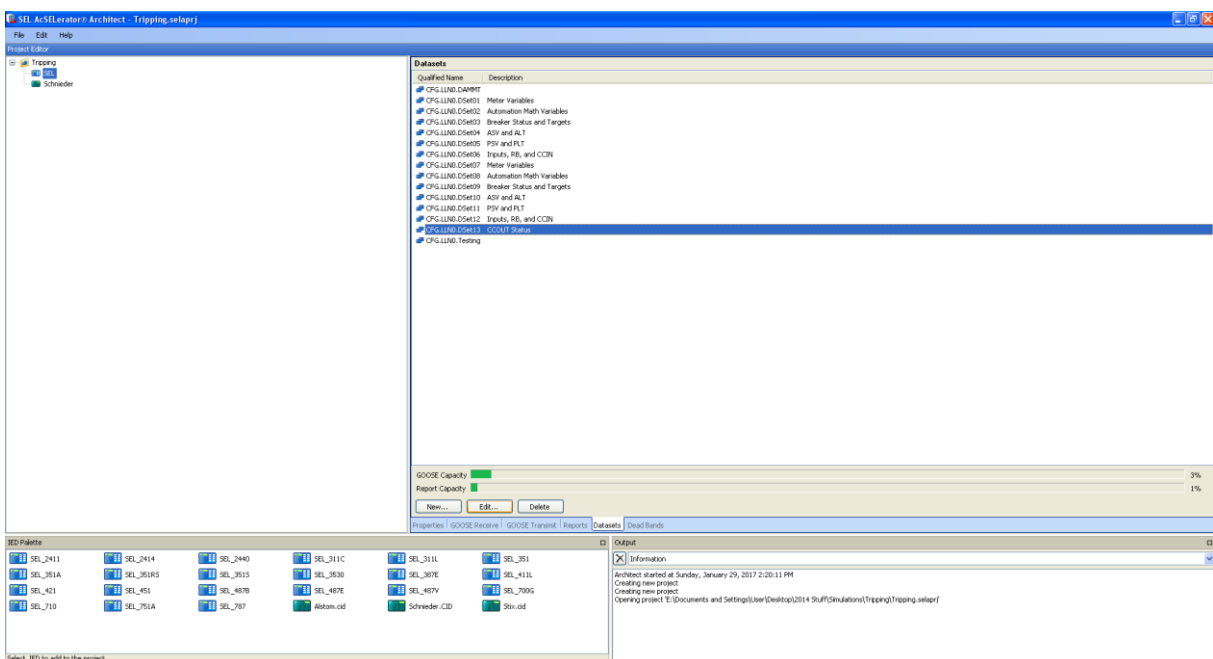
Figure 5.15: SEL Device GOOSE Publishing Settings

Figure 5.16 illustrates the GOOSE message dataset as per the Dataset column. The next step is to define the data that is needed to publish in the GOOSE message. Dataset is determined in the form of FCDA (Functional Constrained Data Attribute).
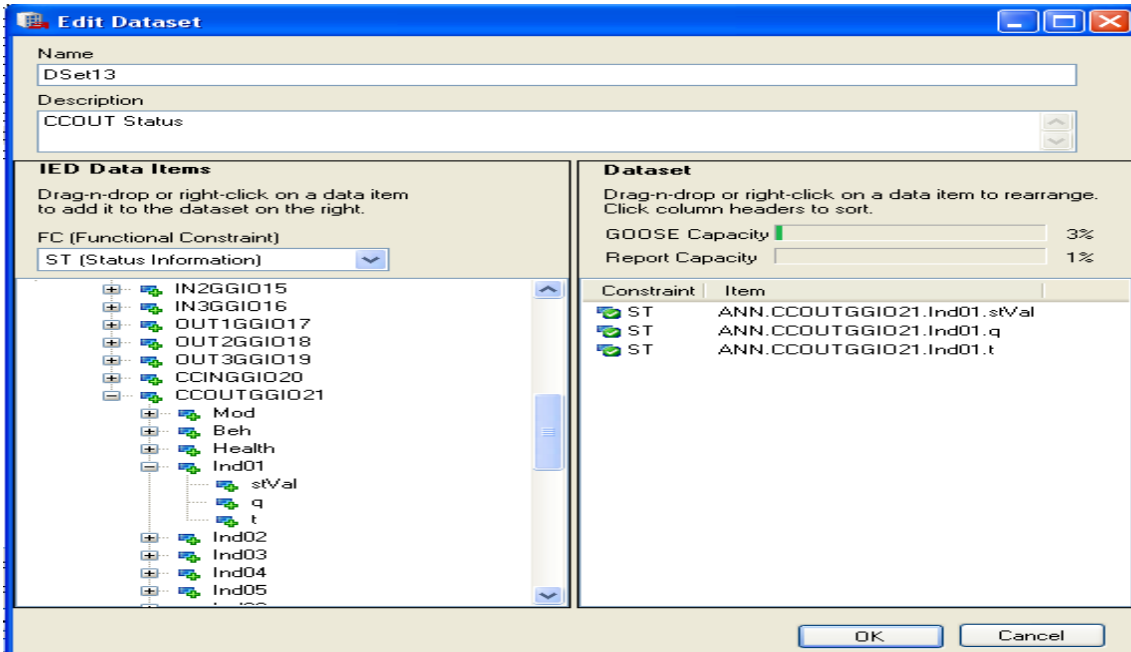
Figure 5.16:SEL Device GOOSE Publishing Settings

Note CCOUTGGIO21 in Figure 5.16 is the GOOSE message publish virtual output which is linked to the virtual output CCOUT01 in Figure 5.7. Once the dataset is configured the next step is to configure the GOOSE control block. Figure 5.17 illustrates the GOOSE control block settings.
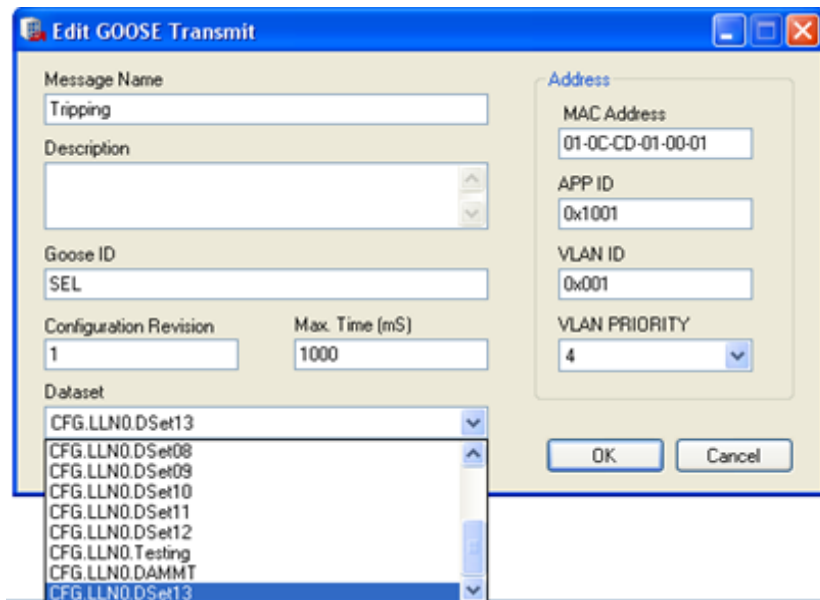
Figure 5.17:SEL Device GOOSE message control block

On completion of the GOOSE control block configuration the settings need to be loaded to the device. The next step is to configure the Siemens device GOOSE message subscription and publication.

5.3.2.3 Digsi 4 - Siemens Device

Siemens device GOOSE message settings are illustrated on Figure 5.18 below. The GOOSE message settings are to map/subscribe to the GOOSE message and publish. The definition of dataset is done in the configuration matrix as per Figure 5.8 for both subscription and publication of GOOSE messages.
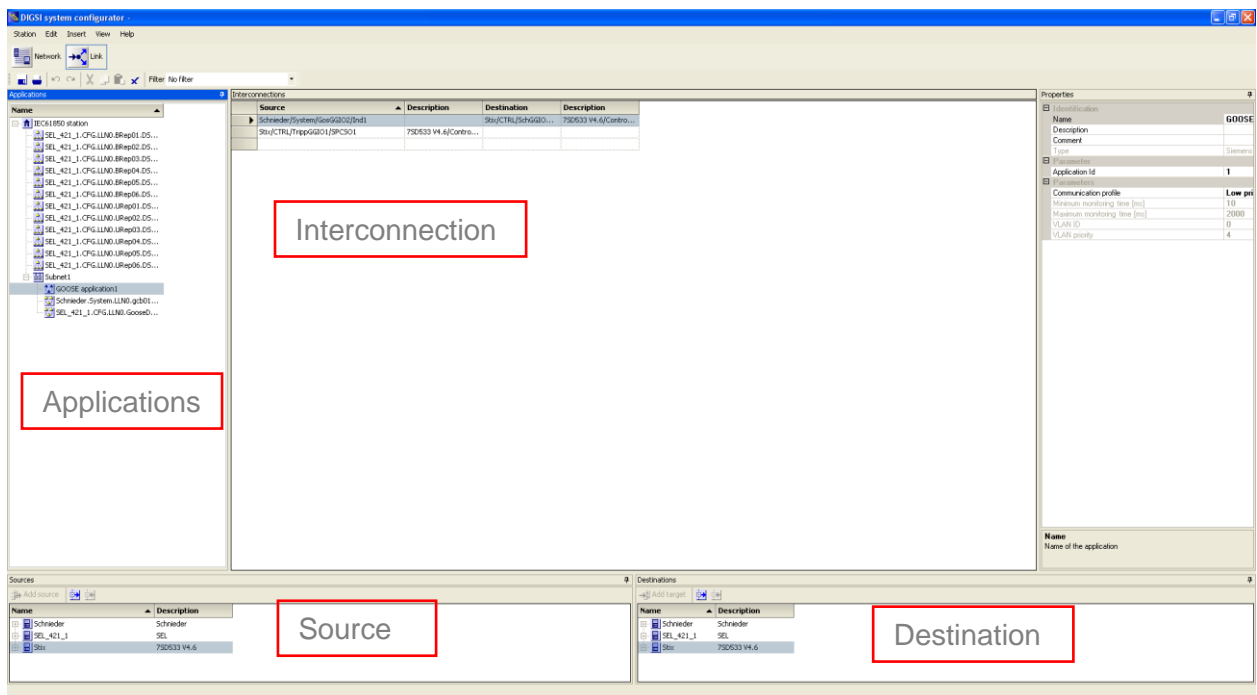
Figure 5.18: Siemens Device GOOSE Configuration

Siemens IEC 61850 configuration tool shown in Figure 5.18 consists of the following canvases: Application, Sources, Destination and Interconnections. Figure 5.19 illustrates the Application canvas and houses GOOSE control blocks
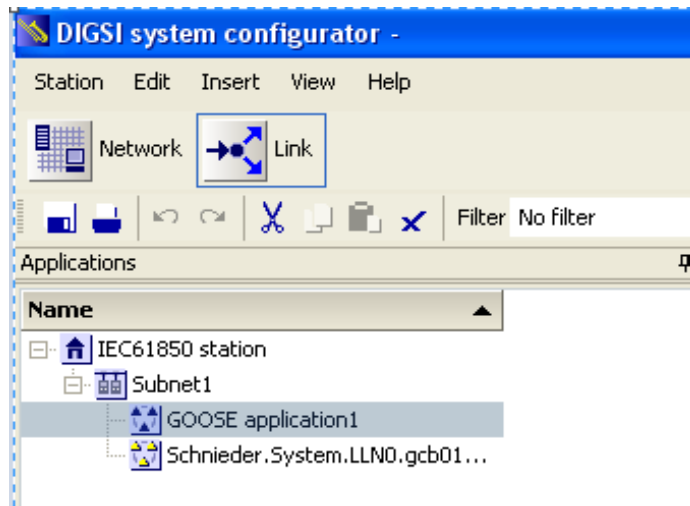
Figure 5.19: Siemens Device Application Canvas

Two GOOSE control box namely "GOOSE application1" (Siemens Device) and "Schnieder.System.LLNO.gcb…" (Schneider Device) are included. Note the Figure 5.20 presents the potential sources of the GOOSE messages for publications.
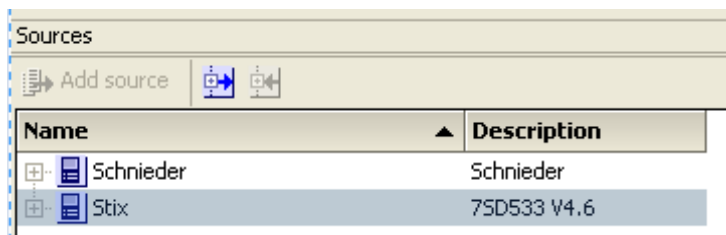
Figure 5.20: Siemens Device Source Canvas

For the case study the source of the GOOSE message is the Schneider device and the Siemens device is reactionary to the GOOSE message from the Schneider device. Figure 5.21 illustrates potential destinations for GOOSE messages for subscriptions.
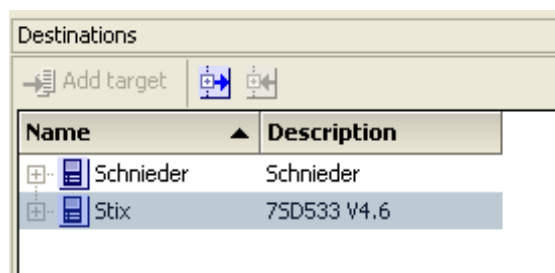
Figure 5.21: Siemens Device Destination Canvas

The destination for the GOOSE message is from the Schneider device to the Siemens device. Figure 5.22 demonstrates the interconnections of the GOOSE messages between the Siemens and Schneider devices including Siemens device publications of these messages.

Figure 5.22:Siemens Interconnections Canvas

Once GOOSE configuration is complete the setting can be uploaded to the device. Note all settings for the devices have been completed, thus testing of the case study can commence.

5.4   Results

To test the formulated case study a fault current needs to be generated. An Omicron CMC 356 was used to generate a fault current in Feeder IED (Schneider IED). Once a fault current is generated Feeder IED (Schneider IED) generates/publishes a GOOSE message. The GOOSE message transfers to Feeder IED (Siemens IED) and Incomer IED (SEL IED). The Figure 5.23 below presents the case study system architecture
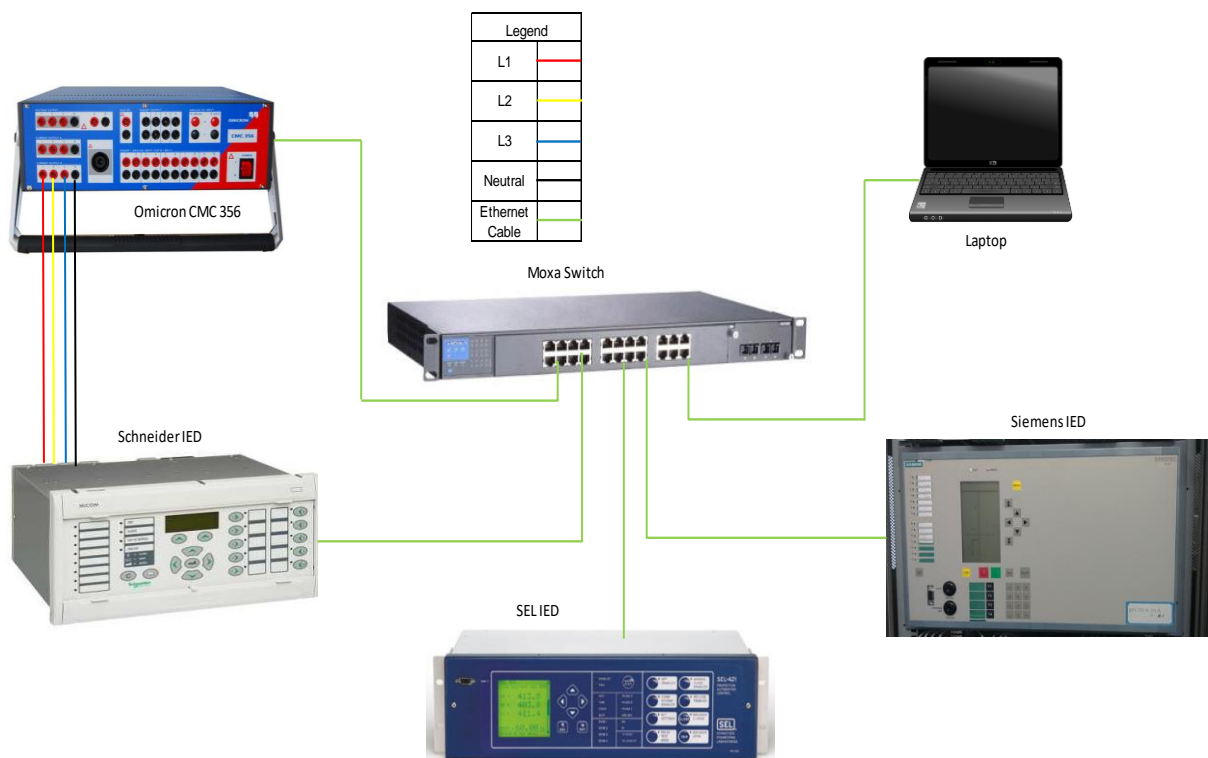
Figure 5.23: Case Study System Architecture

Note that binary inputs are wired to the Omicron device and the Schneider device. The start binary input is mapped to the pickup overcurrent element and the trip binary

input is mapped to the overcurrent element. The Figure 5.24 shows tripping curve characteristics and the actual one from testing the device.

Figure 5.24:Characteristic Test Results

Figure 5.25 shows the tripping curve of the settings of the Schneider device. It also illustrates the tripping points for the case study test.
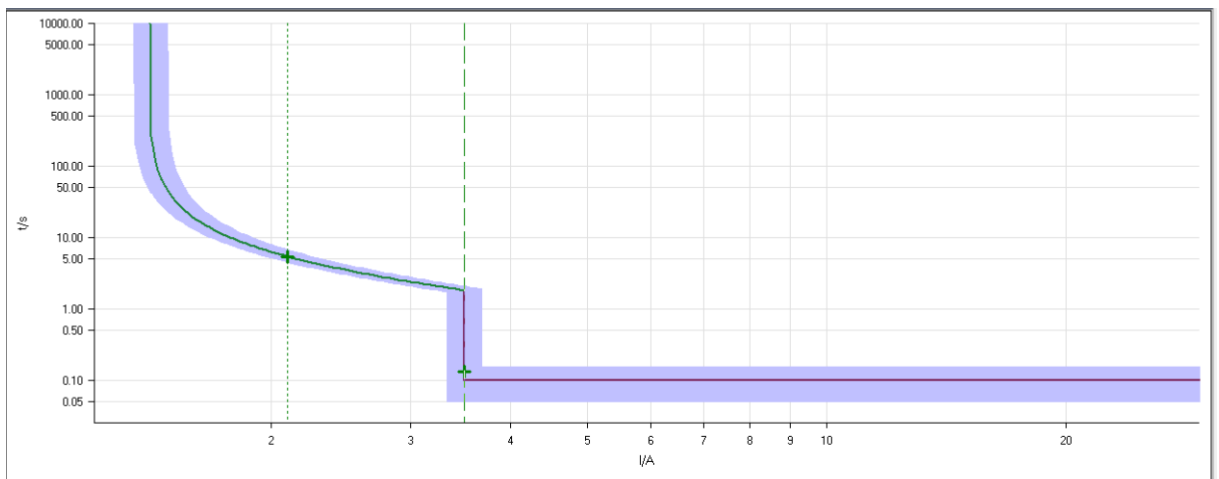
Figure 5.25: Tripping Curve

During the testing of the case study the GOOSE messages need to be monitored. Wireshark is used to sniff the network for any broadcasted packets. Once the injection test using the Omicron device is completed, the Wireshark captured packets needed to be analysed. The following should be noted that the Schneider device GOOSE message state is catalyst in this chain reaction and SEL and Siemens devices respond by publishing a GOOSE message meaning a state on the two device GOOSE messages. Figure 5.26 illustrates the Schneider device GOOSE message prior to the event change. The status number, sequence number and data needs to be monitored on the GOOSE message captures.

No.	Time	Source	Destination	Protocol
64 21.594658		ArevaT&D_91:a1:f5	Iec-Tc57_01:00:03	GOOSE
65 21.740039		Schweitz_00:be:2d	Iec-Tc57_01:00:01	GOOSE
66 21.838520		ArevaT&D_91:a1:f5	Iec-Tc57_01:00:03	GOOSE

```
> Ethernet II, Src: ArevaT&D_91:a1:f5 (00:02:84:91:a1:f5), Dst: Iec-Tc57_
v GOOSE
    APPID: 0x0001 (1)
    Length: 157
    Reserved 1: 0x0000 (0)
    Reserved 2: 0x0000 (0)
    v goosePdu
        gocbRef: SchniederSystem/LLN0$GO$gcb01
        timeAllowedtoLive: 2010
        datSet: SchniederSystem/LLN0$Dataset1
        goID: SchniederSystem/LLN0$GO$gcb01
        t: Jan 29, 2017 13:40:52.801999986 UTC
        stNum: 1
        sqNum: 5396
        test: False
        confRev: 1
        ndsCom: False
        numDatSetEntries: 3
        v allData: 3 items
            v Data: boolean (3)
                boolean: False
            v Data: bit-string (4)
                Padding: 3
                bit-string: 0000
            v Data: utc-time (17)
                utc-time: Jan 29, 2017 13:40:52.693999946 UTC
```

Status Number

Sequence Number

Data

Figure 5.26: Schneider Device GOOSE Capture Before the Event

The Figure 5.27 presents the Schneider device GOOSE message after the event has changed. Note the data field refers to that the Schneider device has tripped. The status number has also changed to 2 when compared to Figure 5.26. The sequence number indicates this is the first packet after the event changed.

Figure 5.27: Schneider Device GOOSE Capture After the Event

The Figure 5.28 illustrates the Siemens device GOOSE message prior to the event change.

Figure 5.28:Siemens Device GOOSE message capture before the event

The Figure 5. 29 presents the Siemens device GOOSE message after the event has changed. Note the data field change refers to that the Schneider device transfer trip has been received and acted upon by the Siemens device. The status number has

also changed to 2 when compared to Figure 5.28. The sequence number indicates this is the first packet after the event change. Note that this is the 67th packet captured and responds before the SEL device.

Figure 5. 29: Siemens Device GOOSE Capture After the Event

The Figure 5.30 illustrates the Siemens device GOOSE message prior to the event change.

Figure 5.30: SEL Device GOOSE message Capture Before the Event

The Figure 5.31 presents the SEL device GOOSE message after the event has changed. Note the data field change refers to that the Schneider device transfer trip has been received and acted upon by the SEL device. The status number has also change to 3 when compared to Figure 5.30. The sequence number indicates this is the first packet after the event change. Note that this is the 67th packet captured and responds after the Siemens device.
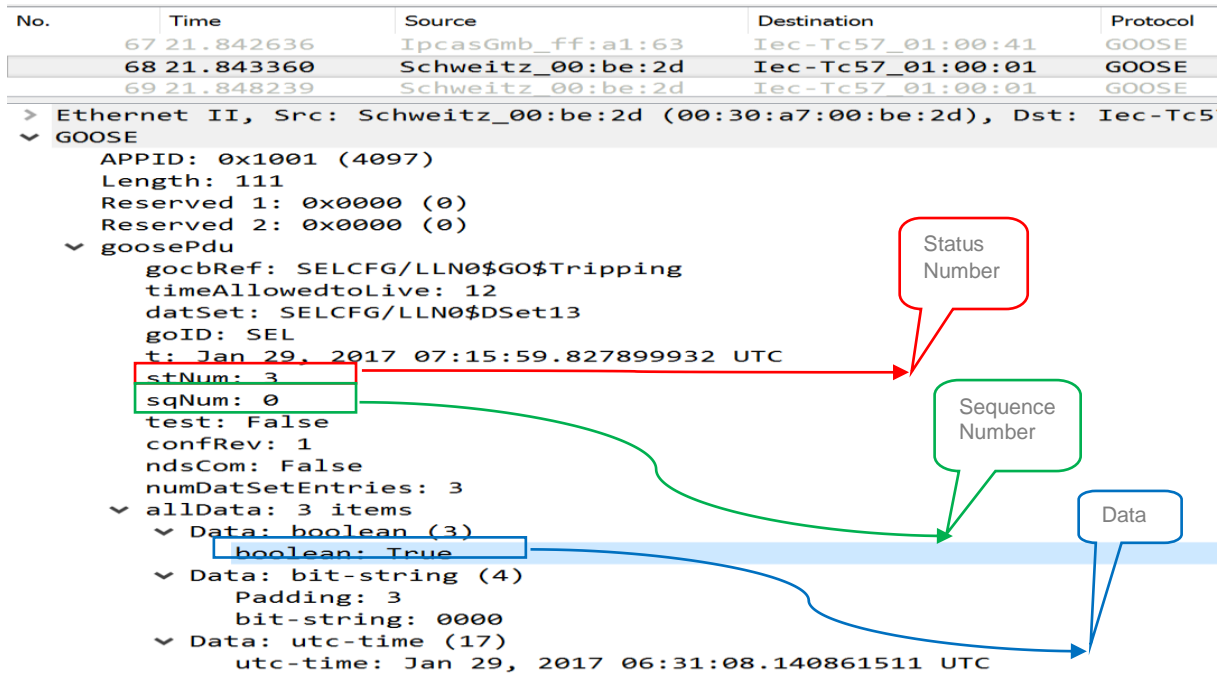
Figure 5.31: SEL Device GOOSE message Capture After the Event

The GOOSE message captures indicate that interoperability is possible between the Schneider Device to Siemens device and Schneider device to SEL device. Note this is with reference to the Schneider device publishing a GOOSE message and the two devices subscribing to the GOOSE message and acting upon the subscription.

5.5   Discussion of Results

The results indicate that a transfer trip has been realised based on that GOOSE messages are transferred from Feeder 2 to Feeder 1 and Incomer 1. This is illustrative that should a breaker failure in Feeder 2 can be remedied using the back the backup protection. This also illustrates that interoperability is also a reality for GOOSE messages in a SAS.

The difficulty with interoperable SAS is the lack of a single file to describe IEC 61850 communication in a SAS. The SCL files of an interoperable SAS are not possible due to the nature at which different vendors handle SCL files. The problem is narrowed down to the vendor specific configuration tool as different vendors interact different with SCL files and the manner which SCL files loaded to the IEDs.

Vendors use their own propriety configuration tools to configure their individual IED's. This includes GOOSE messaging configuration tools. This creates documentation problems as there is no single CID file. Applications become torrid to investigate even in a laboratory scenario let alone a multi-bay substation scenario.

A generic flow of files can be compiled for all different tools according to Tan et.al, (2009) as illustrated below:

1. *"Generate ICD or CID files*

   Each IED produces a self-description IED Capability Description (ICD or CID) file with the information required for exchange already configured for GSSE/GOOSE publication. The file extension, which can be ICD or CID, must contain the following specific IED configurations:

   - *IED name*
   - *IP address*
   - *Multicast MAC*
   - *VLAN ID*
   - *Ethertype, AppID*
   - *Publishing GOOSE dataset information*

   This part remains as proprietary, must be performed by the vendor-specific IED configuration tool

2. *Configuring the data flow between IEDs*

   Import ICD/CID files generated from (1) into a System Configurator such as Digsi 4.8. The information published for each IED will be auto-displayed in the source window ready to be configured.

3. *Configure the data flow between IEDs by subscribing to the published GSSE/GOOSE messages. Once all configuration is done, export the project configuration to create the Substation Configuration Description (SCD) file.*

4. *Send Back the CID files*

   Feedback the SCD file to the IED configurator, where the specific CID file will be extracted and downloaded into the IED. The data flow information should not be changed by the IED Configurator."

The SCL (Substation Configuration Language) flow chart for this case study is illustrated in Figure 5.32. Unlike the above SCL configuration integration (Tan et al 2009) no single SCL file exists to define the entire system. This is because although Digsi 4(Siemens System Configurator) allows for mapping to be done in the configuration tool but exporting file renders it useless for the third party use. Although Siemens device mapping is intact the SEL device and Schneider device mapping simply disappeared. Thus meaning any third party mappings done in Digsi 4 are not

valid once the SCD file is exported out of Digsi 4. The main difference between Figure 5.32 and Tan et.al, (2009) SCL Flow Chart is that in point it referred that CID / ICD file can be imported into Digsi. The results indicate that it's possible to import ICD files but not CID files which are from a different vendor. The Figure 5.32 under Siemens IED indicates that the extension file name of a third party vendor needs to be changed from CID to ICD to ensure an import is possible.
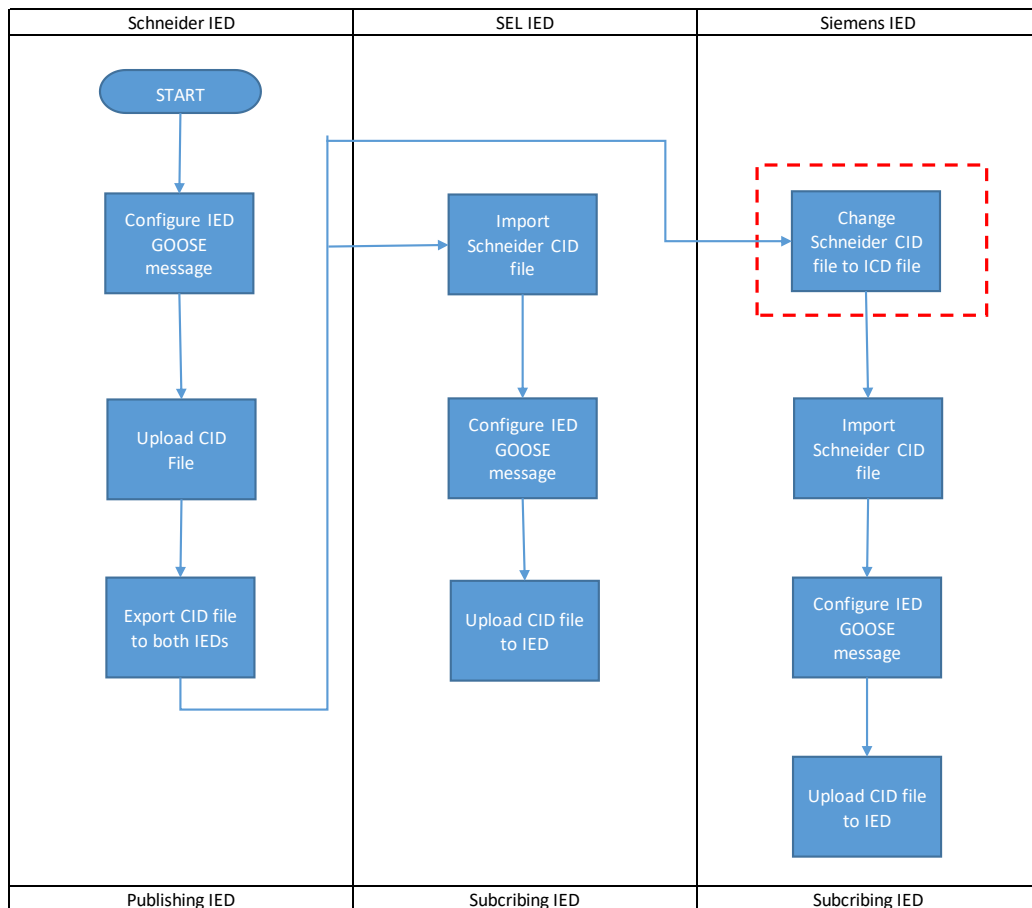
Figure 5.32: SCL Flow Chart

Vendors seem to have taken the context of virtual mapping literally as all GOOSE messaging seems to be done via GGIO rather that designated IEC 61850 application naming. By doing so this causes unnecessary confusion when commissioning or troubleshooting IEC 61850 communication system due to the use of GGIO's. All vendors used for the case study make use of GGIO's to map GOOSE message in and out of devices. GOOSE message publishing is made pedantic due to the use of GGIO's. Now with GOOSE message subscription it can be argued that GGIO's can be used because it depends on the subscribing device on how to utilise the data received. Although it becomes cumbersome if GGIO's are used for publishing and

subscribing. Numerous TISSUES have been brought with regards to whether Edition 1 devices are complaint to IEC 16850-7-4 (Chapter A 1.1).

On completion of the virtual mapping of GOOSE messages there is no way to identify the source of the subscription. This merely means the source Logical Node cannot be identified by only looking at the subscribing device. This lack of transparency can be attributed to the incorrect use of GGIOs. Edition 2 of IEC 61850 seems to have remedied this by introducing input reference models for GOOSE messages being subscribed.

5.6   Conclusion

Chapter Six presents test scenarios which are formulated to assess GOOSE message interoperability. As different vendors make use of proprietary configuration tools, the implementation using these tools is discussed.

Chapter Six presents the various experiments to evaluate GOOSE message interoperability and evaluate configuration tools. The different configuration will be discussed in detail and compared.

CHAPTER SIX
EXPIRIMENTS

6.1 Introduction

This chapter presents test scenarios which are formulated to assess GOOSE message interoperability. As different vendors make use of proprietary configuration tools, the implementation using these tools is discussed.

The section 6.2 presents the various configuration tools limited to the three manufactures namely Schneider Electric, Schweitzer Engineering and Siemens. Part 6.3 presents a case study to showcase the configuration of an interoperable GOOSE messages. Section 6.4 formulates a case study to illustrate that all devices can subscribe and publish GOOSE messages to each other respectively. The section 6.5 discusses various problems encountered and requirements to achieve interoperability and section 6.6 concludes the chapter.

6.2 IED Configuration Tools

IED vendors provide own propriety tools to configure their IED's. The configuration tools used for this particular investigation are from Siemens, Schweitzer Engineering Laboratories (SEL) and Schneider Electric. The Table 6.1 below illustrates the different configuration tools

Table 6.1: IED Configuration Tools

Manufacturer	Configuration Tool	Version
Siemens	Digsi 4	4.83.11
SEL	Ascelarator Quickset	5.0.4.3
SEL	Ascelarator Architect	1.1.98.0
Schneider Electric	Micom S1 Studio	3.4.1

6.2.1 Siemens Digsi 4 Tool

Digsi 4 is a tool used to ensure seamless configuration of IED's. The tool is a modular one as it houses various interfaces to allow seamless configuration of a protection relay. The tool houses the IEC 61850 system configurator, Settings parameters and the Continuous Function Chart (CFC). The individual modules provide their own instrumental role which is as follows:

Setting Parameters – used for setting of protection functions and various annunciations on the IED and the IEC 61850 interconnections to the device.

CFC – used for setting user desired logic, timing and various functionality with regard to logic functionality

IEC 61850 system configurator – used for configuring IEC 61850 based communications.

Each of the above mentioned modules has extensive user manuals which extend to 1000's of pages each. The learning curve is very steep in order to fully understand and use the configuration tool.

6.2.2 Schweitzer Engineering Laboratories (SEL)

SEL makes use of two configuration tools namely

- Ascelarator Quickset
- Ascelarator Architect

SEL has a different philosophy to Siemens with regards to configuration tools. SEL does not house all tools required to configure IED's in one package. SEL implements the use of separate independent tools as named above. The two tools provide their individual functions to ultimately integrate them in the IED to ensure correct functionality. The two tools functionality is as follows:

- Quickset – creates, edits settings and allows for graphical logic programming
- Architect – used to configure IEC 61850 based communications

6.2.3 Schneider Micom S1 Studio

Schneider Micom S1 Studio makes use of the same philosophy as Siemens with regards to housing all the tools required to configure Schneider IED's in one tool. Schneider IED's and Alstom IED's seem to use the same platform and differ with regards to branding

The integral tool Micom S1 Studio provides its specific functions namely:

- Settings - used to configure protection settings and device settings
- PSL (Programmable Scheme Logic) – used to set up logic scenarios for various applications
- IED 61850 IED Configurator - used to create IEC 61850 communications/ interfaces

The tools are used to configure GOOSE message capable IEDs in accordance with any kind of adopted protection application implemented in the device. To achieve interoperability IED configuration tools take centre stage as IEC 61850 based

communications are critical, configuration is crucial hence evaluating the tools is imperative to achieve interoperability.

6.2.4 Configuration Tools Functionality

The configuration tools for all vendors in the study are propriety software tools. Although the software is freely available this does not mitigate the cumbersome process required to configure an interoperable system. The SEL device configuration is described in the Figure 6.1 below. Ascelarator Quickset is for protection and logic settings for a SEL IED. Ascelarator Architect is for the formulation of IEC 61850 communications for a SEL IED. Both Quickset and Architect send/upload their respective files separately.
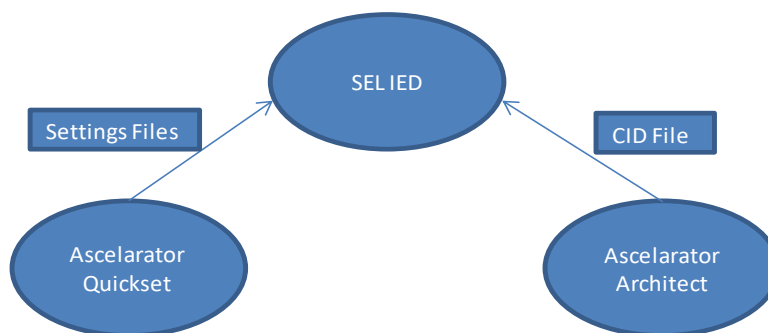
Figure 6.1: SEL Configuration Flow

The Figure 6.2 below illustrates Schneider device configuration. Micom S1 Studio is for protection, logic settings and IEC 6180 communications for a Schneider IED. All files uploaded at the same time as this tool is modular in nature as compared to SEL software tools where software tool are standalone tools for specific configurations.
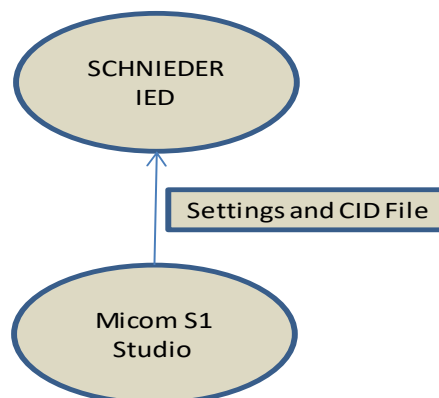
Figure 6.2: Schneider Configuration Flow

The Figure 6.3 below illustrates Siemens device configuration. Digsi 4 is for protection, logic settings and IEC 6180 communications for a Siemens IED. All files uploaded at the same time as this tool is modular in nature as compared to SEL software tools where software tool are standalone tools for specific configurations. Note the software tool is modular the same as Micom S1 Studio for the Schneider IED.
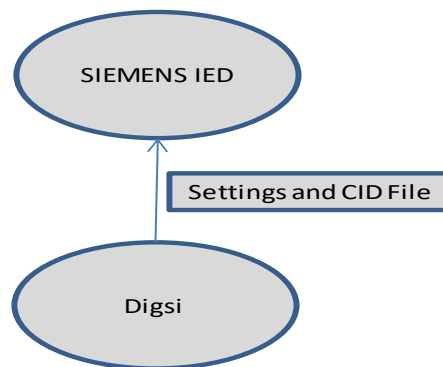
Figure 6.3: Siemens Configuration Flow

6.3   Case Study 1: IED Configuration Tools Evaluation

6.3.1 Case Study Aim

The purpose of this case study is to verify/investigate

- the ability of a GOOSE message to be interpreted by a different vendor IED

- the ability of an IED configuration tool, to acknowledge changes in the communication parameters (i.e. Subnet name, IP address), IED parameters (i.e. LN attribute), and data type template parameters as they are needed to build an SCD file.

- the ability of an IED configuration tool, to acknowledge changes of GOOSE messages from an SCD file

- To verify that the IED configuration tool can import and implement GOOSE subscription data from other IEDs enclosed within an SCD file.

- To verify that SCT (System Configuration Tool)-B or SCT-C can export an SCD file containing vendor 1 devices and that this SCD file can be imported by SCT-A or vice versa. (Note SCT refers to Micom S1 Studio, Ascelarator Architect and Digsi 4)

- To verify that SCT-A or SCT-C can make changes, i.e. add vendor 2 devices, engineer further the formation, export the altered SCD file and that this SCD file can be imported by SCT-B without any manual configuration or vice versa.

- To confirm the aptitude of a SCT to reuse the SCD file of an already designed project from alternative SCT for forthcoming changes in the design

130

6.3.2 Case Study Operation

The case study showcases that the three devices are interoperable (provided the proposed methodology in Chapter 4 is applied) and evaluate the IED configuration tools. This is basically proof of concept with regards to GOOSE messaging interoperability. The case study is presented in Figure 6.4.

The devices used for the case study are as follows:

- SEL 421 – application in transmission levels
- Siemens 7SD5 – application in transmission and distribution levels
- Schneider P145 – application in transmission and distribution levels.
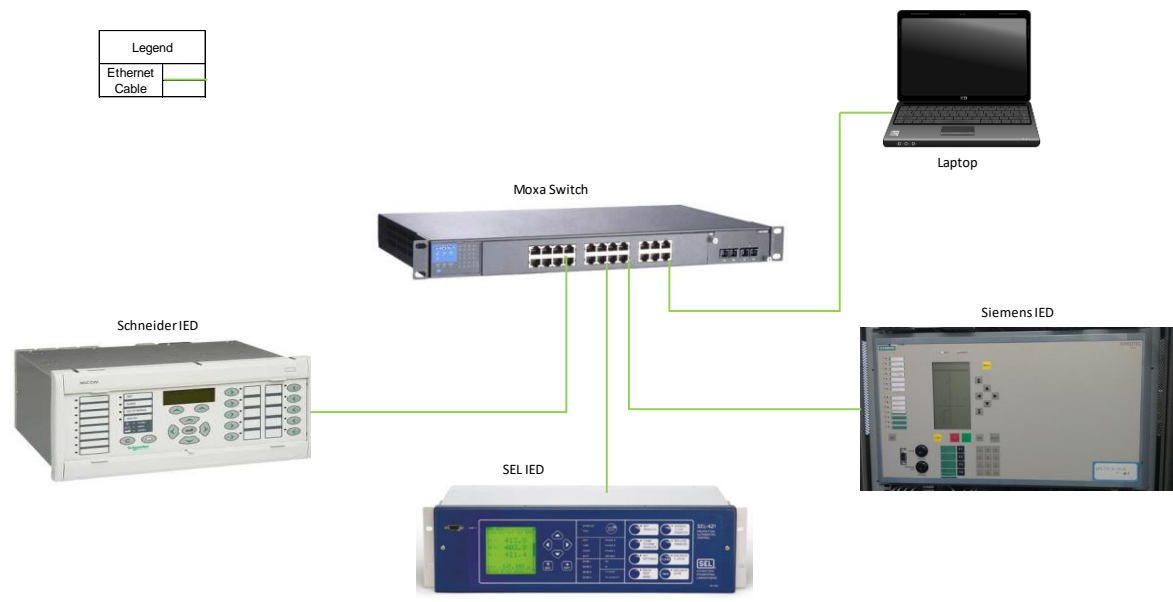
Figure 6.4: Case Study Network Configuration

The Case study is set up as follows:

- The Siemens device serves as a bay controller in the case study. The bay controller initiates an event change. This is done by using the F1 and F2 function on the device. The logic used is a flip flop logic where F1 is set and F2 is reset. By pressing F1 the GOOSE message being published changes its status.

- The SEL device serves as slave in the system. The SEL device subscribes to the Siemens GOOSE message. Upon receiving the GOOSE message from the Siemens device after F1 has been pressed on the device, SEL GOOSE message being published will also change state. The Siemens device

GOOSE message will illuminate LED1, 2 and 3 on the SEL device due to the logic set up in the SEL device.

- The Schneider device will be the last to receive a changed status GOOSE message. The Schneider device logic set up will turn on LED 1, 2 and 3 on the Schneider device.

- Note that the Siemens device logic setup is flip flop thus the GOOSE message state will be latched/unchanged until F2 is pressed. This means that all LED's switched on remain on until F2 is pressed to release the high state. Thus resetting the Siemens device effectively changes the state of its GOOSE message

Note the Figure 6.5, Figure 6.6 and Figure 6.7 below illustrate the logic and network configuration of the case study.
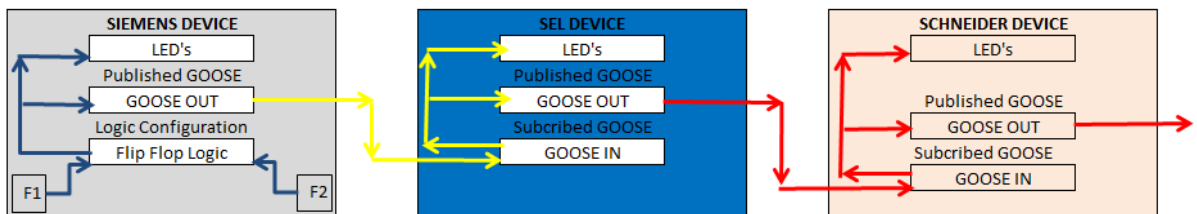
Figure 6.5: Logic Flow GOOSE message
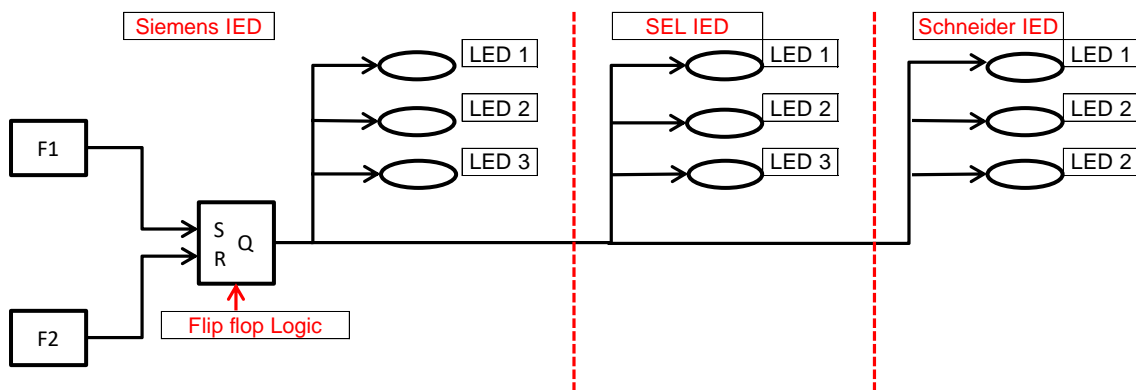
Figure 6.6 Case Study Logic Diagram (Reset)
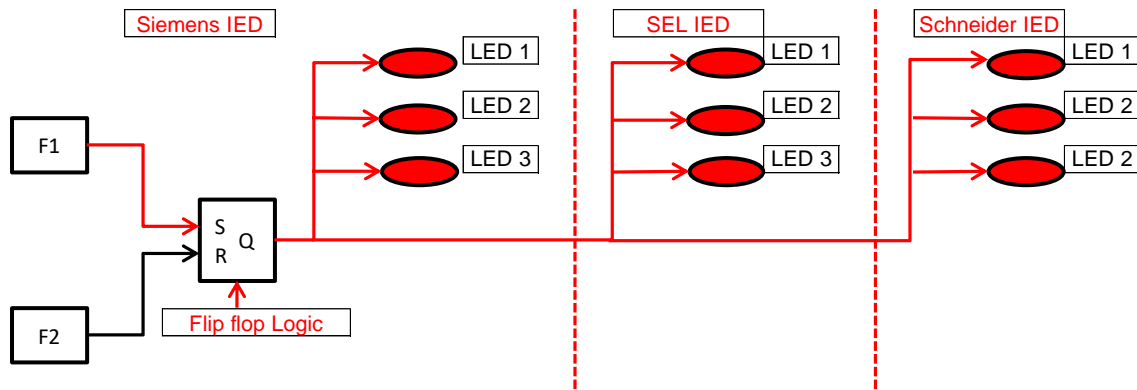
Figure 6.7: Case Study Logic Diagram (Set)

The configuration flow is as follows:

- Start by configuring the logic on Siemens.

- Next configure logic for SEL

- Next configure logic for Schneider

- Configure Siemens GOOSE message

- Configure SEL GOOSE message

- Configure Schneider GOOSE message

The above provides high level steps to configure the devices. There are more intermediary steps required to complete configuration namely the use of the IED configuration tools or SCTs.

6.3.3 Siemens IED Configuration using Digsi 4 Tool

6.3.3.1 Setting up the system

Double click on Digsi 4 icon to star up the program. On completion of start up the below is displayed. Click on file and select "New" as per Figure 6.8.
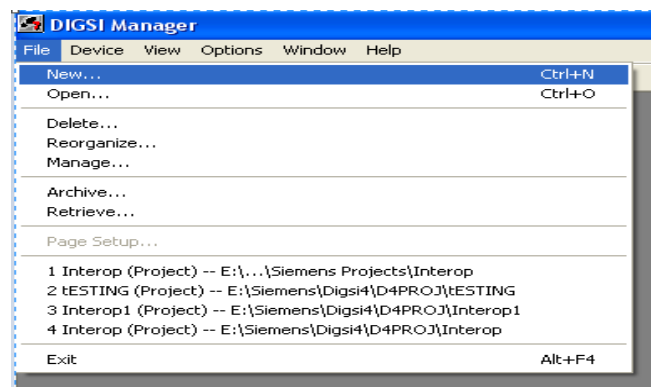
Figure 6.8: Digsi 4 Landing Page

Once the selection is made a New Project pop-up dialogue box appears as per Figure 6.9. Insert the name of the substation/study and select where the file must be saved. On completion please select "OK".
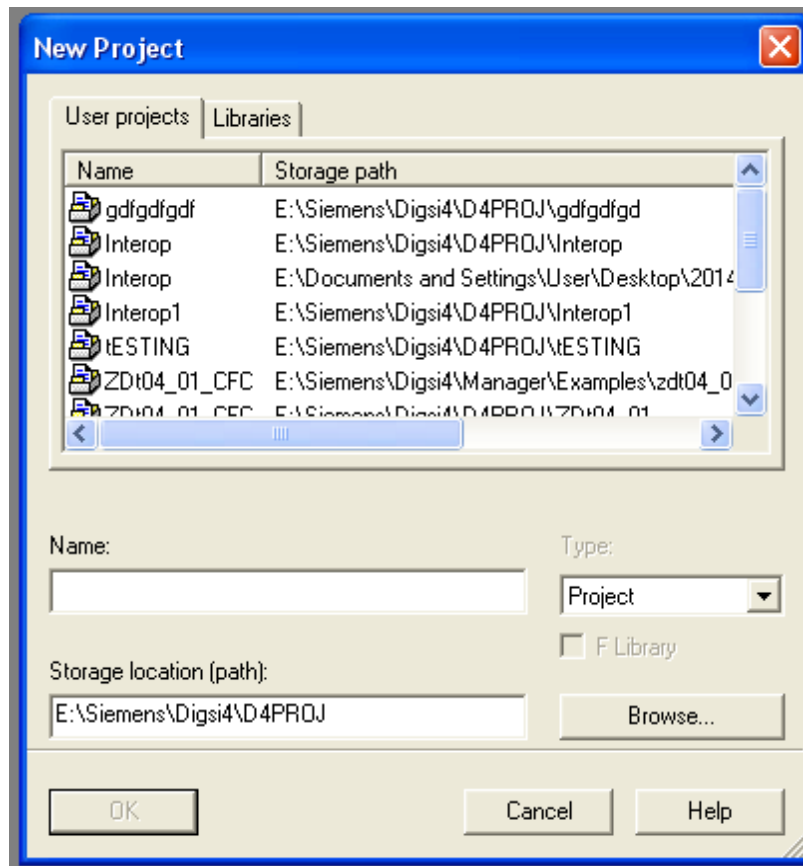
Figure 6.9: Project Naming Dialogue Box

6.3.3.2 Adding a device to the system

This creates a file (substation) which contains now IEDs. The next step is to insert IEDs into the substation. This is done by right click on the folder and select insert new object. A pop-up menu appears and the SIPROTEC device must be selected as per Figure 6.10.
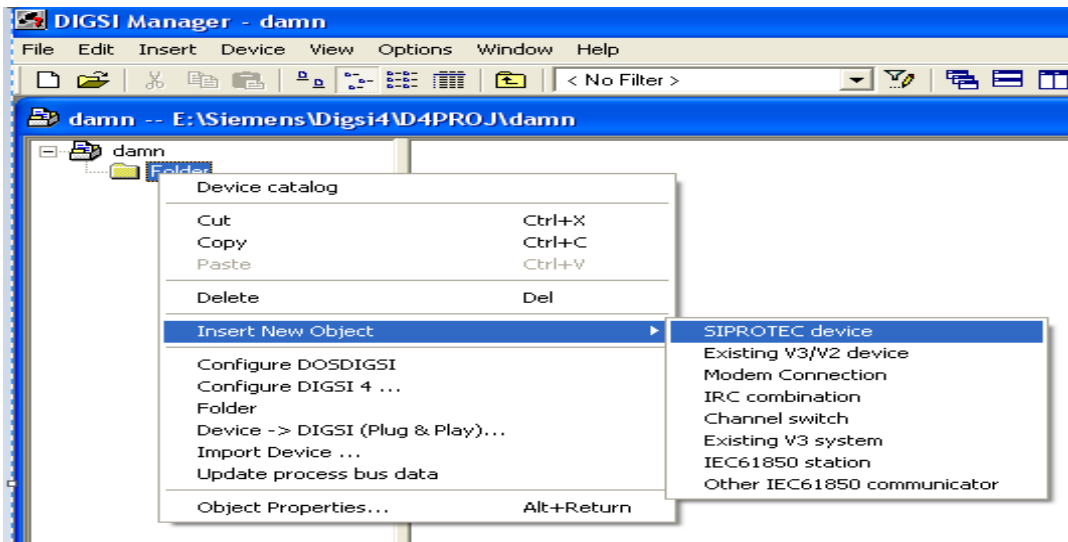
Figure 6.10: Digsi Manager Canvas

The selection brings up a pop-up dialogue box "Device catalog". This allows for a selection the exact IED model required in the substation. In the case of this study the IED 7SD533 is selected note Figure 6.11.
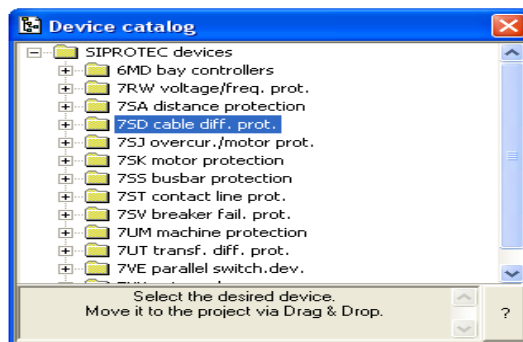
Figure 6.11: Device Catalogue

The selection further provides various models of the IED. The selection must match the IED in the substation; this also implies the correct version of the IED. Left click on the "V4.6" as per Figure 6.12.
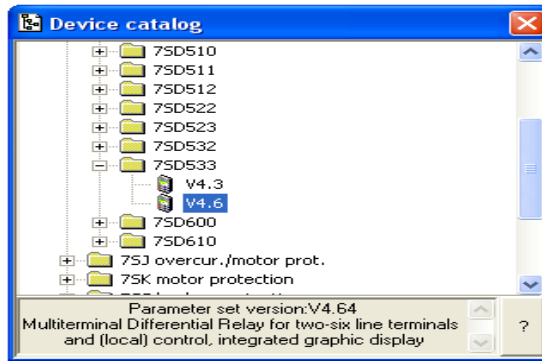
Figure 6.12: Device Catalogue

The selection brings about the SIPROTEC device properties requesting the order number (MLFB) of the device as illustrated by Figure 6.13. This is to ensure the software template matches the hardware of the IED.
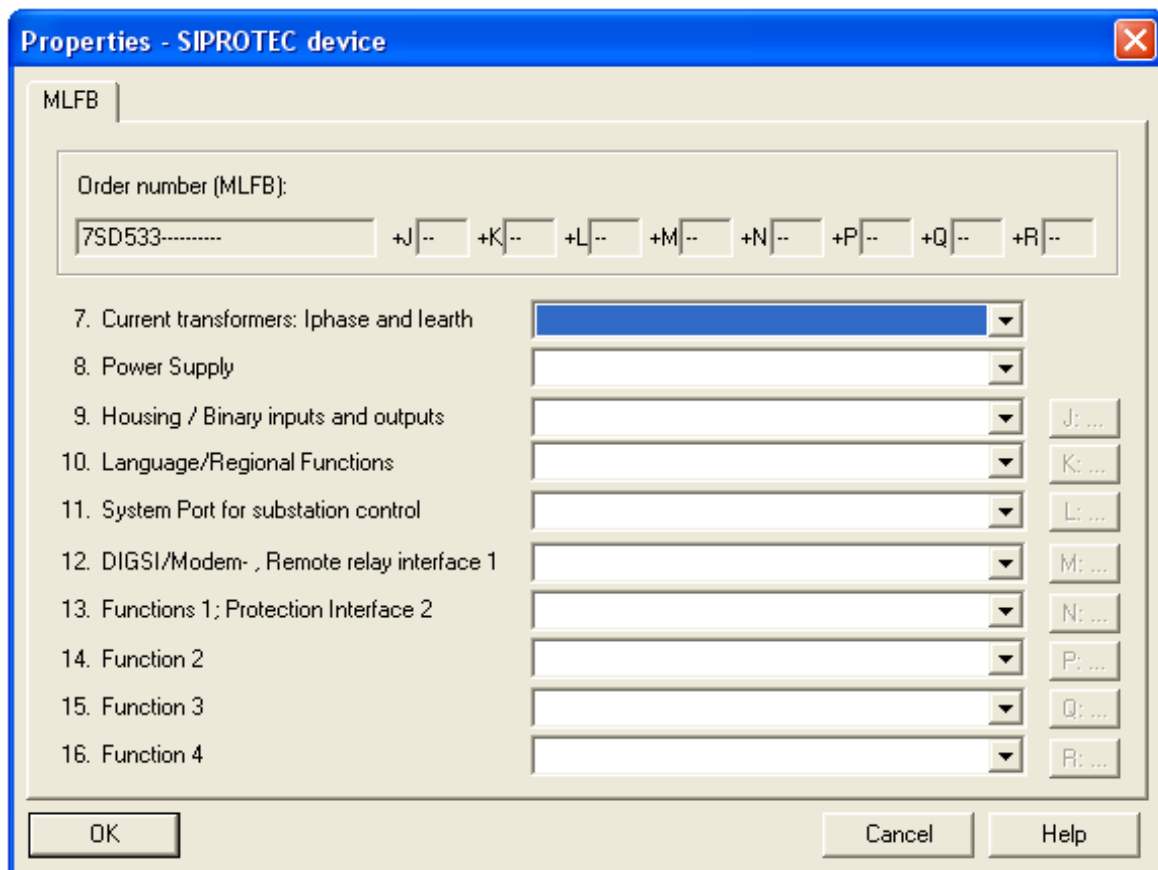
Figure 6.13: Device Specifications

The order number must be entered as shown below. Left click on "OK" on completion as per Figure 6.14
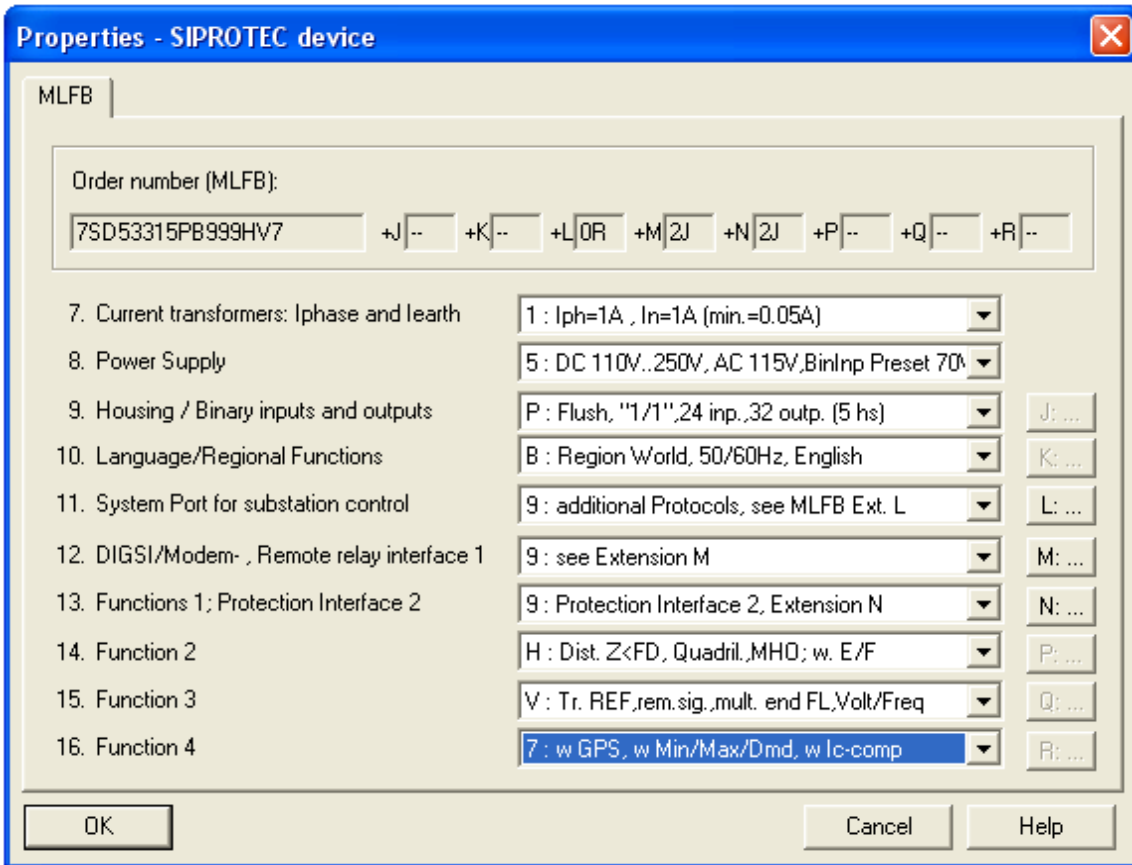
Figure 6.14: Device Specifications

The program returns to Digsi Manager; select the device that has just been inserted into the substation. Right click the inserted device and select configure DIGSI 4 as per Figure 6.15.
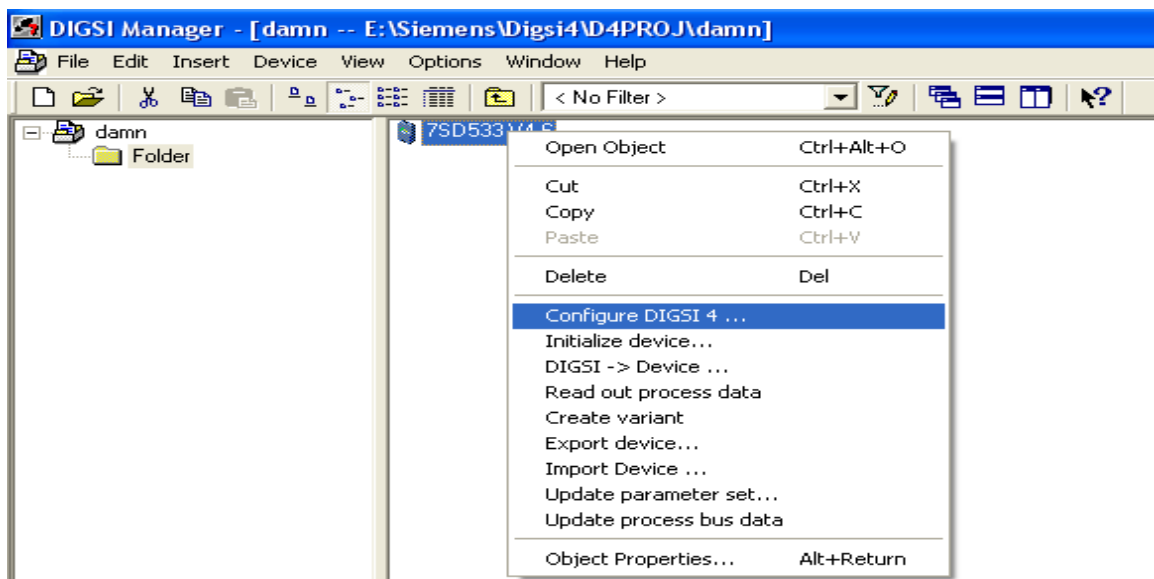
Figure 6.15: Digsi Manager with Device

The configure Digsi 4 pop-up dialogue box appears as per Figure 6.16. The IP of the personal computer (PC) needs to be inserted and the subnet mask too. Ensure the IP is within the subnet of the IED. On completion left click "OK" to proceed.
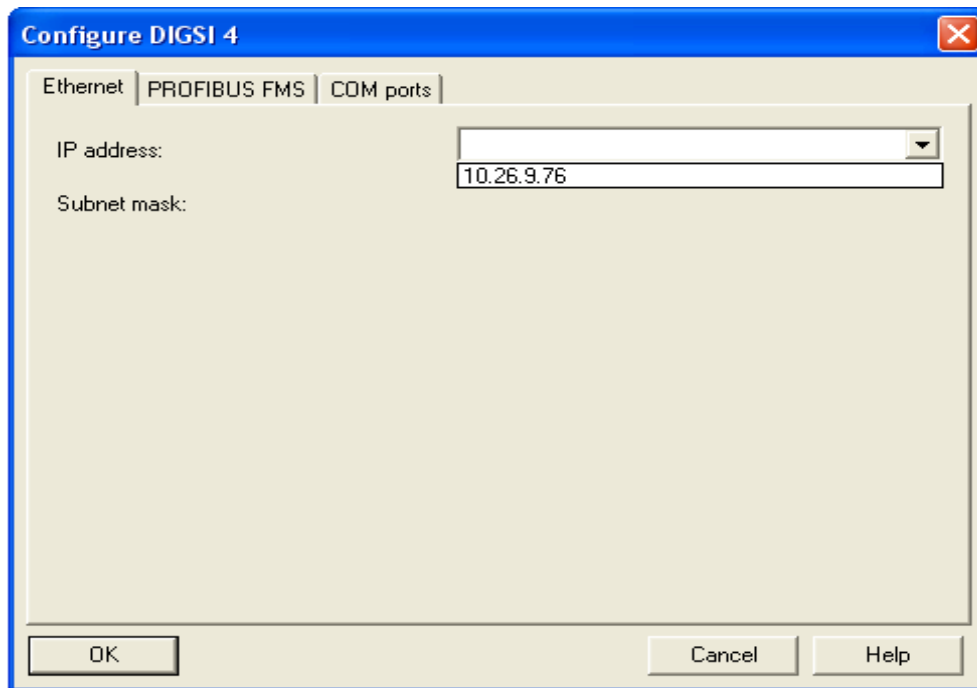
Figure 6.16: Port Communication Settings

6.3.3.3 Configure the logic

To configure the logic select the SIPROTEC device and right click as per Figure 6.17. On pop up menu select "open object".
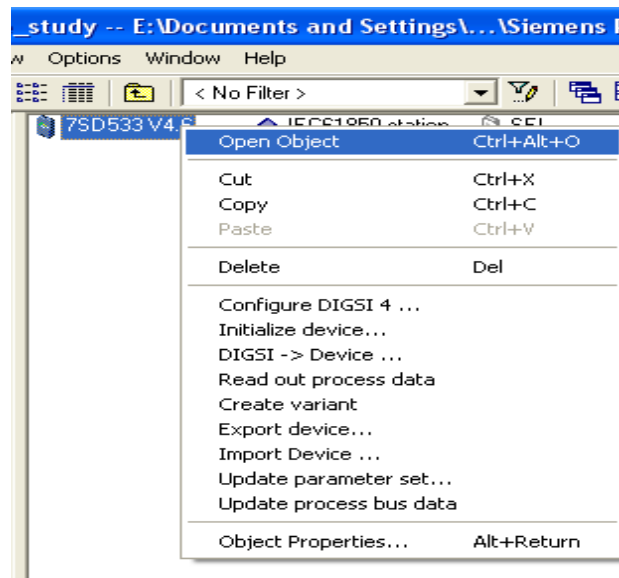
Figure 6.17: Device Menu

On selecting "Open Object" a pop dialogue box appears. This offers the type of communications to device which are as follows:(as per Figure 6.18)

- Offline – opens settings files on the PC.

- Direct – opens settings files on the SIPROTEC device

- Modem Connection

- Ethernet - opens settings files on the SIPROTEC device

- Select "Direct" to access setting files on the SIPROTEC device.
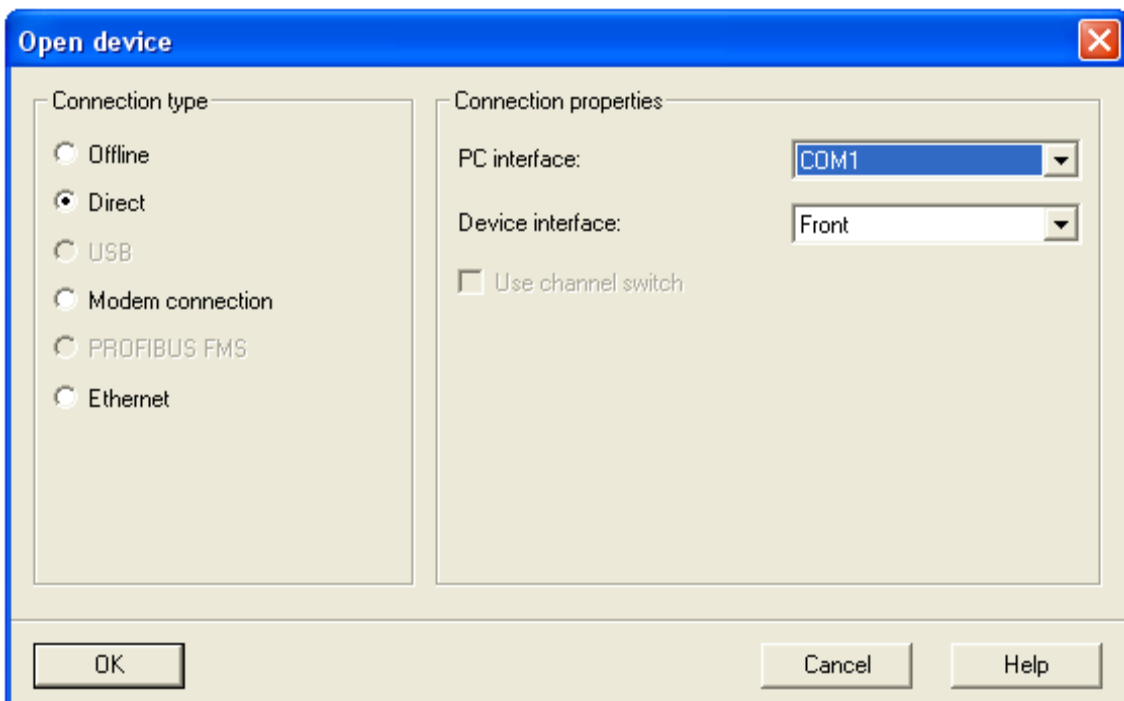
Figure 6.18: Device communication type

This brings settings, annunciation, measurement, oscillographic records, control and test files as shown in Figure 6.19. The next step is to double click on "Settings".
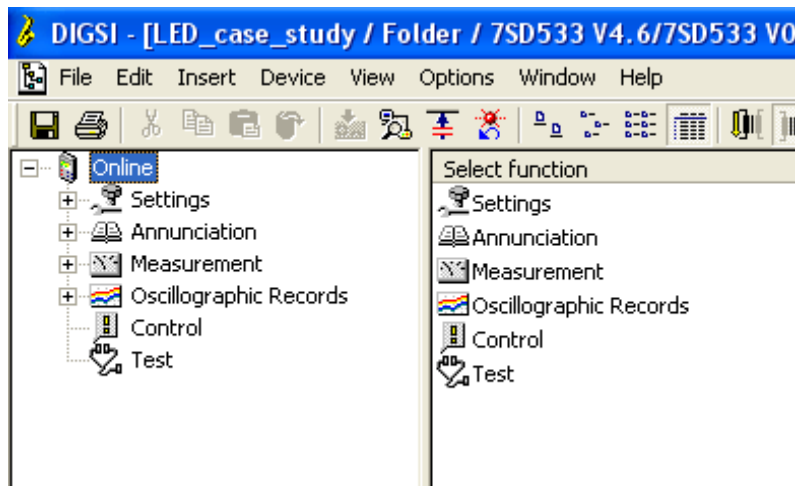
Figure 6.19: Device Settings Hierarchy

After accessing the settings, the sub-settings files appear as per Figure 6.20. The sub-settings that are of interest are I/O (configuration matrix) and Continuous Function Chart (CFC) programming. First click on configuration matrix in order to start with setting up the logic required.
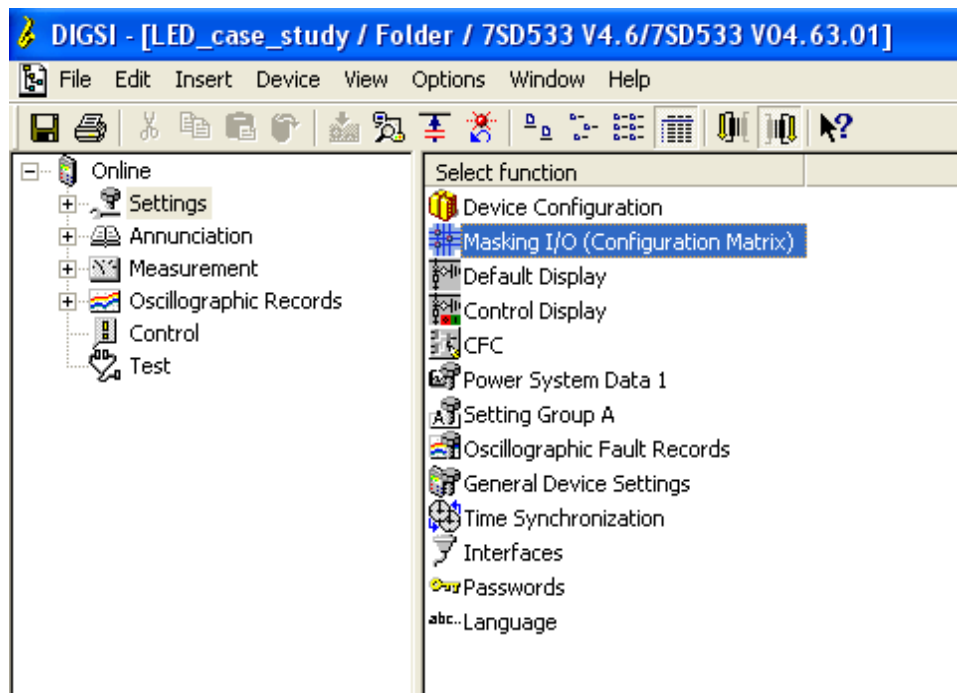
Figure 6.20: Device Settings Files

The matrix configuration provides interconnections for all functions in the SIPROTEC device. The matrix top vertical headings are as follows: (as perFigure 6.21)

- Information
  - Number – for identifying the information and its description in the device documentation.

140

- o Display text – information text for display unit of a SIPROTEC 4 device
- o Long text – Detailed description of the information
- o Type – Detailed specification of the information
- Source
  - o BI –Binary Input
  - o F – Function Keys
  - o S - System Interface
  - o C - CFC
- Destination
  - o BO – Binary Output
  - o LEDs
  - o B – Buffer
    - ▪ O – Operational Indication Buffer
    - ▪ T – Trip Log
  - o S – System Interface
  - o X – System Interface extended
  - o C – CFC
  - o D – Display
    - ▪ C – Control Display
    - ▪ D – Default Display
  - o CM – Control Menu

Figure 6.21: Configuration Matrix

Right click on the left side of matric where there are headings for the various functions. This will bring up a pop up menu to select Insert Group as per Figure 6.22

141
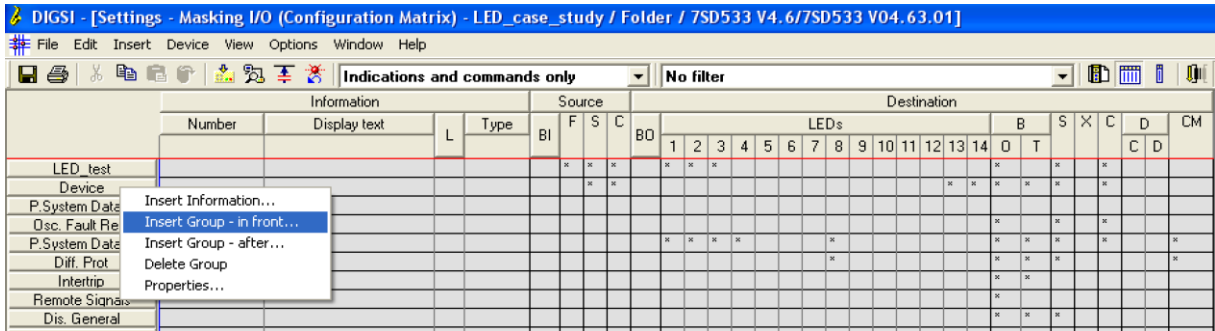
Figure 6.22: Configuration Matrix

A pop up dialogue box appears which is for naming the group as per Figure 6.23. Name the group and click "OK".
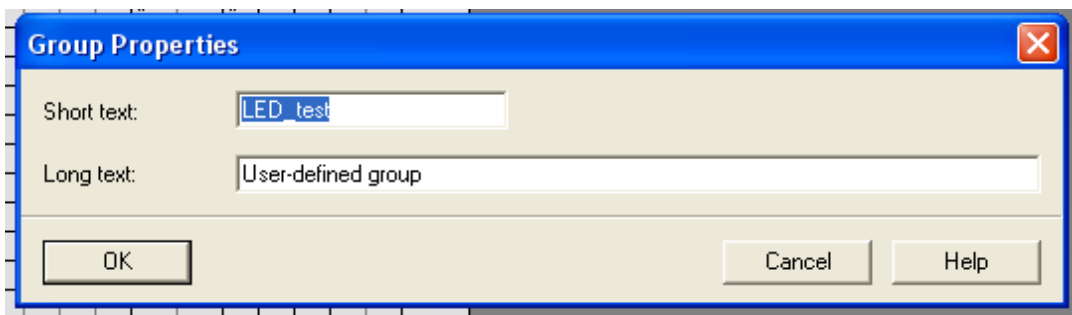
Figure 6.23: Group naming interface

On clicking "OK" the configuration matrix appears showing the name of the group of interactions. On the group that was recently being created right click inserts new interactions/interfaces. A pop-up menu with "Insert Information" appears; then click on the item to proceed as shown in Figure 6.24
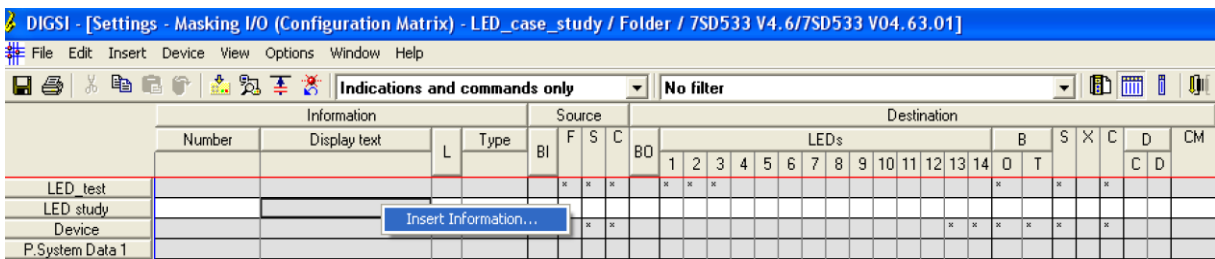
Figure 6.24: Configuration Matrix

On completion an information catalog appears as per Figure 6.25. Click on annunciation or relevant folder.

142
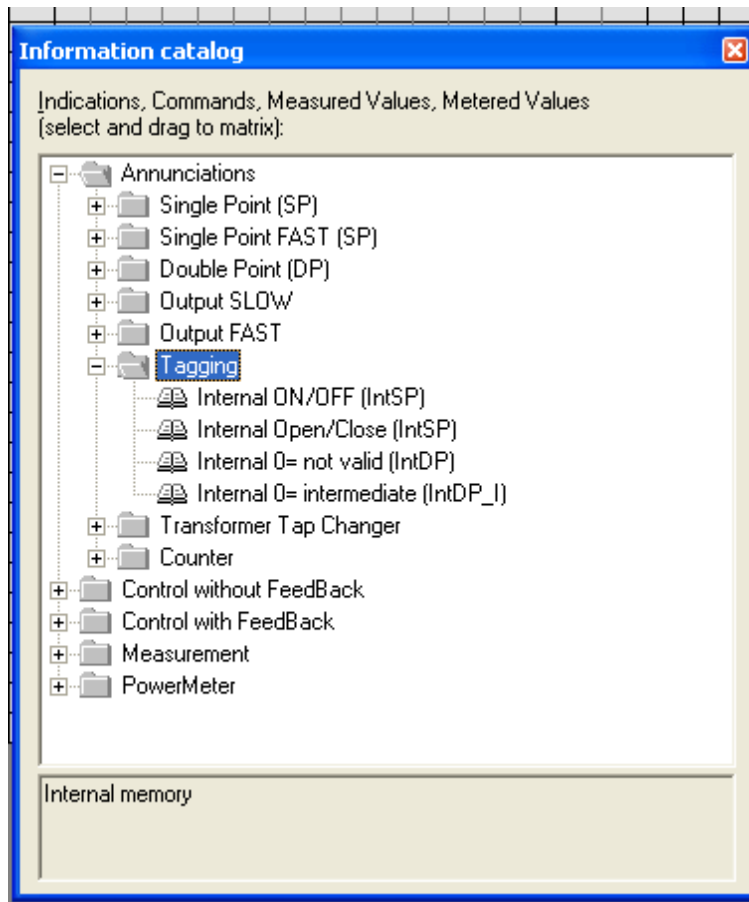
Figure 6.25: Information Catalogue

The Figure 6.26 illustrates the information that has been added. Repeat the procedure to populate the group with the required information.

143
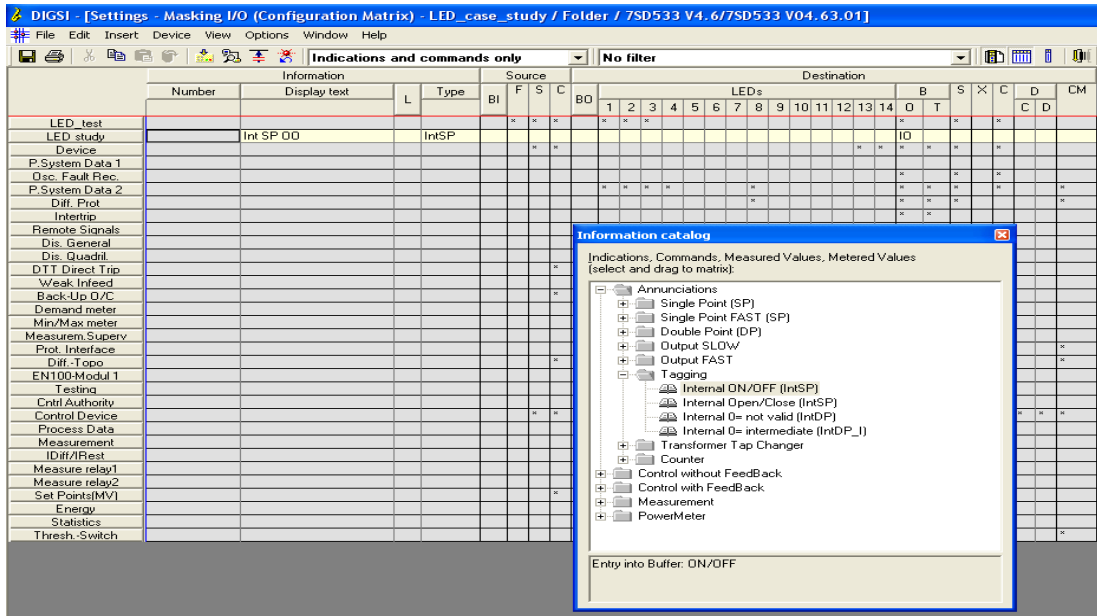
Figure 6.26: Configuration Matrix and Information Catalogue

The Figure 6.27 illustrates the information added and renamed to better illustrate the case study.

Figure 6.27: Configuration Matrix

On completion of inserting the information required for the study as shown in Figure 6.27. What is required is that interconnections are defined as per source and destination. The source to switch on the LED's is function 1 and the reset is function 2. Click on F to select source to switch on LED's. A pop-up menu will show all the function keys, select the appropriate function key. Select F1 and F2 destination to CFC to enable a flip flop logic operation as indicated in Figure 6.28.

144
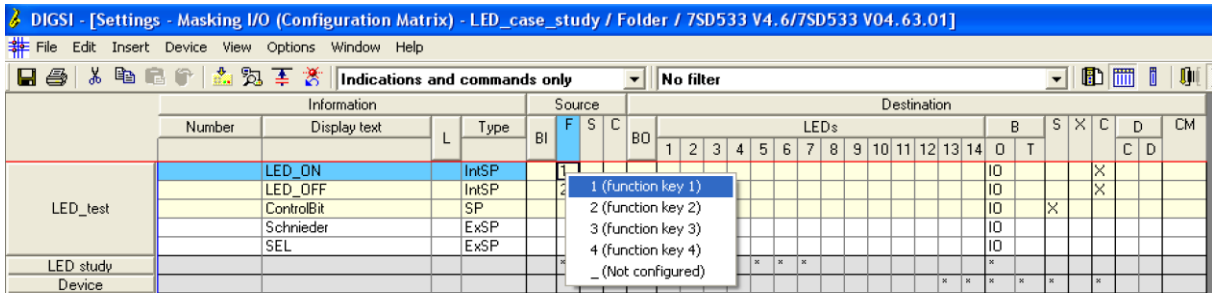
Figure 6.28: Configuration Matrix Function Key Selection

The output of the flip flop logic operation source is from CFC. The destination of the flip flop is LED 1, 2 and 3 and the system interface (GOOSE messaging) is as per Figure 6.29.
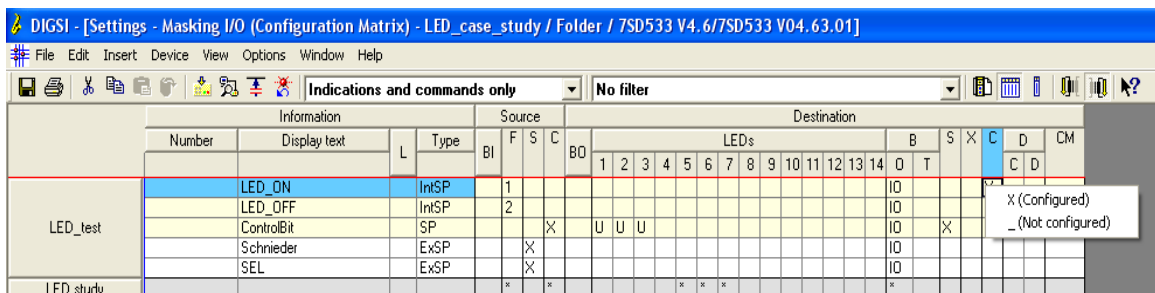
Figure 6.29: Configuration Matrix CFC Selection

The Figure 6.30 illustrates the source of the flip-flop output which is from the CFC and configuration/mapping thereof.
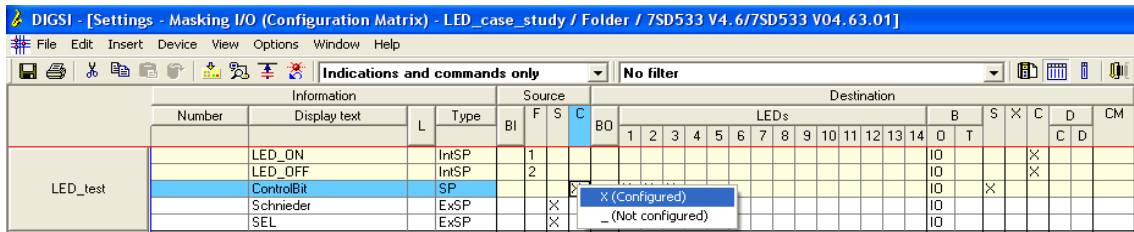
Figure 6.30: Configuration Matrix Control Bit Source Selection

The flip flop output is to trigger 3 LEDs (which is also a destination) and this is done by right clicking and mapping the said LEDs as per Figure 6.31.
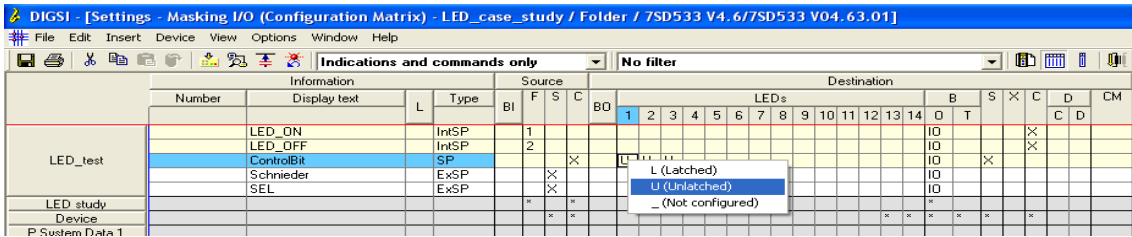
Figure 6.31: Configuration Matrix for LED mapping

The destination of the flip flop output is the system interface which is for GOOSE message publication. To map/configure the destination right click and select 'Configured' as illustrated in Figure 6.32.
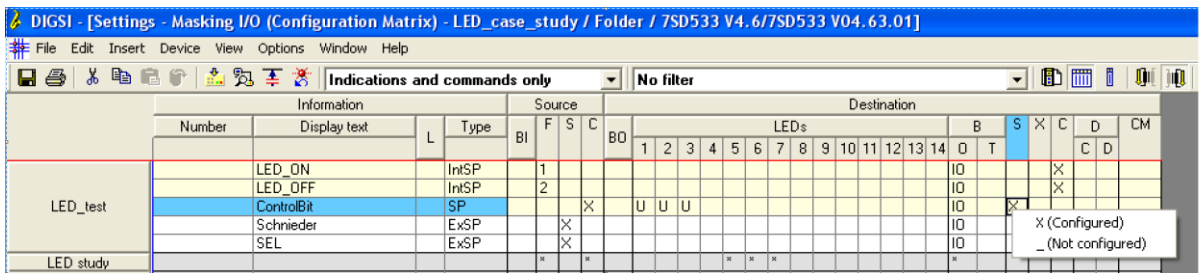
Figure 6.32: Configuration Matrix

A pop-up dialogue box will pop up when configuring a system interface as per Figure 6.33. Insert the name of the GOOSE message and click "OK" on completion.
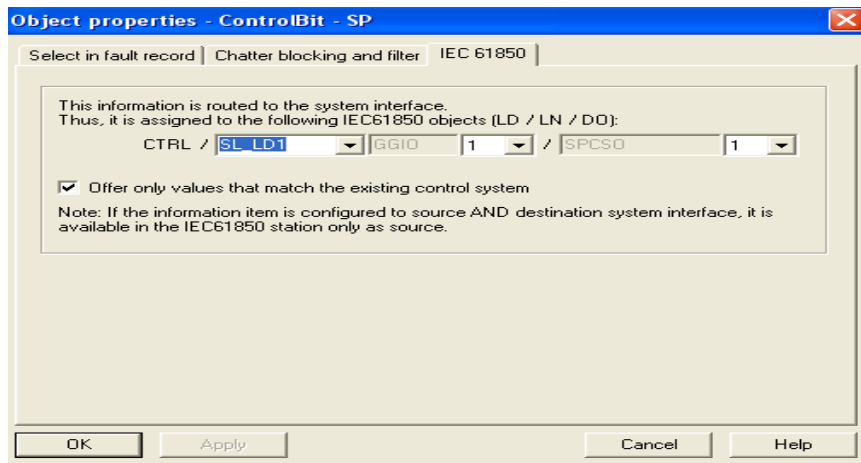
Figure 6.33: GOOSE Message interface

On completion of configuring all system interfaces; close the matrix configuration. The configuration matrix shall be as shown in Figure 6.34.

Figure 6.34: Configuration Matrix Completed Configuration

The next step is complete the flip flop logic right click on CFC and select "Open object" as per Figure 6.35.
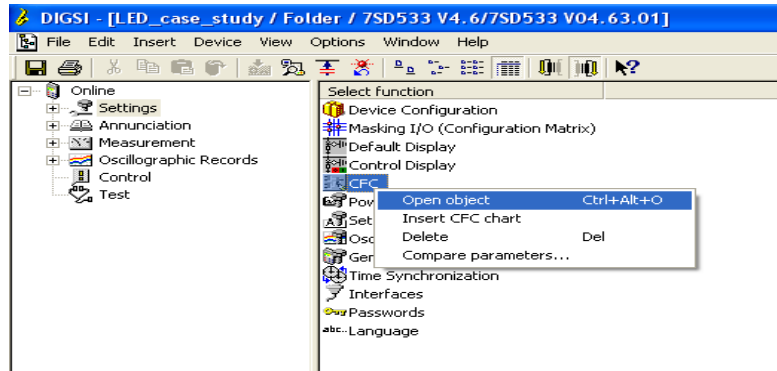
Figure 6.35: Device Settings Files

A clean canvas will appear and under logical functions select S&R (set and reset) function. Right click on S and pop-up menu appears. Select interconnections address this is to enable selection for the correct information to function as set for the flip flop logical operation as per Figure 6.36
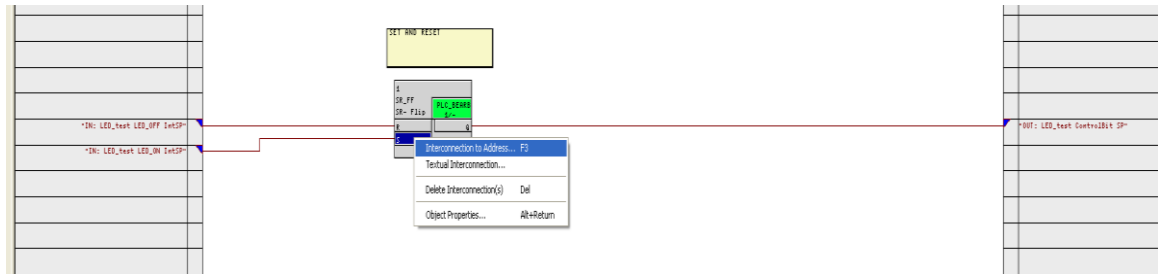
Figure 6.36: Device Set and Reset Logic (CFC)

On selection of interconnection to the address; a pop-up menu appears as per Figure 6.36. A selection of the appropriate property is required to map out the logic; a pop up dialogue box appears as shown in Figure 6.37. Selection for Set the LED_ON (Display Text) must be done and for Reset the LED_OFF (Display Text) must be selected; thus mapping it to the configuration matrix as per Figure 6.34.

147
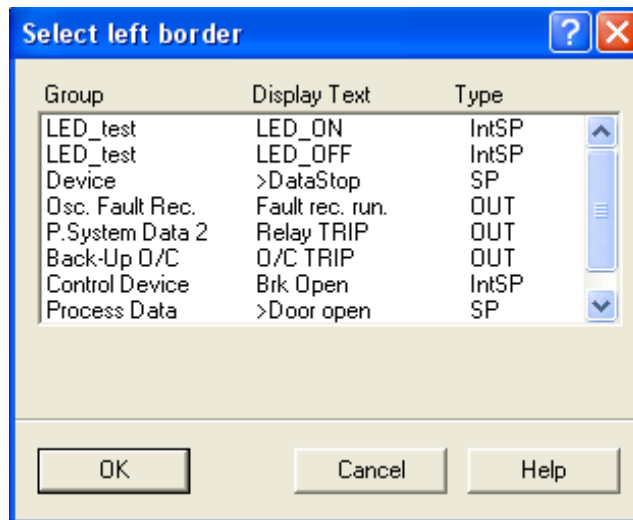
Figure 6.37: Logic input selection list

On completing the mapping of the logical function with all the required properties. Compile the logic operation and close CFC interface and load settings to the device.

6.3.3.4 Configure GOOSE message

The next step is to configure GOOSE messaging. Right click on the canvas of the system configurator. A pop-up menu appears and select IEC 61850 station as shown in Figure 6.38. This provides the ICD file within the IEC 61850 system configuration tool.
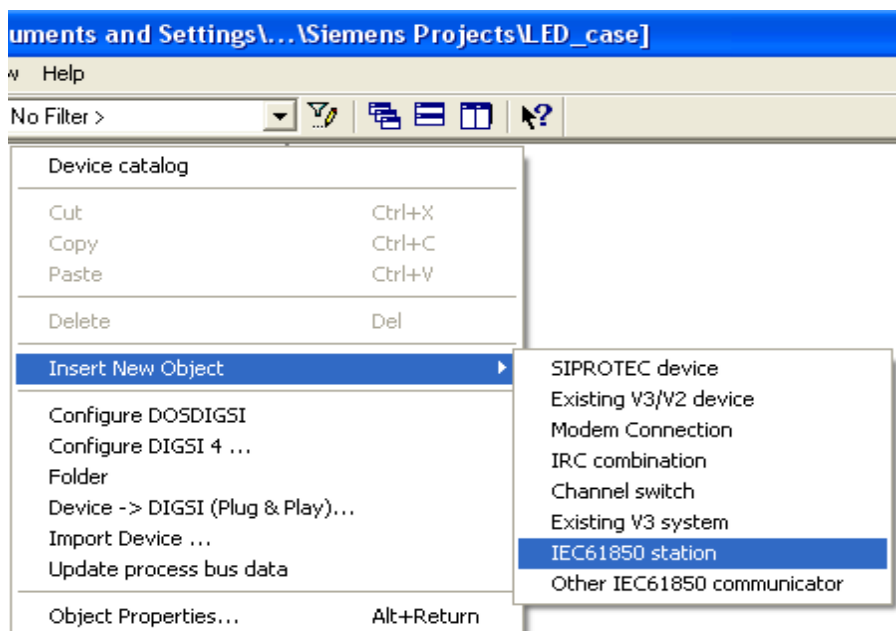
Figure 6.38: Inserting IEC 6850 Station

An IEC 61850 station is inserted alongside the SIPROTEC device as illustrated in Figure 6.39.
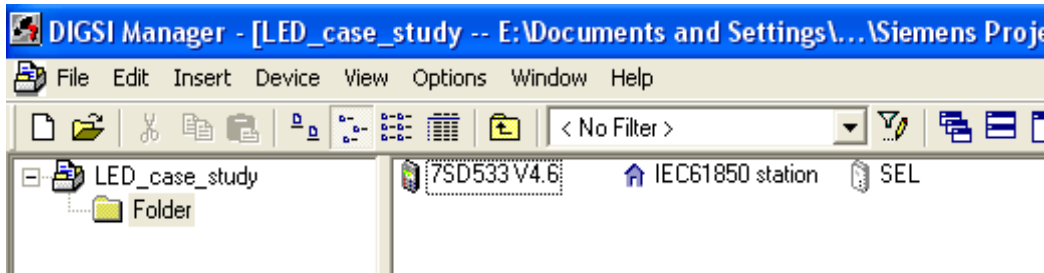
Figure 6.39: Digsi Manager Canvas

Right click on the canvas of the DIGSI manager and select "Insert New Object" and select other IEC 61850 communicator as per Figure 6.40.
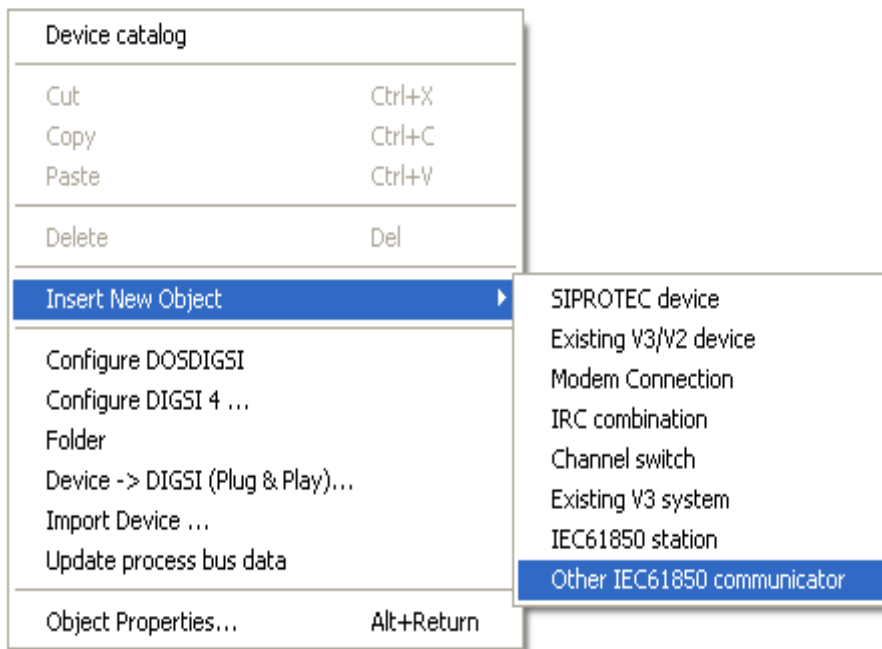
Figure 6.40: Importing third party ICD File

A pop-up dialogue box appears where a selection of SEL ICD files can be made. Click "OK" on completion as shown in Figure 6.41
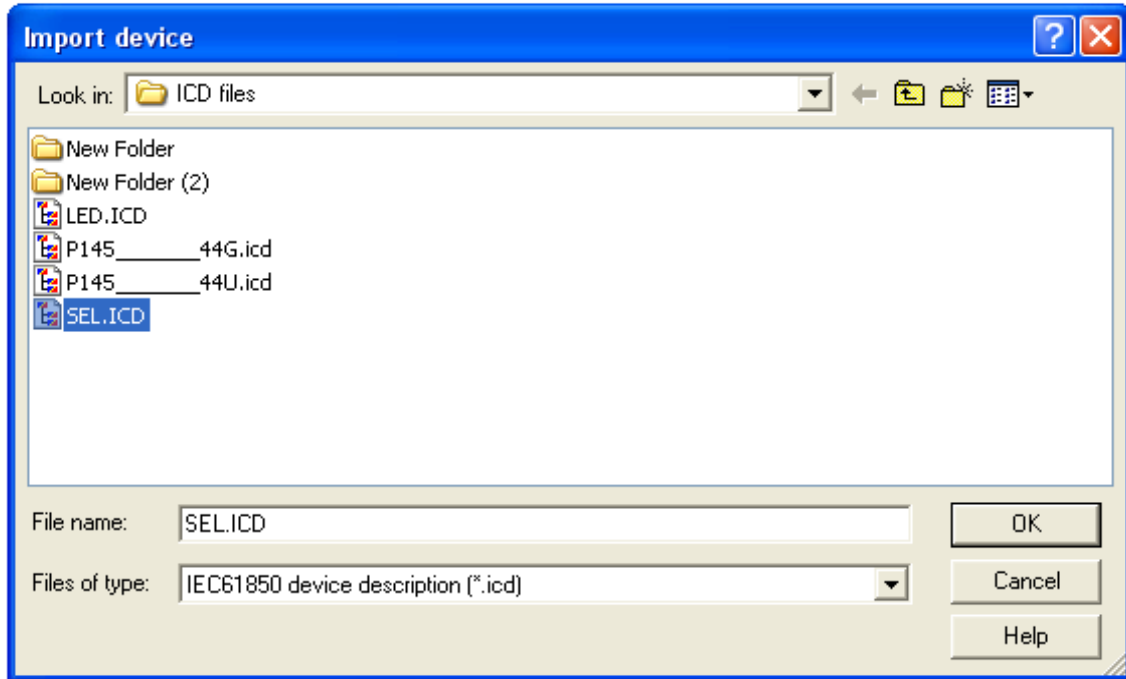
Figure 6.41: ICD File Selection

The IEC 61850 communicator appears alongside the IEC 61850 station. Right click on the IEC 61850 station and on the pop-up menu select object properties as per Figure 6.42.
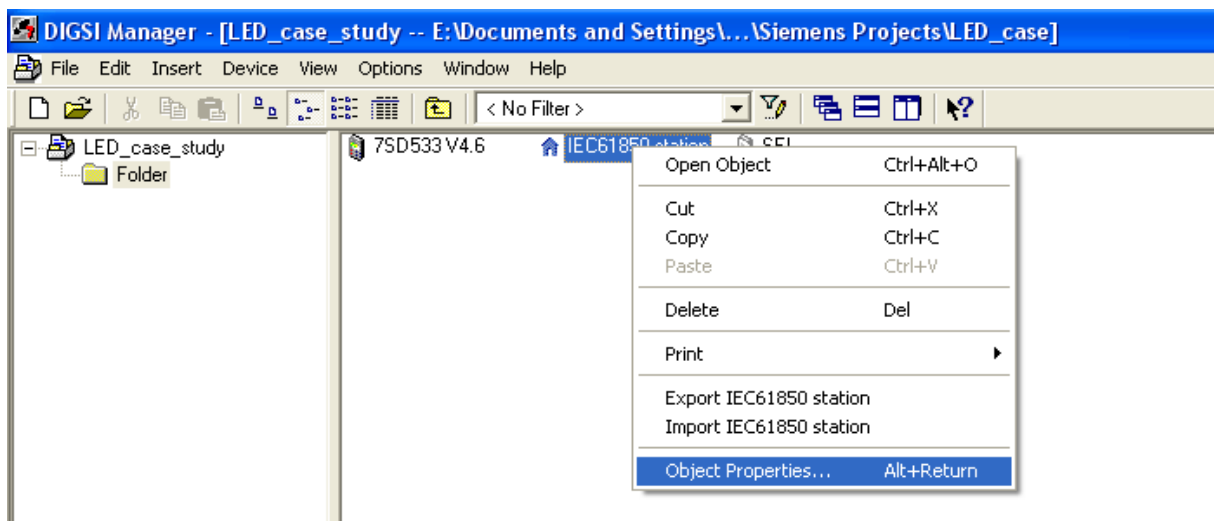
Figure 6.42: Digsi Manager Canvas with SEL ICD file

A dialogue box appears and select communicator tab as per Figure 6.43
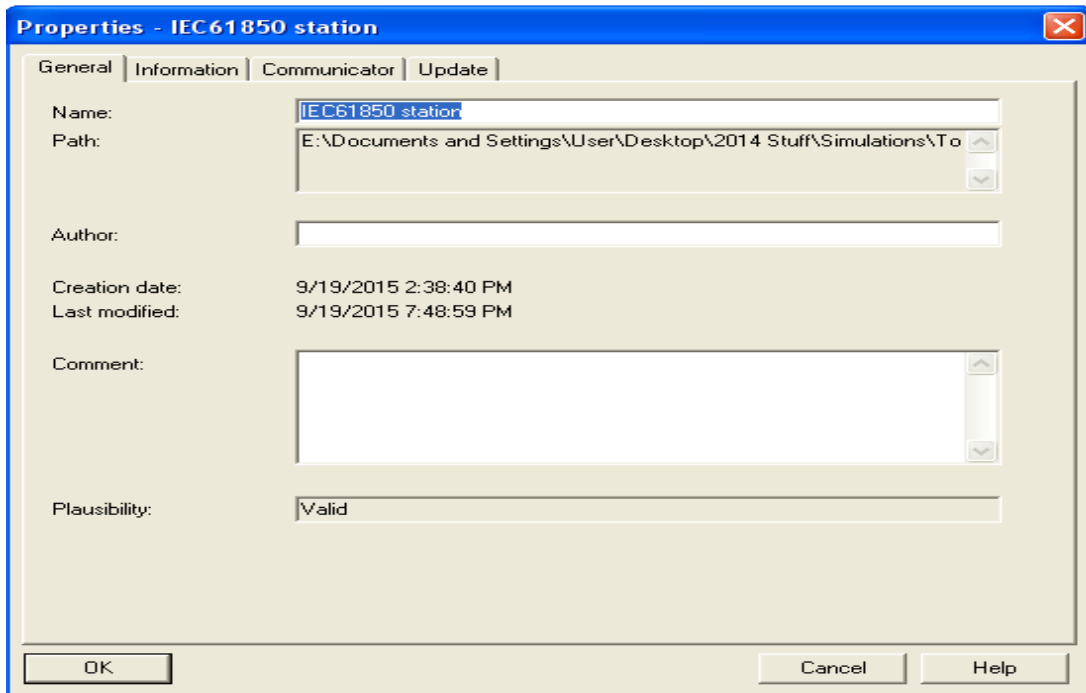
Figure 6.43: IEC 61850 Station Properties

Click on all available IEC 61850 devices and click on "ADD" and click on "OK". Click on update tab as shown in Figure 6.44.
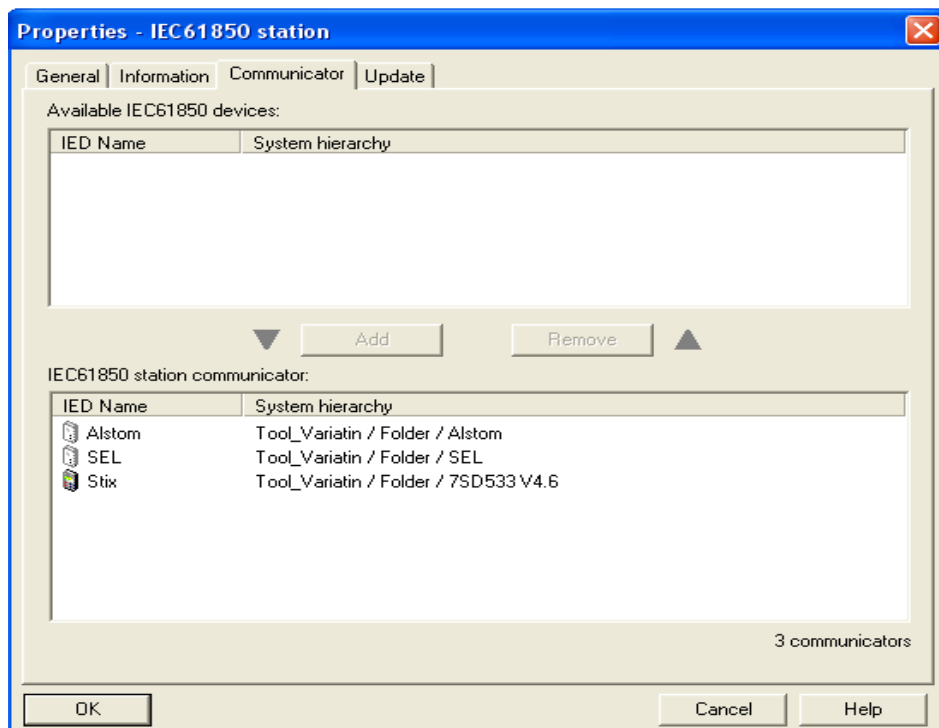
Figure 6.44: Adding SCL Files to IEC 61850 Station

Click on "Update all parameter sets" click on "OK".as per Figure 6.45
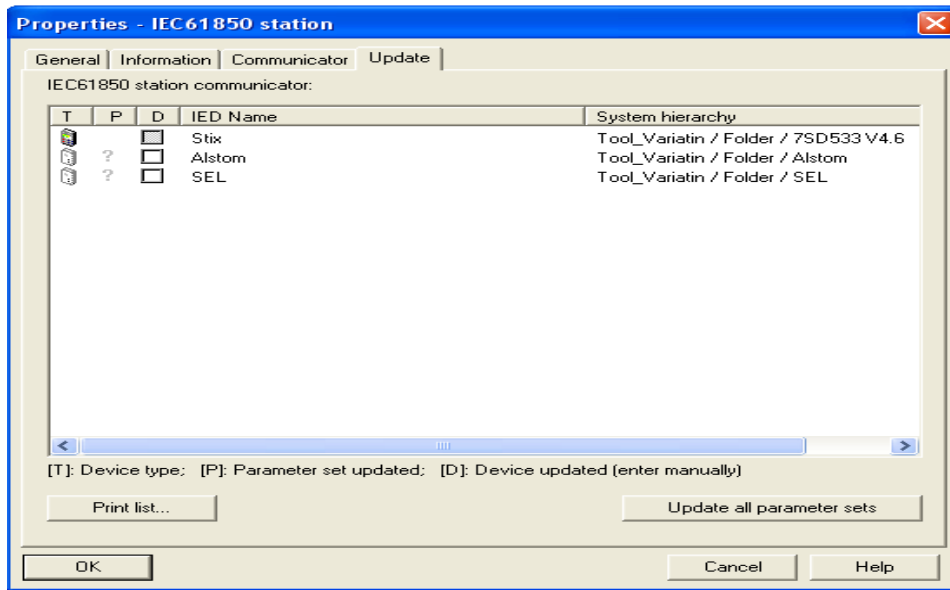
Figure 6.45: Updating SCL files

Right click on the IEC 61850 station and select "Open Object" as shown in Figure 6.46.
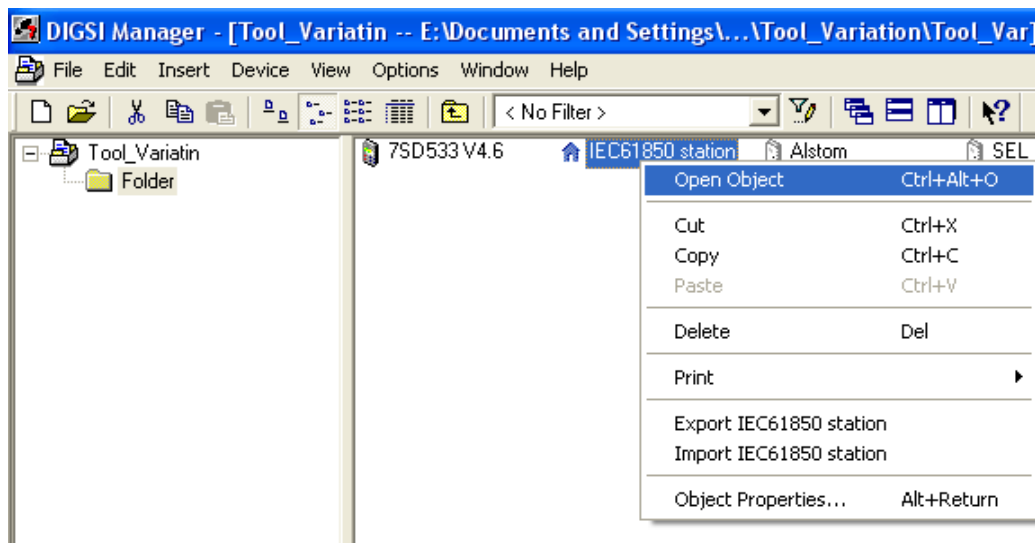
Figure 6.46: Opening IEC 61850 Station

This opens the DIGSI system configurator. Click on "Link" as shown in Figure 6.47
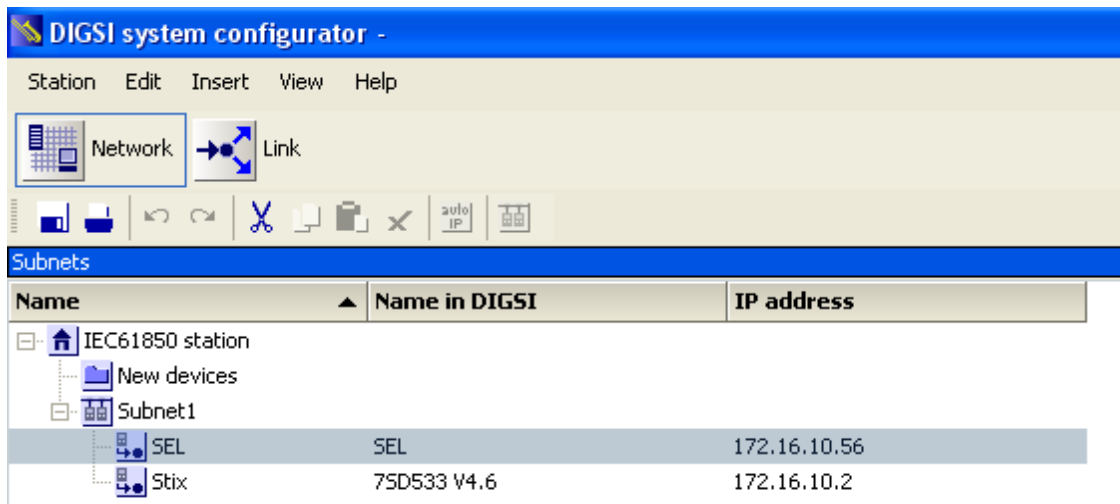
Figure 6.47: Digsi Sytem Configurator (IEC 61850)

This brings about the interconnections page. This page allows for GOOSE messaging mapping. Select from source window the publishing device and select the GOOSE message and drag to the interconnections canvas. Place the GOOSE message on the source labelled publisher. Select from the destination window the device that will subscribe to the publisher and drag and drop it in the destination interconnections canvas labelled subscriber as per Figure 6.48.
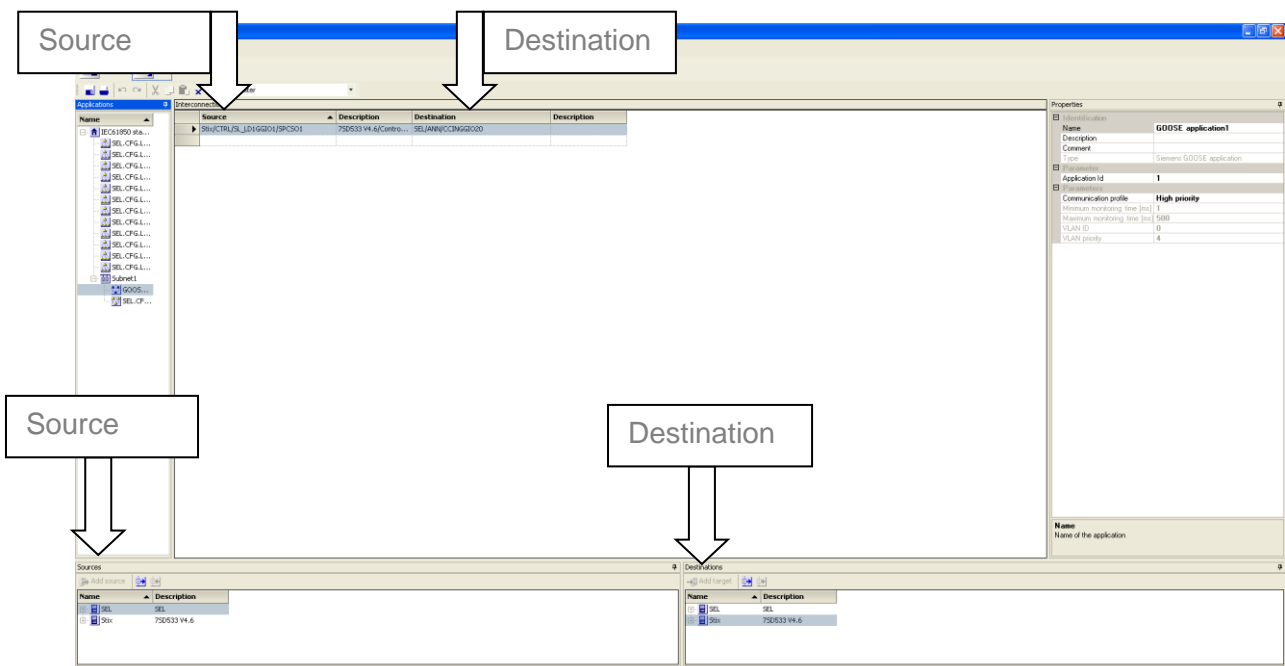
Figure 6.48:GOOSE configuration

Save and close the DIGSI system configurator and GOOSE messaging configuration is complete; then the load settings to the Siemens device.

6.3.4 SEL IED Configuration using SEL Acselerator Quickset and Architect

6.3.4.1   Setting up the system (Quickset)

First start up the Quickset software and landing page appears as per Figure 6.49 and select "New" to proceed.

Figure 6.49: Ascelerator Quickset landing page

A dialogue box will appear in Figure 6.50 and this enables the selection of a device (IED) for which settings are required. Insert the device part number as shown in Figure 6.50. On completion of selecting a device click "OK".
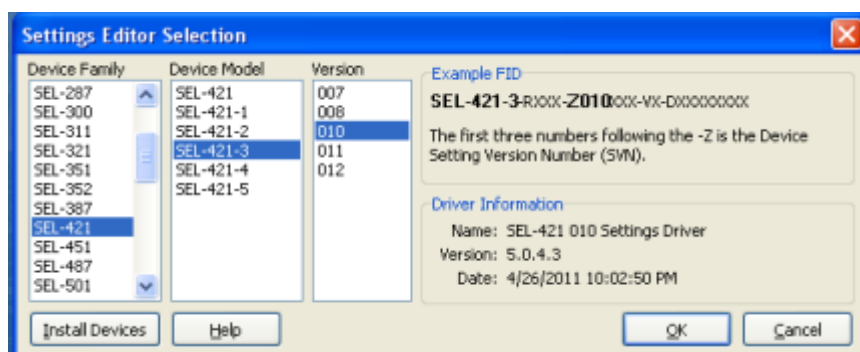
Figure 6.50: Settings editor selection

This will bring about another dialogue box as per Figure 6.51. The part number required is essential for the specifications of the device as the same number is the ordering number for the device. The part number can be found on the device itself or

the ordering documentation. Match the part number on the dialogue box via the drop down menus for each characteristic of the device and on completion click "OK".
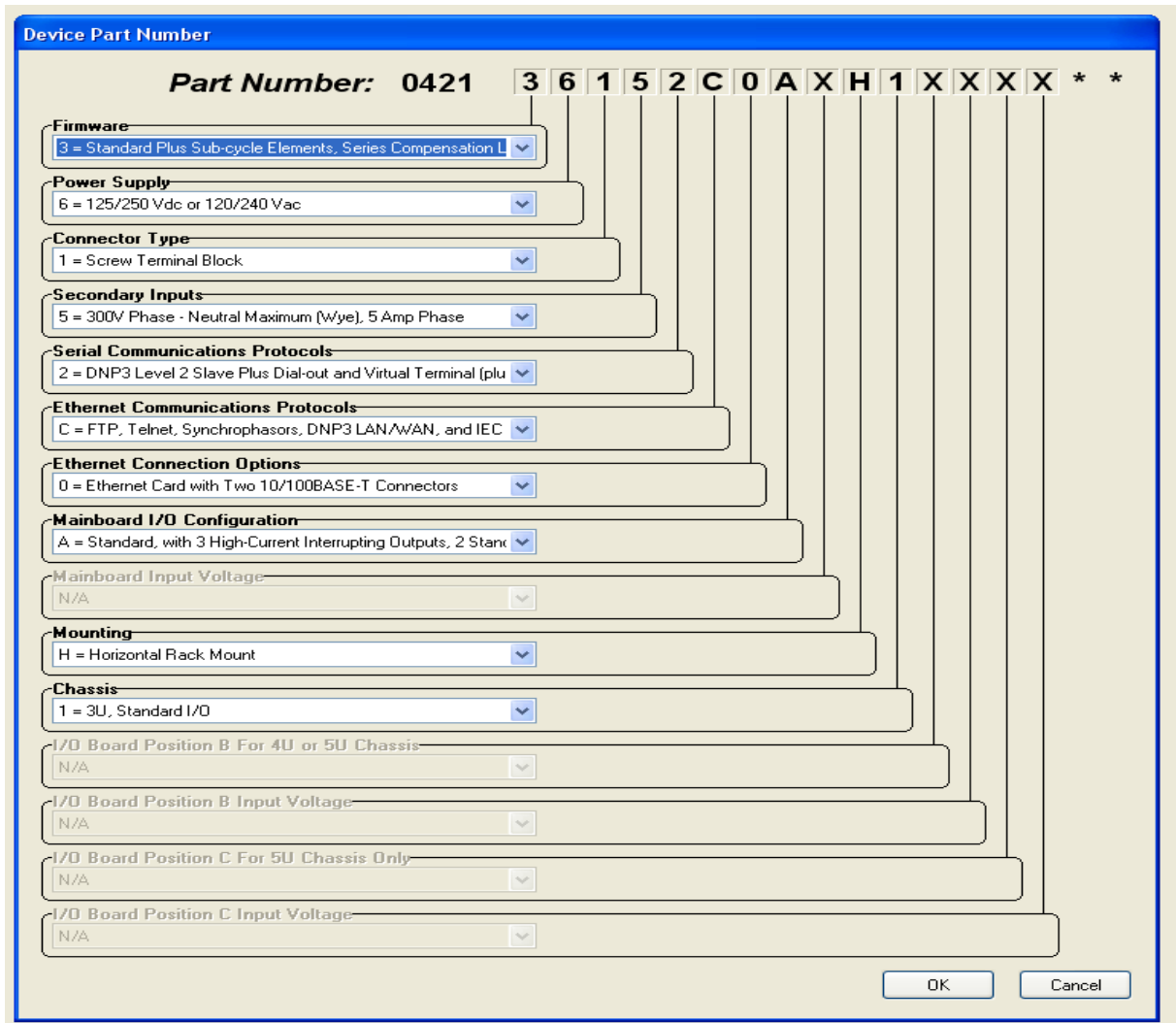
Figure 6.51: Device part number

This opens the settings editor (main screen) where various settings files can be opened and edited as required as shown; in Figure 6.52.
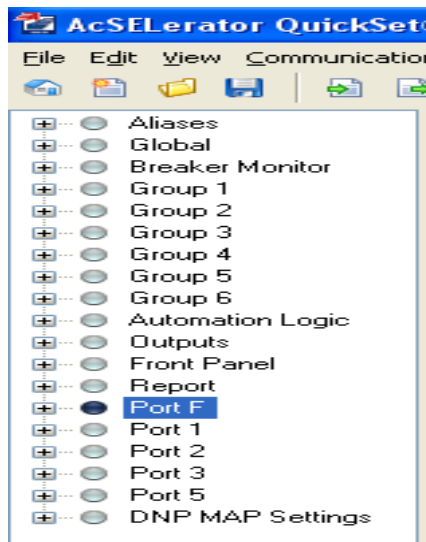
Figure 6.52: IED settings file hierarchy

The next step is to connect to the hardware component the IED. Click on communications which is located on the settings editor's toolbar. On the drop down menu that appears select connect as illustrated in Figure 6.53.
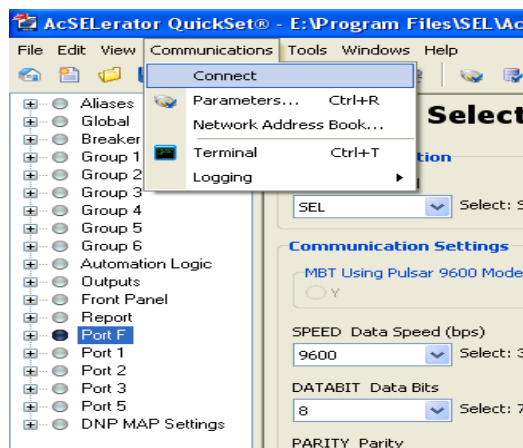
Figure 6.53: Settings editor

A dialogue box appears where the type of connection and subsequent communication parameters can be set as per Figure 6.54. On completion of this task select "OK".
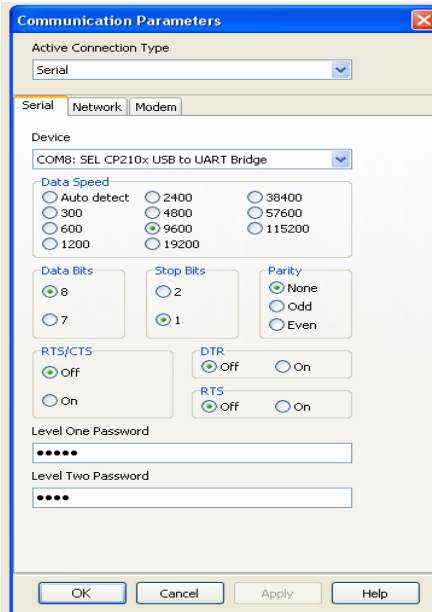
Figure 6.54: Communication Parameters

This connects the device to the configuration tool and allow reading and writing/load settings.

6.3.4.2 Configure logic

The next step is to configure the required logic for the device as per the case study. Select "Group 1" settings file and expand to reveal sub-settings files. Select "Graphical Logic 1" to access the graphical settings file as per Figure 6.55.
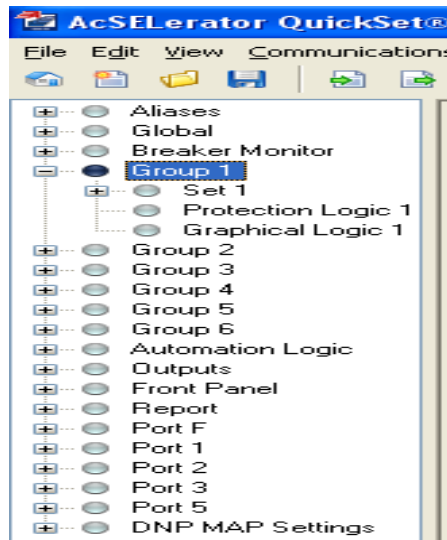
Figure 6.55: Settings file

This opens the graphical editor. The case study calls for SEL device to subscribe to Siemens device GOOSE message. On receiving the GOOSE message; three LEDs should illuminate and the SEL device should publish a GOOSE message. The

GOOSE message input to the SEL device is "CCIN00". The output is the LEDs namely "T1_LED", "T2_LED" and "T3_LED". To publish a GOOSE message an output is required which is "CCOUT1" and "T16_LED" is set up to monitor the GOOSE message status. The graphical representation of the SEL device logic functionality is shown in Figure 6.56
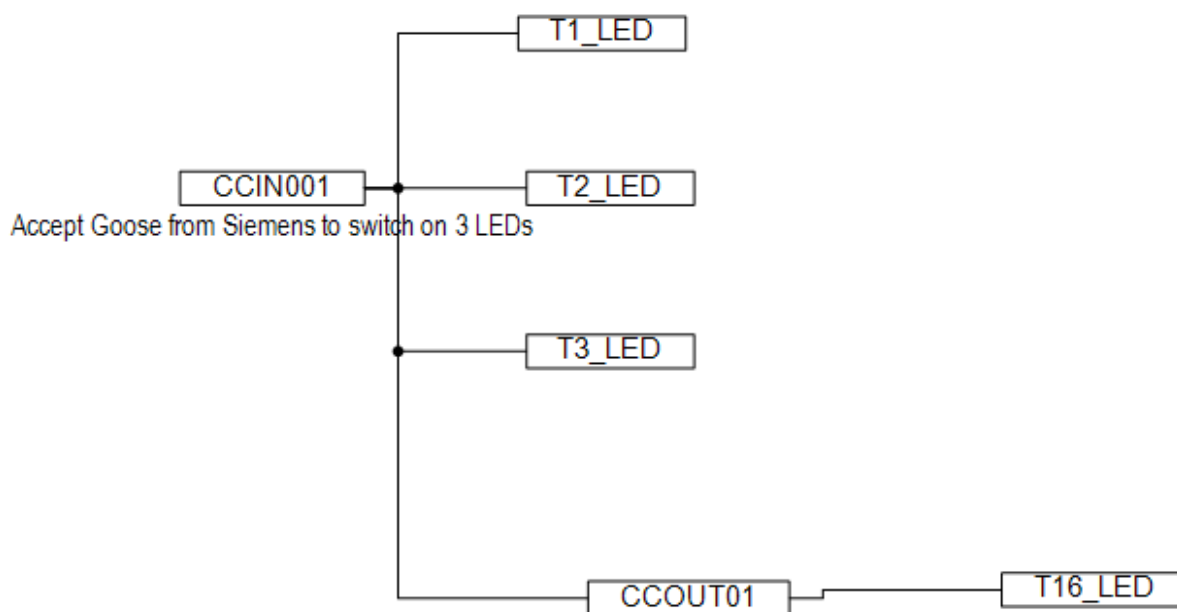
Figure 6.56: Graphical Representation

On the Graphical editor's toolbar select "Compile" to ensure the logic valid and detect if any clashes are present. This completes the logic configuration and the next step is to setup the GOOSE messages. The setting can be loaded to the device.

6.3.4.3 Configure GOOSE message (Architect)

Double click on Architect logo to start the configuration tool. This opens up the landing page of the package. The landing page is made up by four windows namely: (as per Figure 6.57)

- Project Editor – house the SCL files that require communication configurations done
- IED Palette – contains various SEL IED ICD files
- Output – provides information and error messages
- IED settings editor – where editing for the devices occur contains various tabs for communication configurations.

Drag the required IED from the IED Palette into the Project Editor. Select the ICD file in the Project Editor and this will bring up the IED settings editor with the tabs. Select the "*GOOSE Transmit*" tab to start with GOOSE publication. Note that SEL ICD

GOOSE messages (publish) are pre-configured. For the case study use of the default GOOSE message
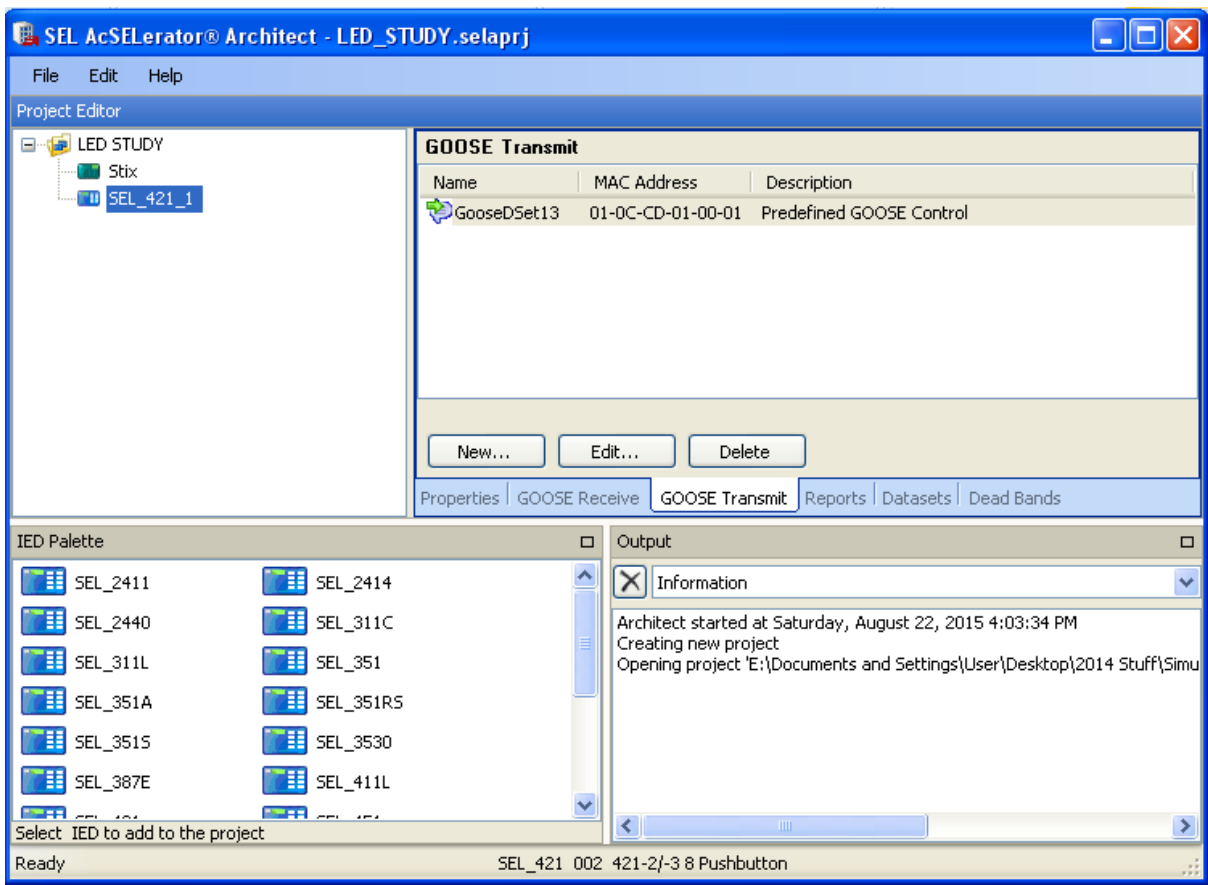
Figure 6.57: IED configurator

The subscription on SEL device is done by selecting the GOOSE Receive tab on the IED settings editor window. The publishing device's CID file would need to be imported into the IED Palette. Select the imported CID and drag into the Project Editor. This enables the SEL device to subscribe to the Siemens device. Select the appropriate dataset or data element and drag into the IED settings editor window to complete the subscription as per Figure 6.58.
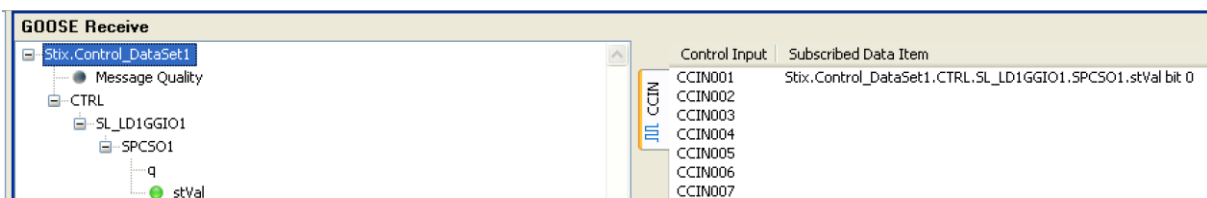
Figure 6.58: GOOSE subscription overview

Further details of GOOSE messages will be discussed on the integration of the entire system in point 6.3.6

159

6.3.5 Schneider IED Configuration using Micom S1 Studio

6.3.5.1 Setting up the system

Double click on S1 Studio icon. On start-up select new this prompts a pop up dialogue box as per Figure 6.59. The dialogue box in the new system is named along with any comments the integrator would like to insert. The dialogue box also indicates the file path and can be altered if need be. Once all information is entered proceed and left click the ok button.
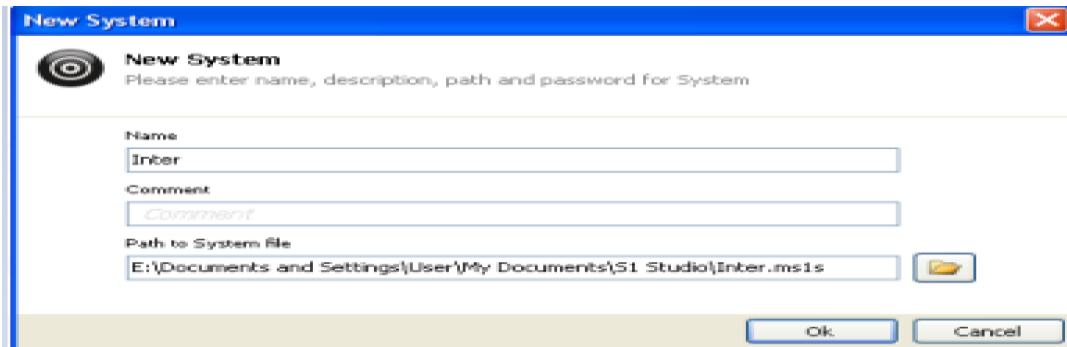
Figure 6.59: System Naming Interface

6.3.5.2 Adding a device to the system

This completes the naming of the system where an IED exists within. With the system created it is needed to insert a device (IED) in to the system. The Figure 6.60 illustrates the expected pop when right click on the system is done. Select new device this is to insert a device into the system.
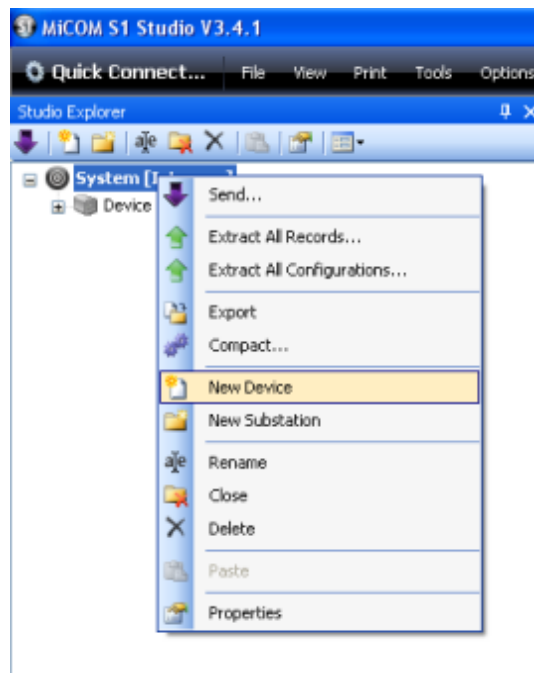
Figure 6.60: Adding a Device

As soon as the new device is selected a pop up dialogue box illustrated in Figure 6.61 appears. The selection is solely dependent on the type of relay looked to be configured in the considered this is P145. Thus our selection is PX40 Series.
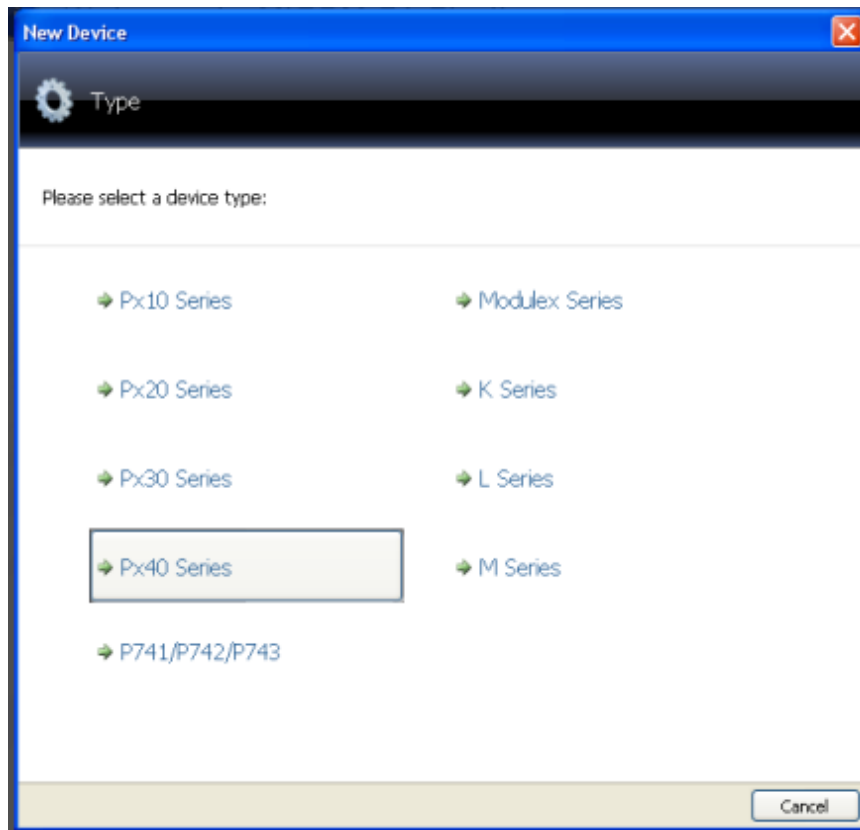
Figure 6.61: Selecting Type of Device

After the selection is made the next step is to select the category of the device. Also note that all devices to configured on S1 Studio require device data models to be downloaded otherwise the S1 Studio cannot configure that particular device as per Figure 6.62.
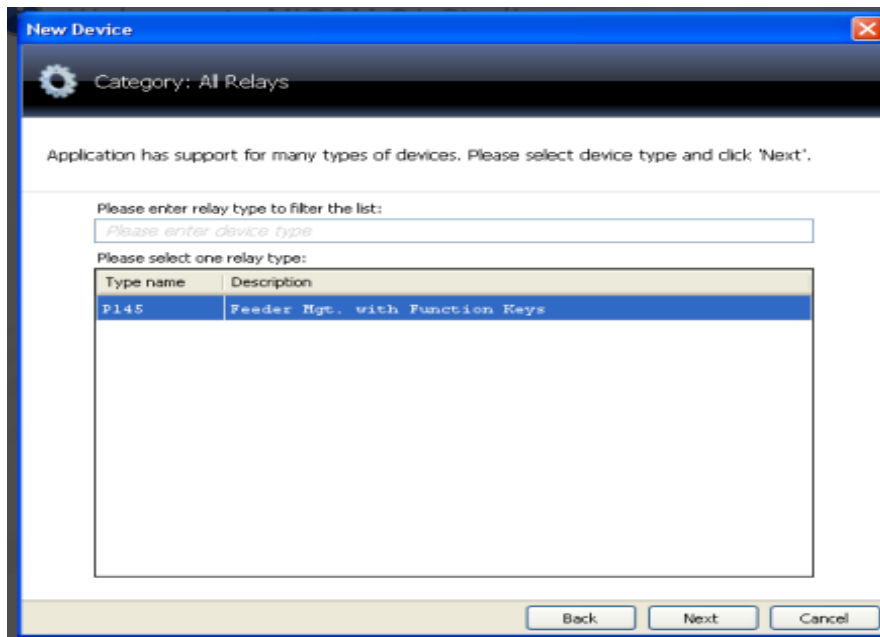
Figure 6.62: Selecting Category of the Device

After selecting the category of the device the dialog box below pops up as shown by Figure 6.63. The pop up window requires specific data to be inputted to ensure hardware and software match-up. To obtain the required information either:

- Check ordering/delivering documentation
- Check for the number on the device itself
- Manual check on the device menu options
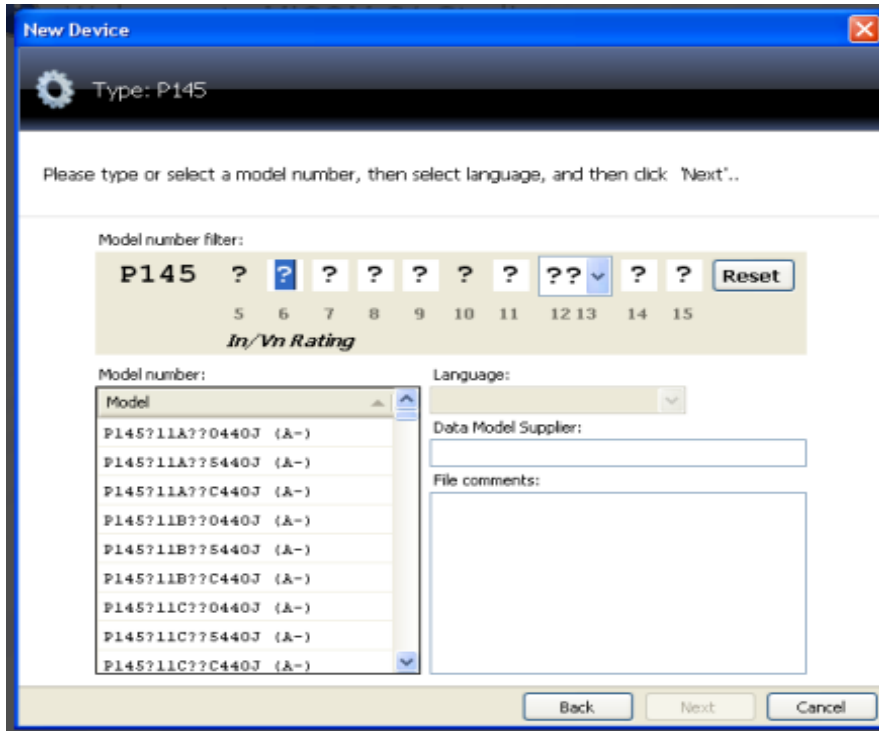
Figure 6.63: Device Specifications

Once all the required information is inserted the model window filters all non-matching models. This ensures that correct model is used with the matching hardware. Select the model and click next as per Figure 6.64.
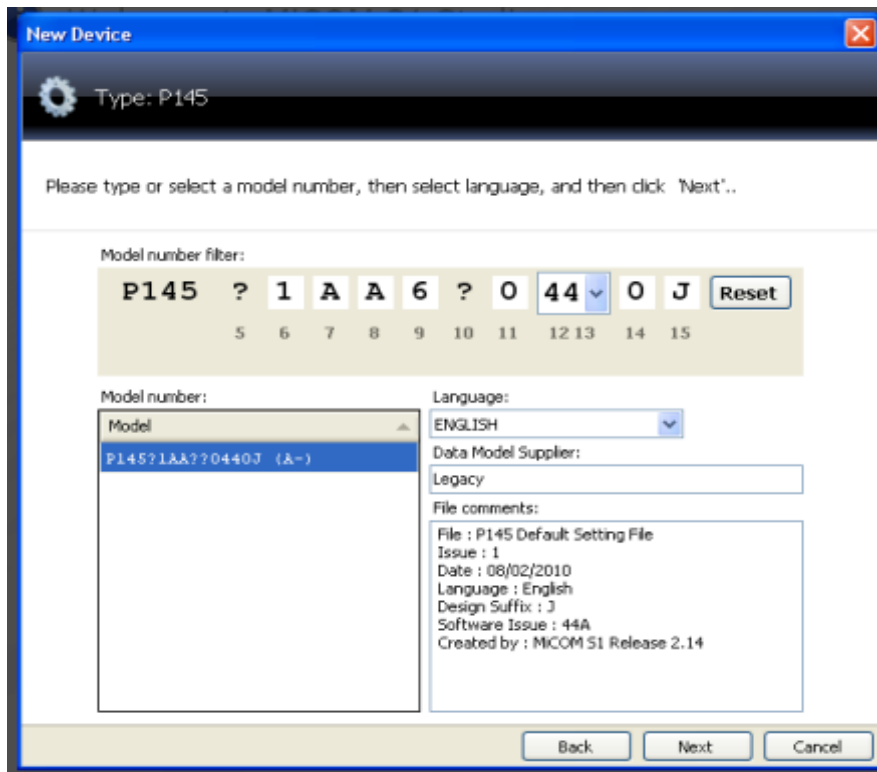
Figure 6.64: Device Specifications

The dialogue box in Figure 6.65 appears. Insert the required information and click on
"Finish".
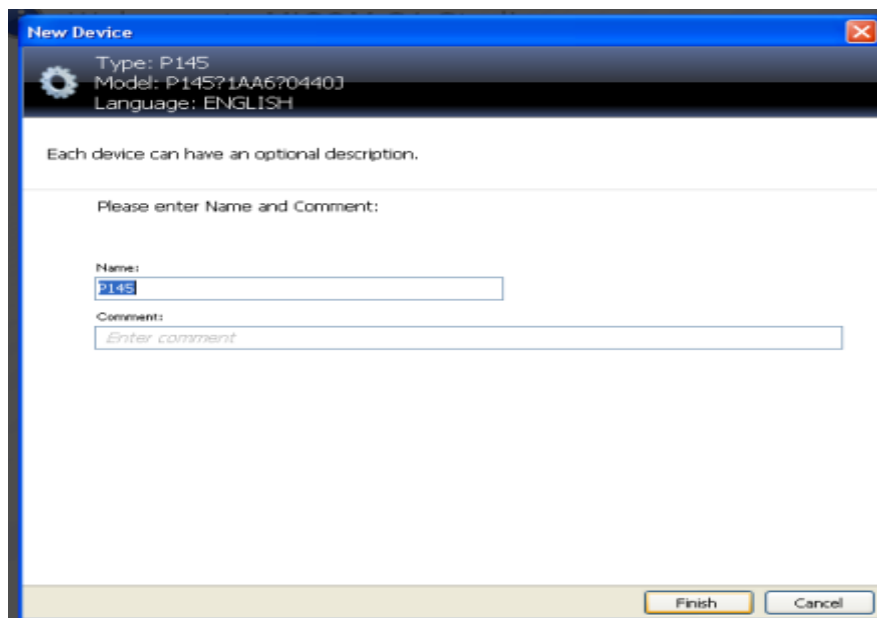
Figure 6.65: Naming Device Interface

The dialogue box appears as per Figure 6.66. Insert the required information and
click on finish. This step completes the setting up of the Schneider IED. The Studio
Explorer should be as illustrated below.
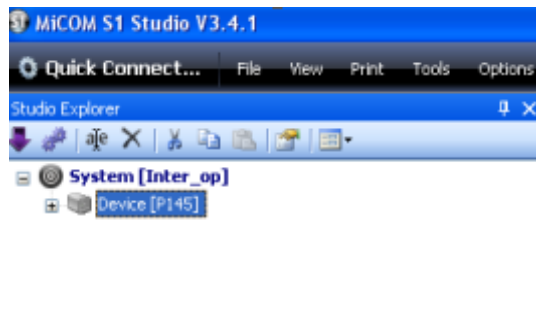
Figure 6.66: Micom S1 Studio Canvas

6.3.5.3 Communication Setup

On the Studio Explorer left click on the "+" sign next to the IED (P145) as indicated in Figure 6.67. A dropdown menu with folders appears as illustrated below.Figure 6.67.
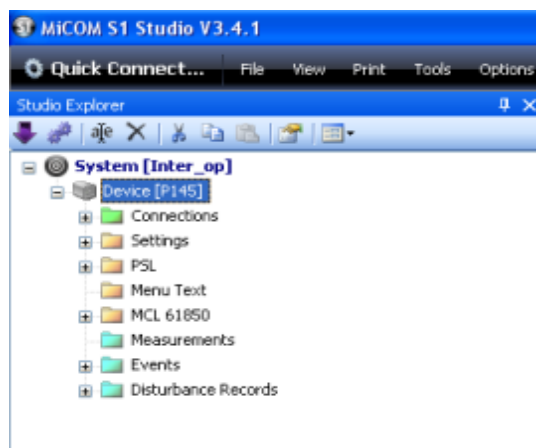
Figure 6.67: Device Hierarchy

Select connections folder and right click to insert a new connection as per Figure 6.68. Left click on the new connection pop up box.
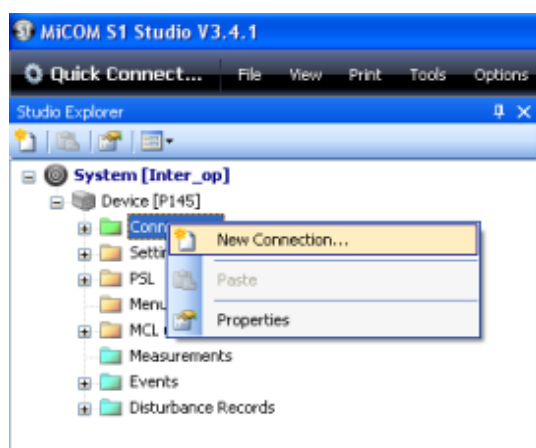
Figure 6.68: New Communication Connection for Device

A new connection dialogue box pops up to provide options with regards to which connection port will be used of as per Figure 6.69. Select front serial port by left click.
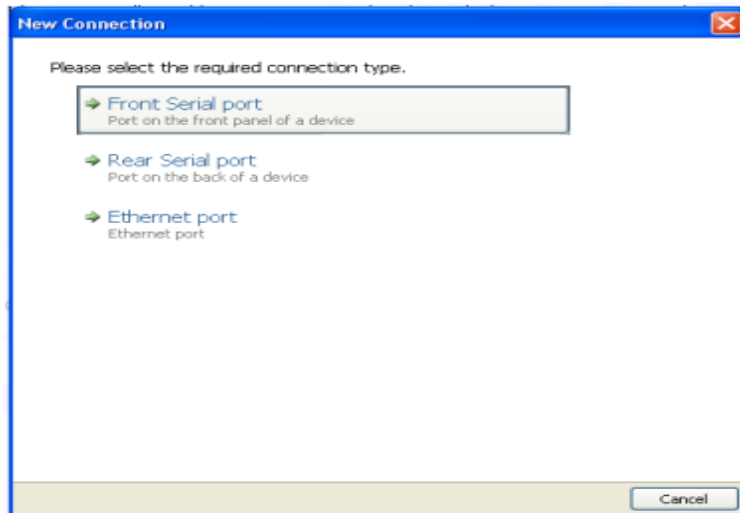
Figure 6.69: Communication Port Selection

A new connection dialogue box appears with different options which are for selection as per Figure 6.70. Select appropriate com port and device address. On completion of the selection, click on "Next" button.
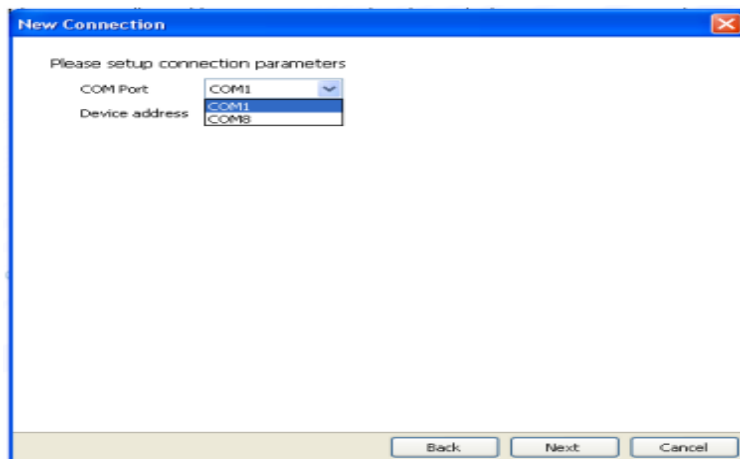
Figure 6.70: Communication Port Settings

A new connection pop up box appears as presented in Figure 6.71. Insert required information and click "Finish".
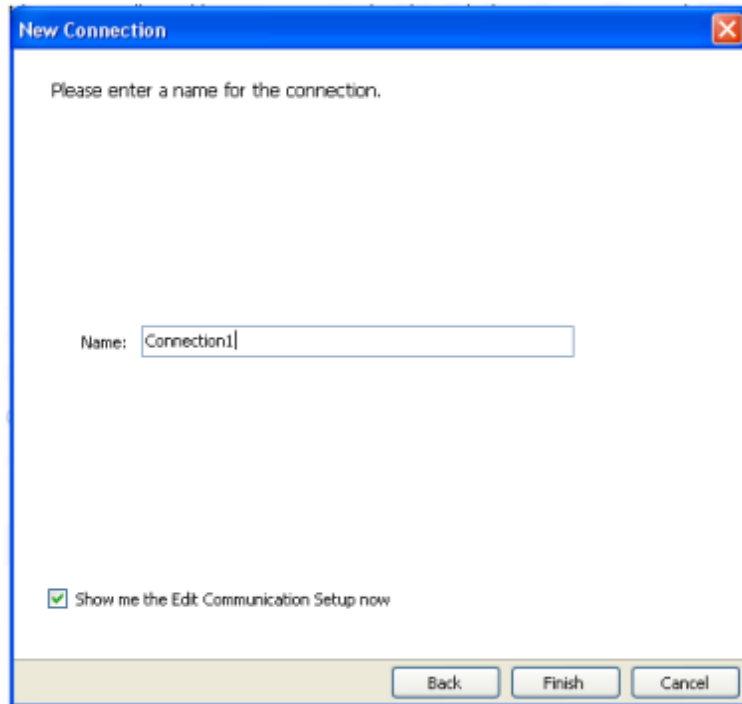
Figure 6.71: Communication Naming Interface

An edit connection dialogue box appears as shown in Figure 6.72. Select the options as shown below and click on "OK".
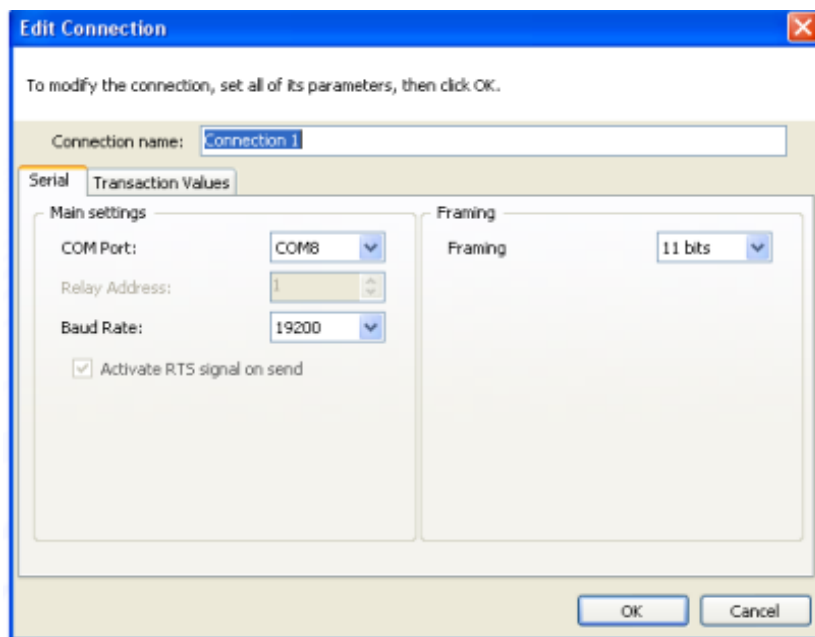
Figure 6.72: Connection Settings

The Studio Explorer window appears as shown in Figure 6.73. Right click on the connection folder sub-item connection1 (as named previously).
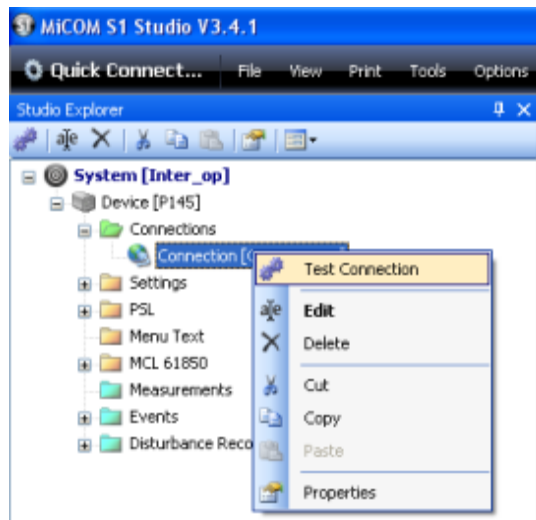
Figure 6.73: IED file hierarchy

Should the connection settings be valid the pop up box below should be displayed as per Figure 6.74.
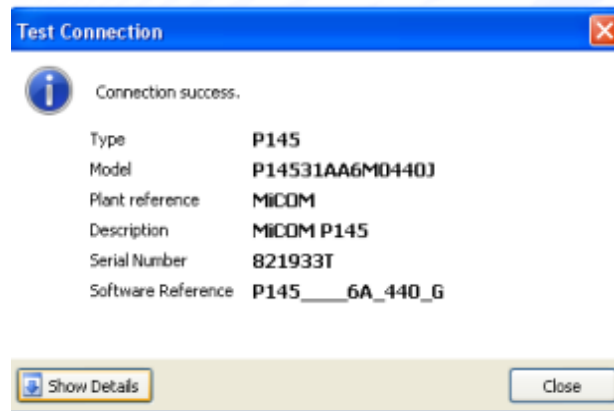
Figure 6.74: IED Connection Test

6.3.5.4 Creating Settings File

Right click on settings folder on the Studio Explorer. A pop-up menu appears as per Figure 6.75 and right click on new file to create a settings file
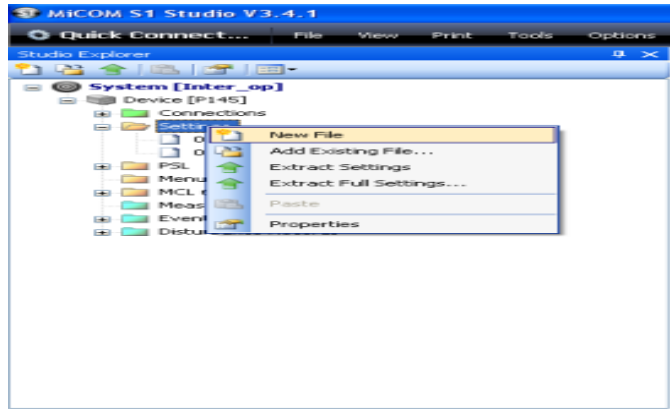
Figure 6.75:IED settings file

The file appears under settings file as per Figure 6.76.
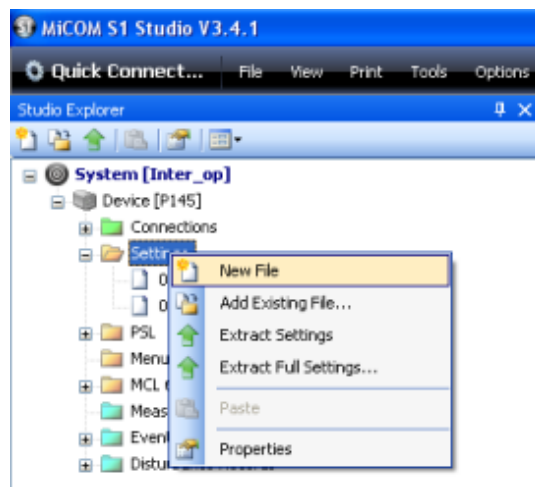
Figure 6.76:New IED settings file

6.3.5.5　Configure logic

To configure the logic functions, click on the PSL folder and create a new file. Right click on the file to open it as per Figure 6.77.
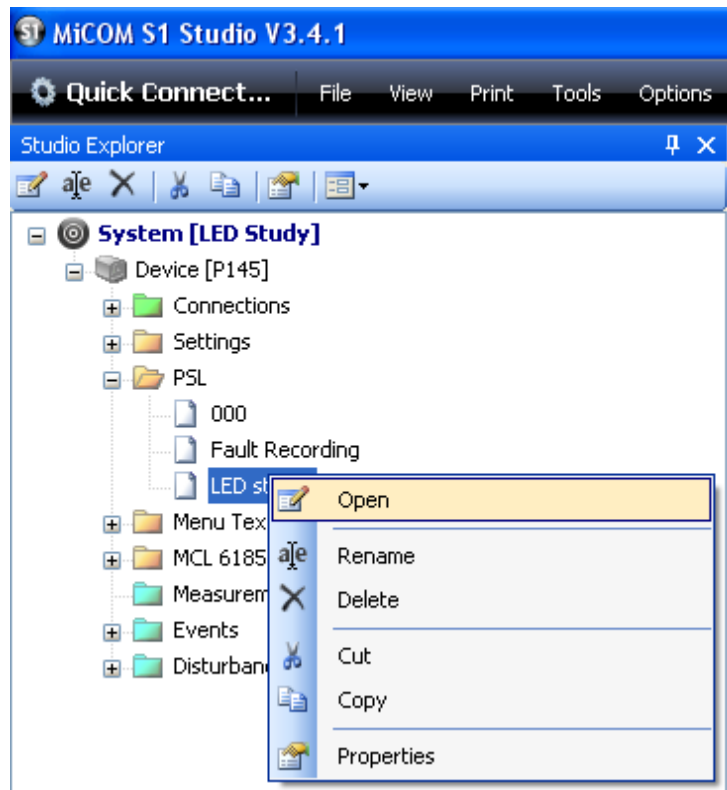
Figure 6.77:IED PSL file

The PSL task bar contains all the logical and interconnections required to configure a logical function as illustrated in Figure 6.78.

Figure 6.78: PSL editor tool bar icons

The logic scheme is as illustrated by Figure 6.79.
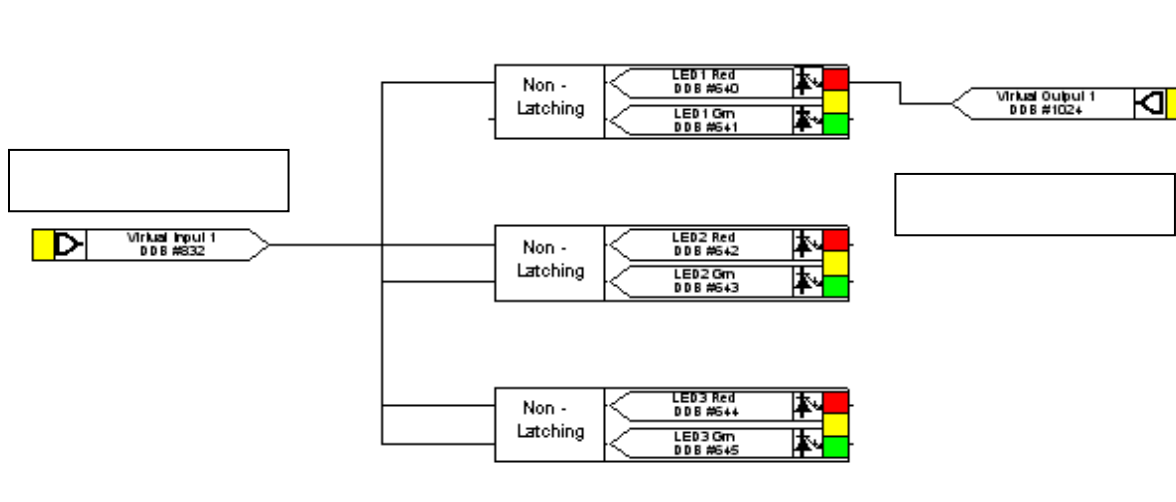
Figure 6.79: IED PSL mapping

6.3.5.6 Configure IED settings

Right click on the setting file to open the settings file as per Figure 6.80. This is to commence with IED settings.
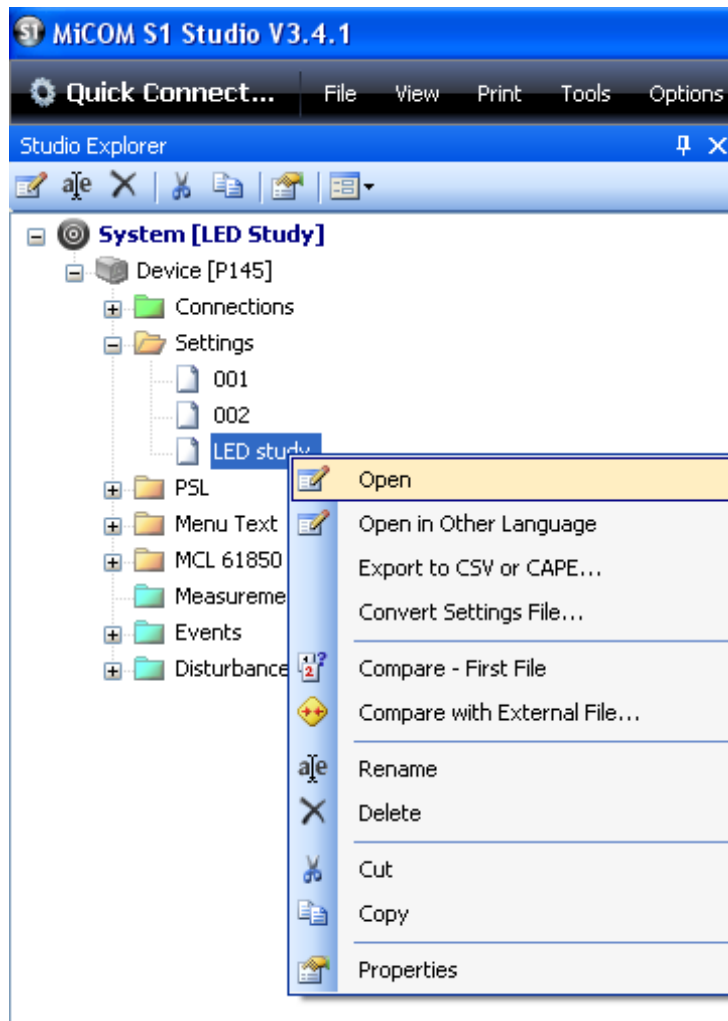
Figure 6.80: Access IED settings file

All the settings will be displayed as per the Figure 6.81.
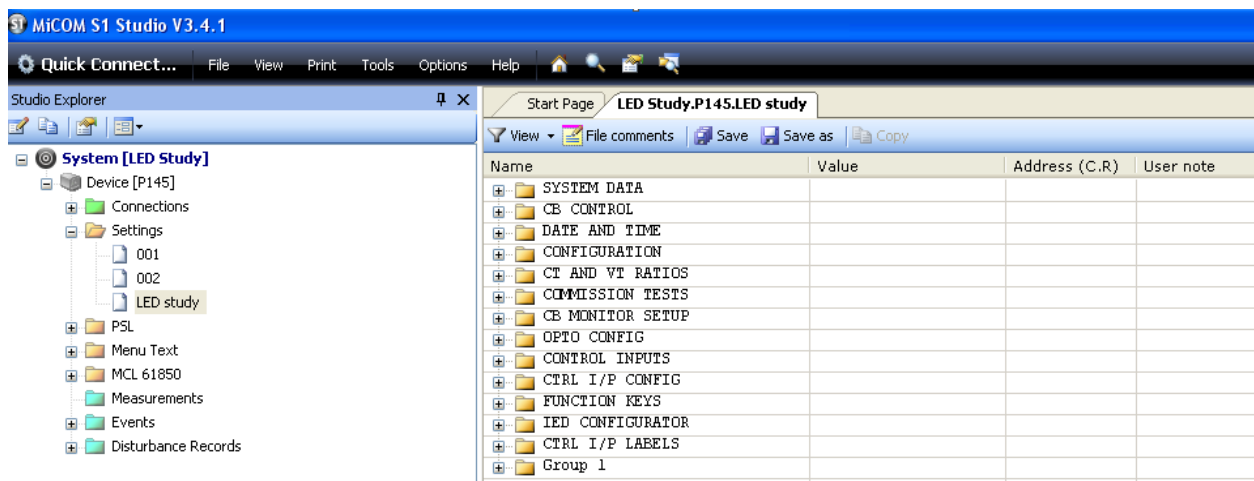
Figure 6.81: IED hierarchy file settings

Click on IED configurations and select "GoEna" and enable all the GOOSE control blocks as per Figure 6.82.

CTRL I/P CONFIG			
FUNCTION KEYS			
IED CONFIGURATOR			
Switch Conf.Bank	No action	19.05	
Restore MCL	No action	19.0A	
Active Conf.Name	Not Available	19.10	
Active Conf.Rev	Not Available	19.11	
Inact.Conf.Name	Not Available	19.20	
Inact.Conf.Rev	Not Available	19.21	
IP PARAMETERS		19.30	
IP address	Not Available	19.31	
Subnet mask	Not Available	19.32	
Gateway	Not Available	19.33	
SNTP PARAMETERS		19.40	
SNTP Server 1	Not Available	19.41	
SNTP Server 2	Not Available	19.42	
IEC 61850 SCL		19.50	
IED Name	Not Available	19.51	
IEC 61850 GOOSE		19.60	
GoEna	11111111	19.70	
Test Mode	00000000	19.71	
Ignore Test Flag	No	19.73	
CTRL I/P LABELS			
Group 1			

Figure 6.82:Enabling GOOSE messaging

The settings are complete at this point.

6.3.5.7 Configure GOOSE message

To configure the GOOSE messages right click on MCL IEC 61850 file to open the IEC 61850 configurator as per Figure 6.83.
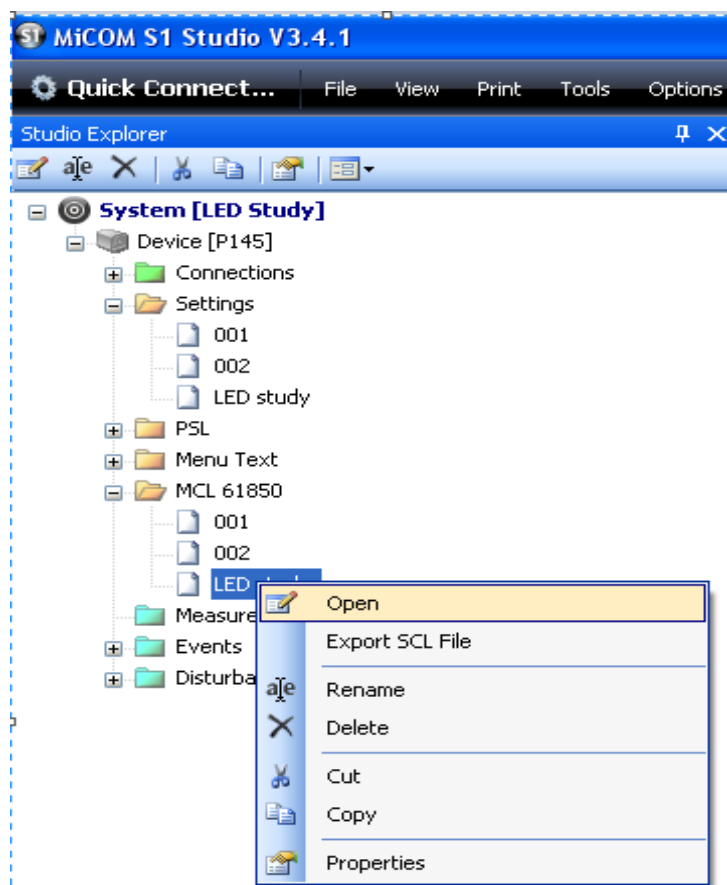
Figure 6.83: Access to IED MCL file

The IEC 61850 IED configurator will open as per Figure 6.84. The next step is to configure GOOSE messages i.e. publications and subscriptions.

173
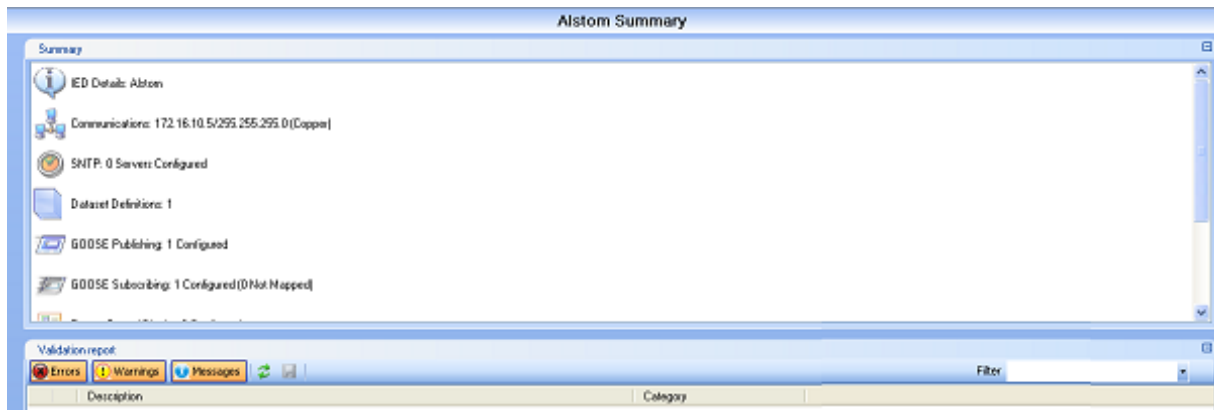
Figure 6.84: MCL Editor (IED configurator)

6.3.5.7.1 GOOSE subscription

Select the device to expand the device sub-files and select GOOSE subscribing as presented in Figure 6.85.
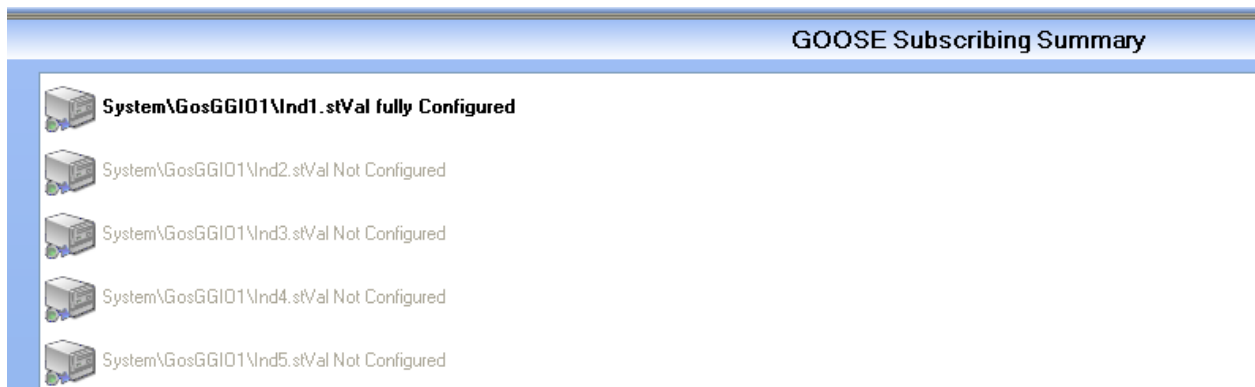

Figure 6.85: GOOSE subscription configuration

Expand GOOSE subscribing item and select a single item to map. Select "Browse" to subscribe to a GOOSE message as per Figure 6.86.
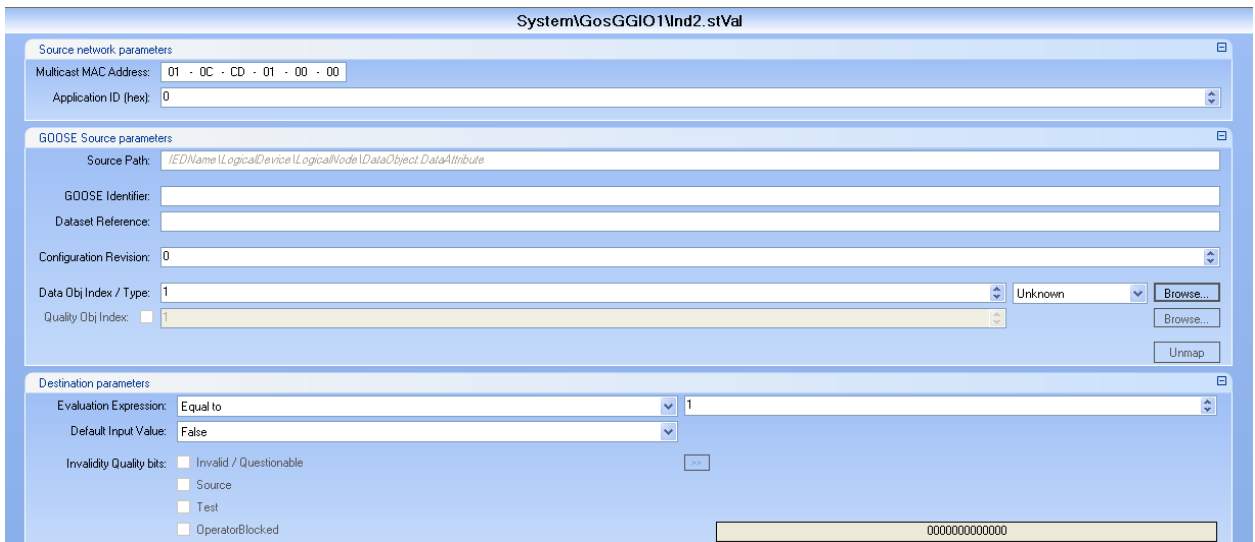
Figure 6.86: GOOSE subscription

This brings up a dialogue box to allow mapping as per Figure 6.87. Browse to the location of the CID or SCD file is located.
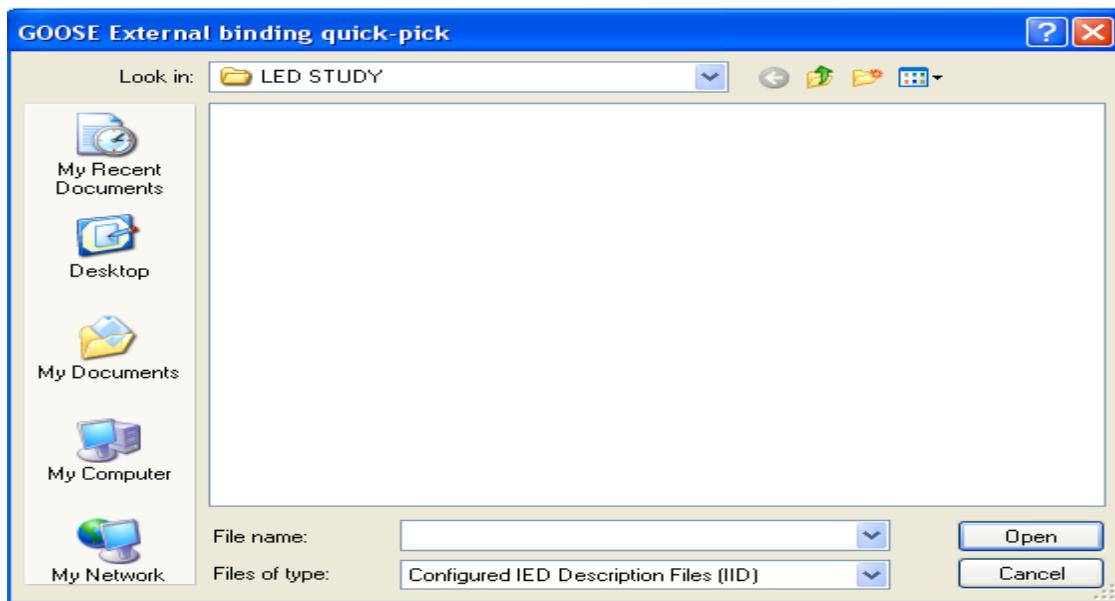
Figure 6.87: GOOSE external binding quick pick

On the dialogue box select "Files of type" drop down menu and select SCD as illustrated in Figure 6.88.
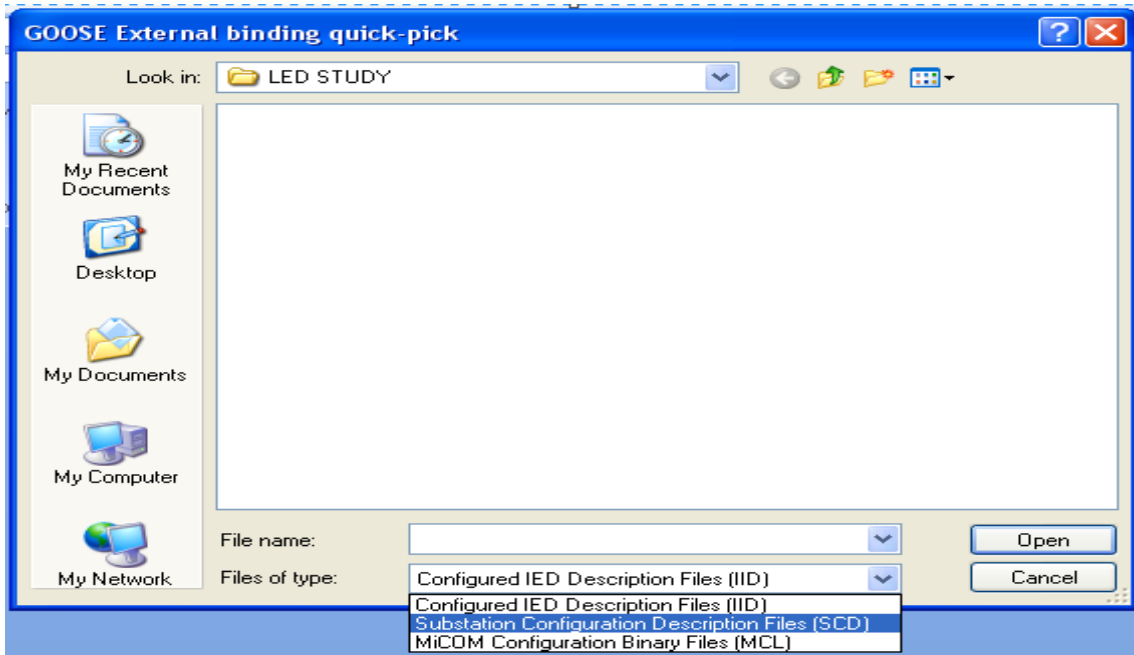
Figure 6.88: GOOSE external binding quick pick

This reveals the SCD files in the location and then select the appropriate SCD file as per Figure 6.89.
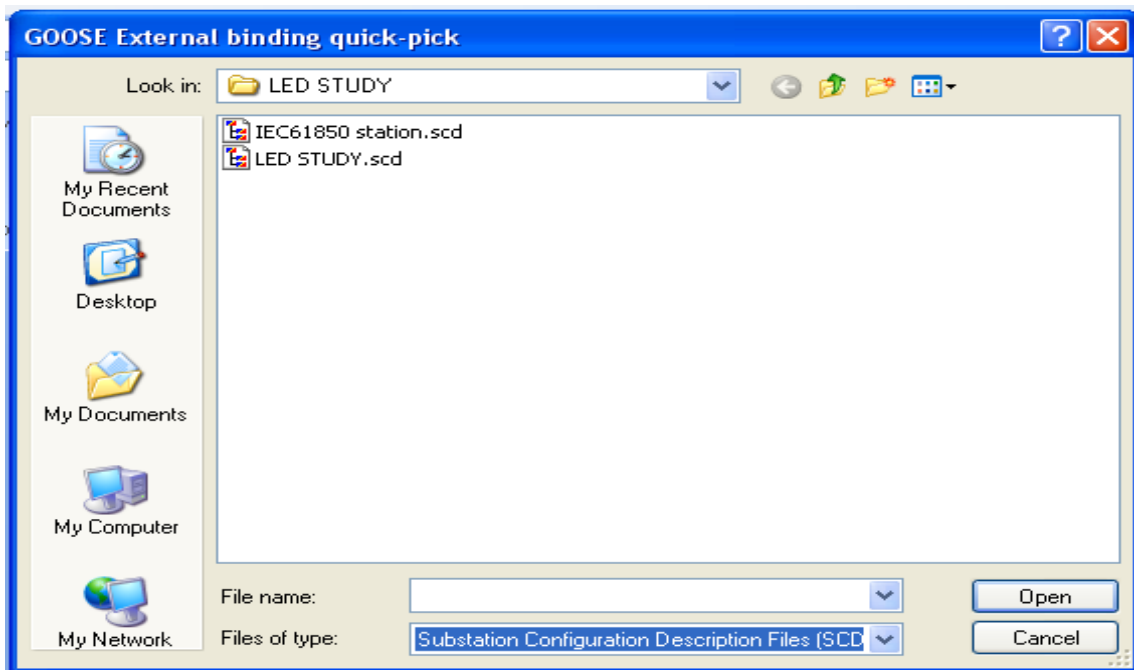
Figure 6.89: GOOSE external binding quick pick

A pop-up dialogue box appears to map GOOSE messages as per Figure 6.90
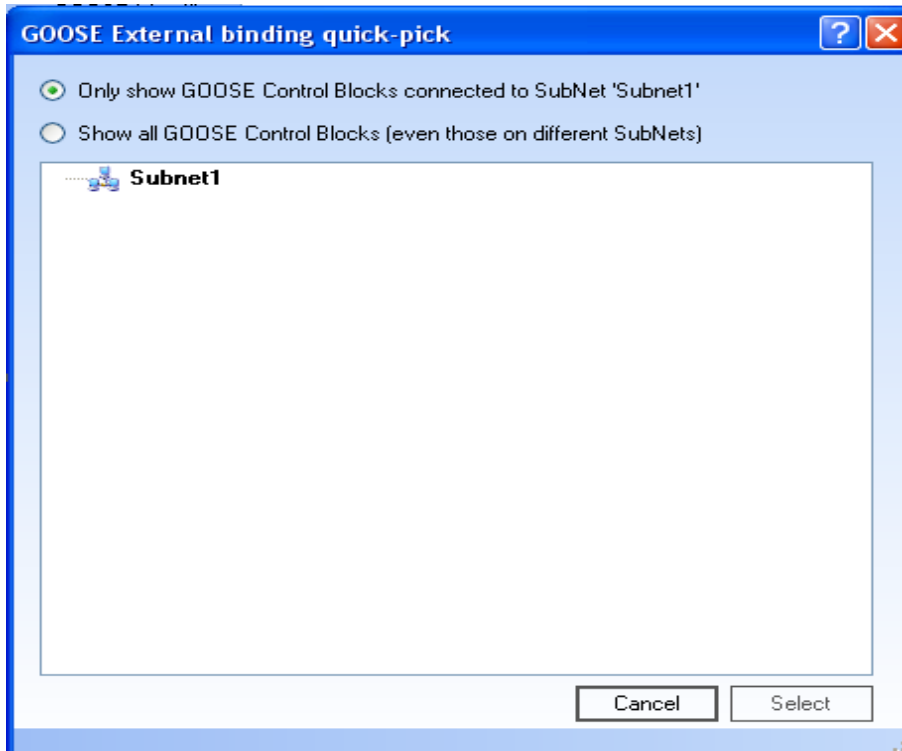
Figure 6.90: GOOSE external binding quick pick

Select "Show all GOOSE Control Blocks" this allows for all GOOSE messages to appear on the dialogue box as illustrated in Figure 6.91.
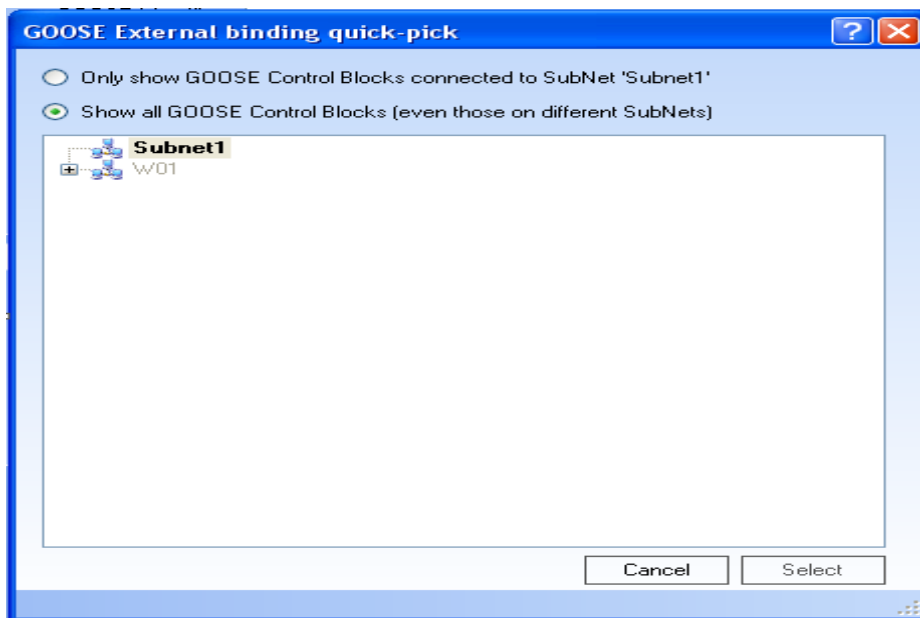

Figure 6.91: GOOSE external binding quick pick

Expand the additional subnet to view the devices containing GOOSE messages as shown in Figure 6.92.
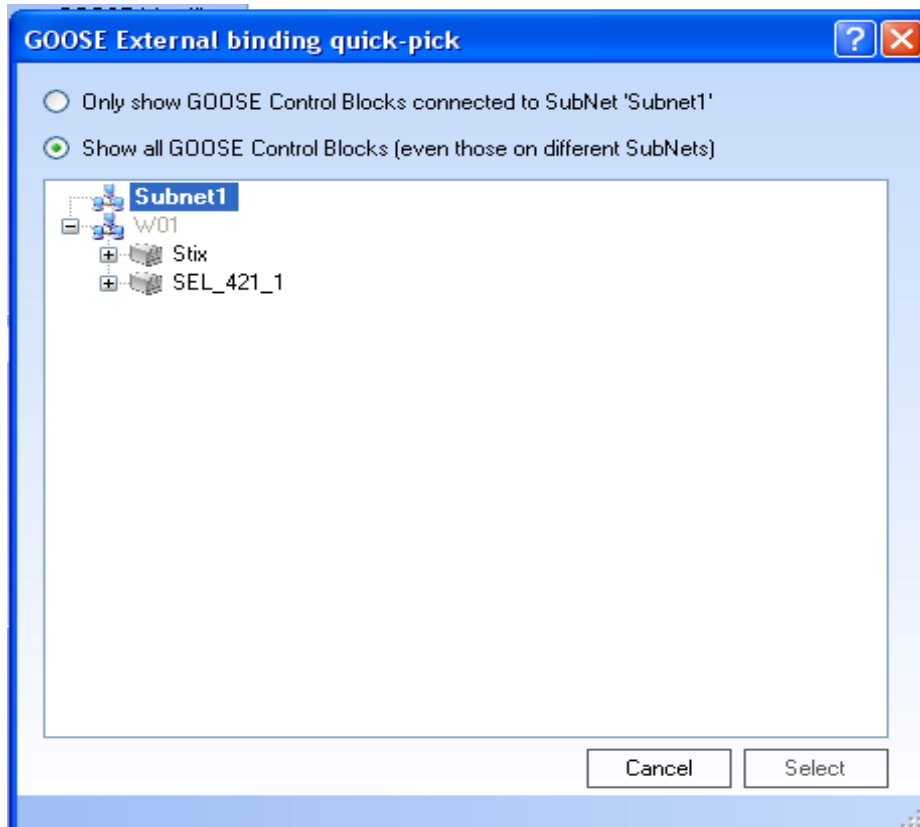
Figure 6.92: GOOSE external binding quick pick

Select the device which the Schneider device is subscribing to. Select the correct GOOSE control block and check whether the data type is supported. If the data type is supported click on "Select" as illustrated in Figure 6.93.
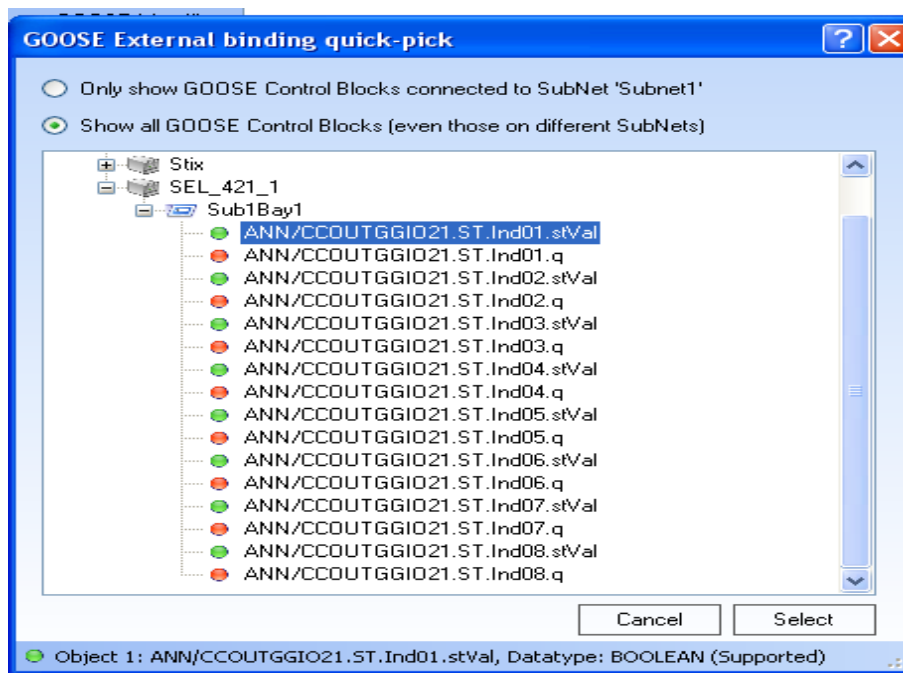

Figure 6.93: GOOSE external binding quick pick

This completes the GOOSE message subscription configuration as per Figure 6.94.
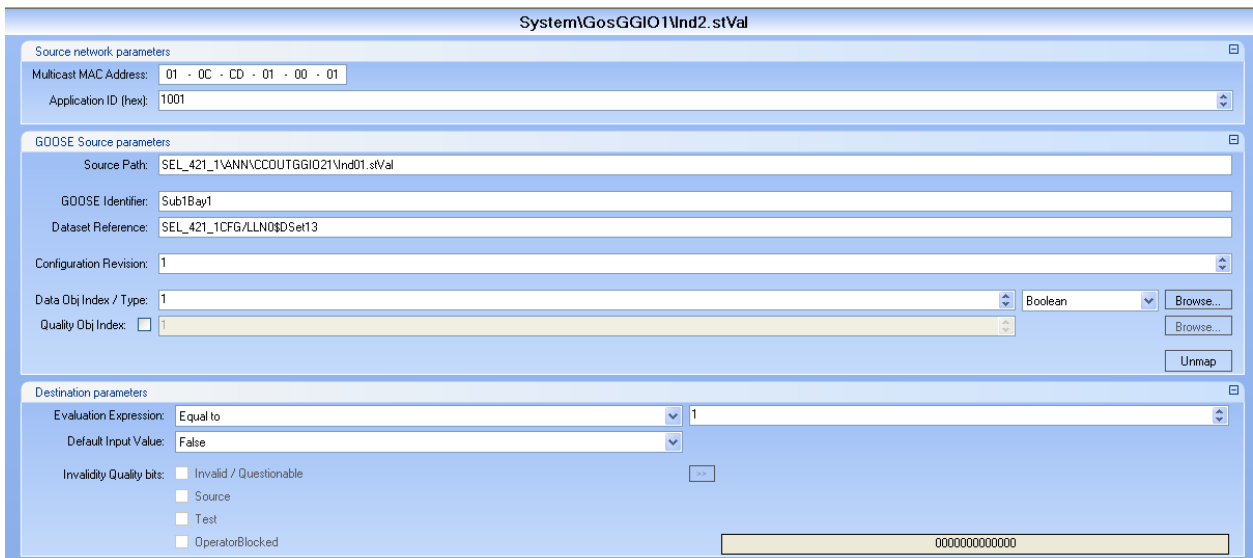
Figure 6.94: GOOSE subscription information

The Figure 6.95 illustrates that the subscription is fully configured and complete.
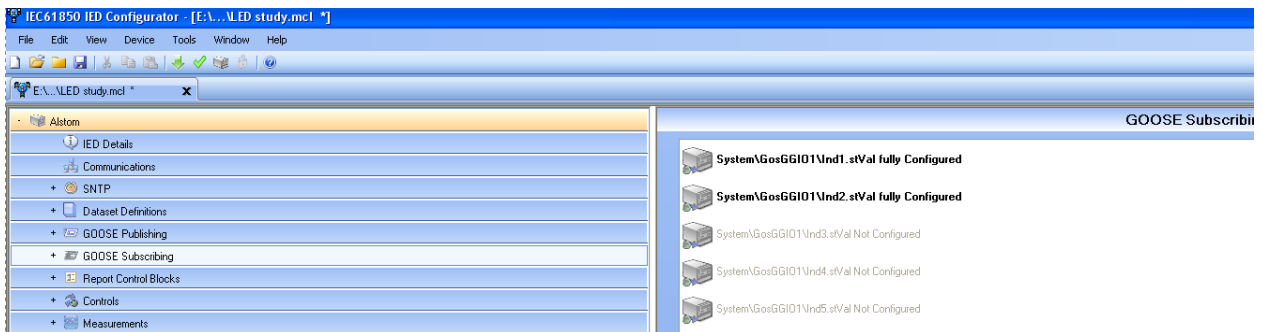

Figure 6.95: GOOSE message subscription overview

The tool verifies that GOOSE messaging subscription has been fully configured. This completes the GOOSE mapping with regards to GOOSE subscription

6.3.5.7.2 GOOSE publication

To enable GOOSE publication dataset needs to be defined. On the IED configurator click on "Dataset Definitions". A window "Dataset Definitions Summary" will appear click on "Add dataset" as per Figure 6.96.
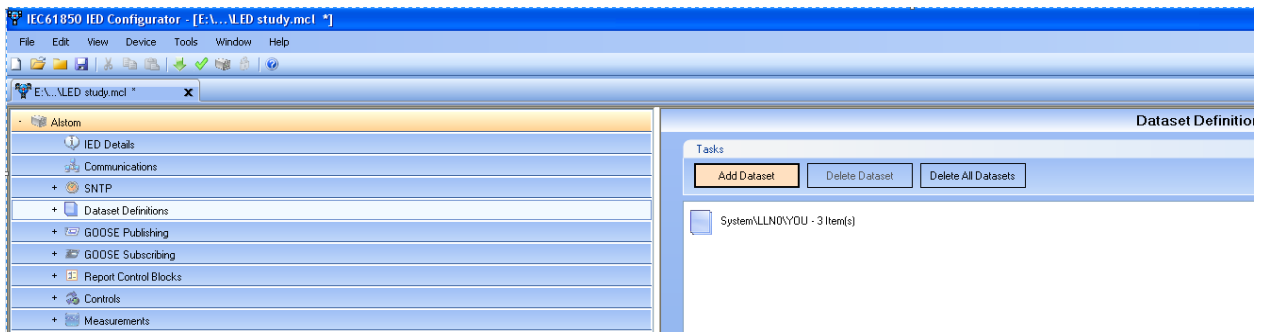
179

Figure 6.96: Dataset definitions

A dialogue box appears with the device of which the publication has to originate from which is the Logical Device (LD) as per Figure 6.97. Expand the view of the device.
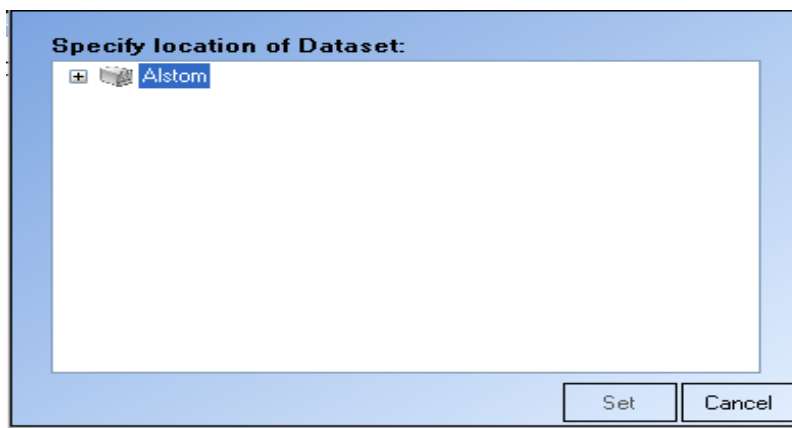

Figure 6.97: Logical Device

On expansion this shows all the Logical Nodes in the Logical Node as per Figure 6.98. The Logical Node to be selected is "System" and expand the view of this Logical Node.
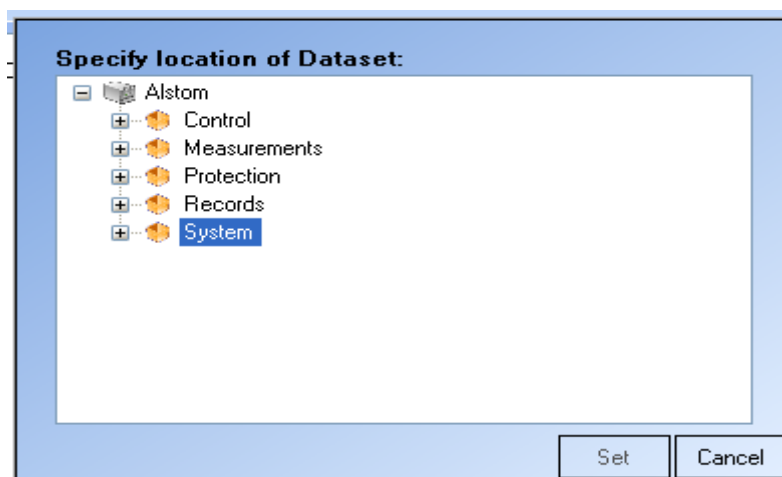

Figure 6.98: IED Logical Nodes

This is as per IEC 61850 that all status values reside with LLNO of a Logical Node. Select "LLNO" and click on "Set" as per Figure 6.99.
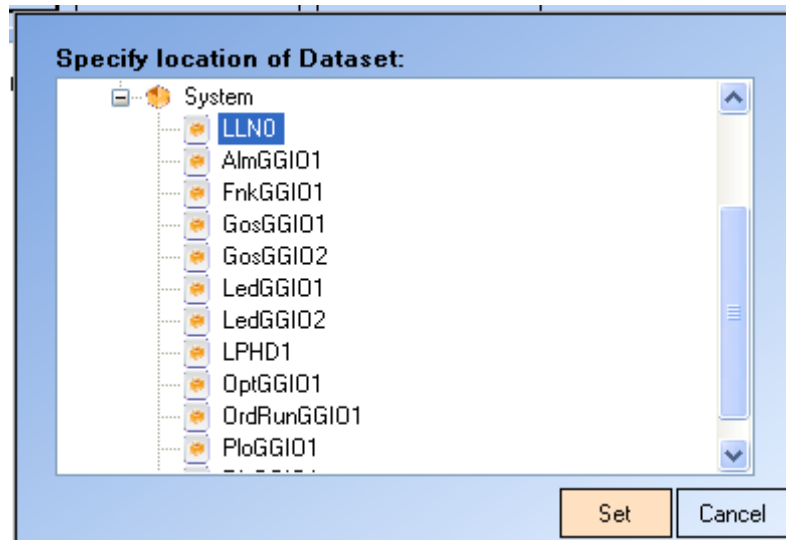

Figure 6.99: Logical Node LLNO

This completes the configurations of the GOOSE message shell. Then the configurations of the contents/datasets of the GOOSE message need to be inserted. Click on the "+" sign to commence as illustrated in Figure 6.100.
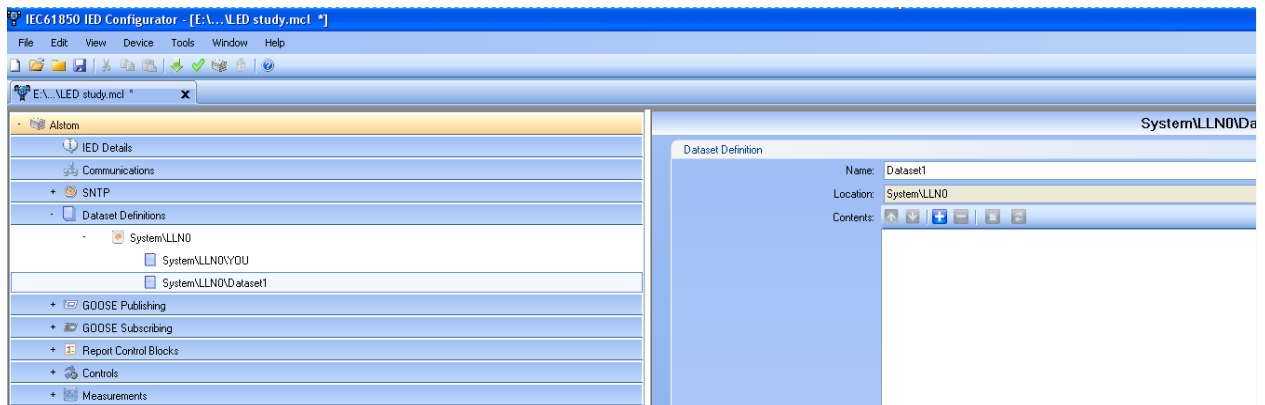

Figure 6.100: IED Logical Node

A dialogue box appears containing Logical Device with its Logical Nodes as per Figure 6.101. Expand the System Logical Node.
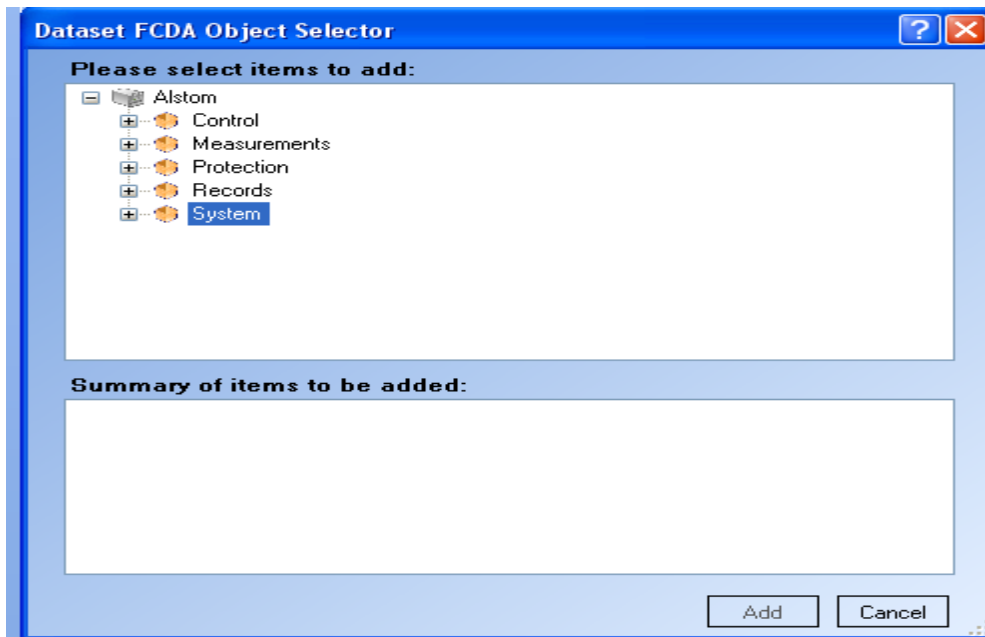
Figure 6.101: FCDA object selector

Select/Expand GOOSE output signal (GosGGIO2) for publication of GOOSE messages as shown in Figure 6.102.
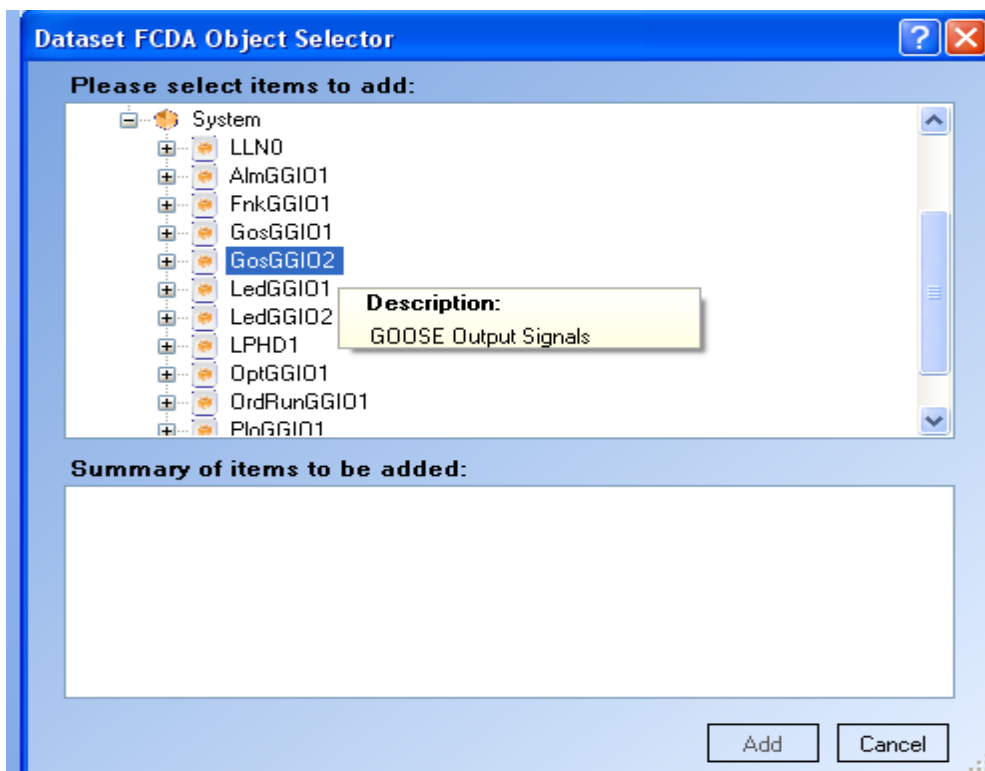

Figure 6.102: FCDA object selector

Select the attributes which are set for publication in the PSL editor as shown in Figure 6.103. Ensure all attributes are selected individually namely a, FCDA and not FCD selection.

Figure 6.103: FCDA selection
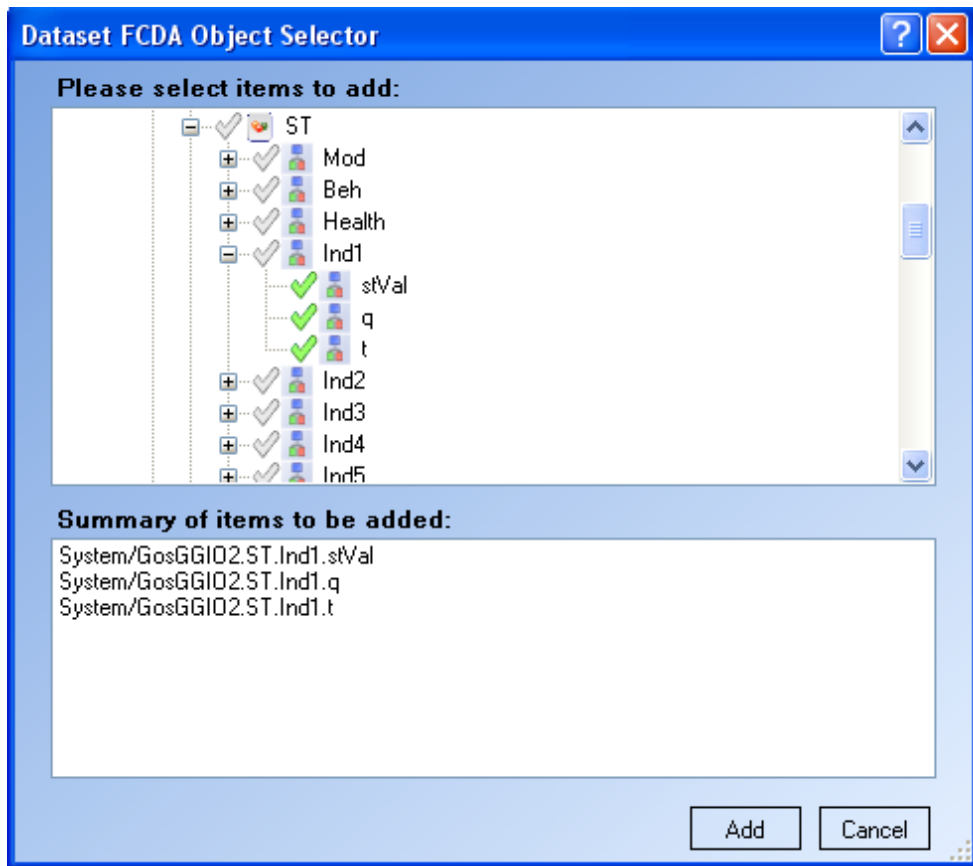
This completes the required attributes for publication. The next step is to enable the publication of the configured dataset by setting a GOOSE control block. Also note the GOOSE capacity bar on the right hand side of Figure 6.104.
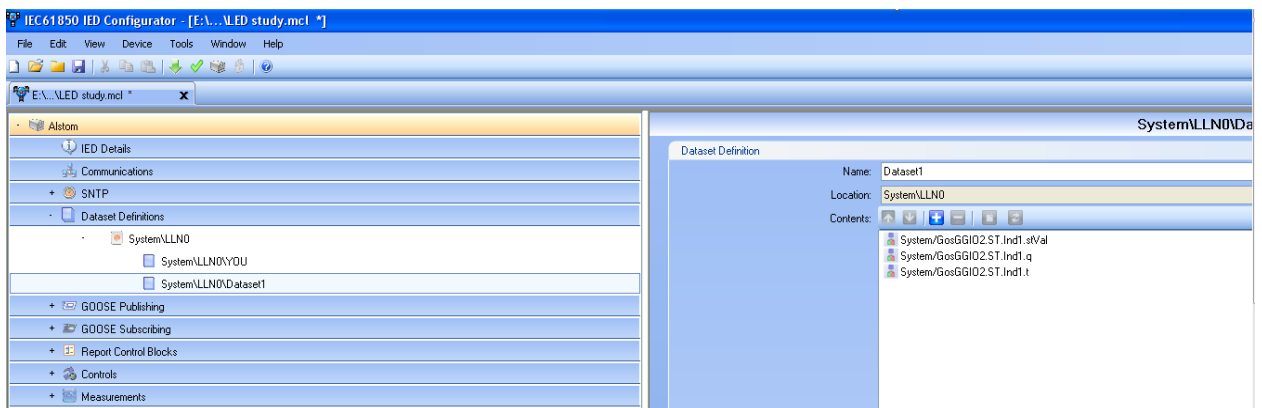
Figure 6.104: GOOSE dataset

Click on GOOSE publishing and on the GOOSE publishing summary window select a GOOSE control block as shown in Figure 6.105.
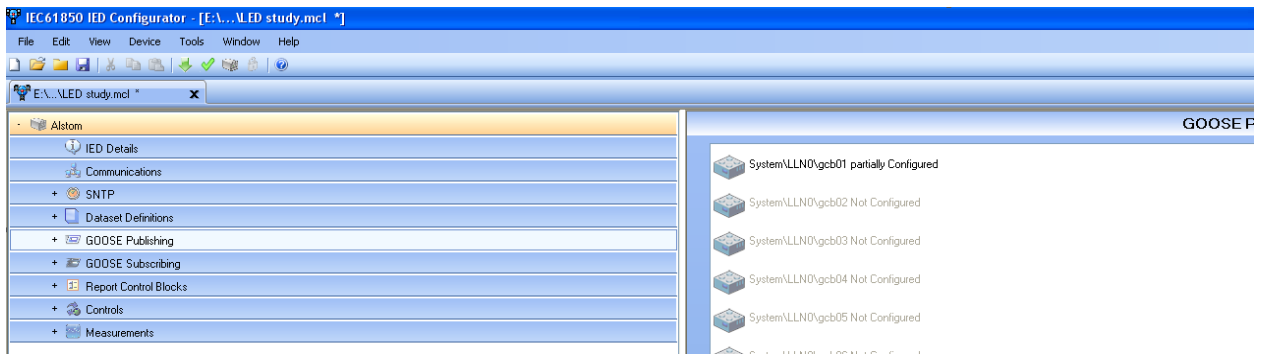
Figure 6.105: GOOSE publishing summary

A GOOSE control block window appears (System\LLNO\gcb02) as per Figure 6.106.
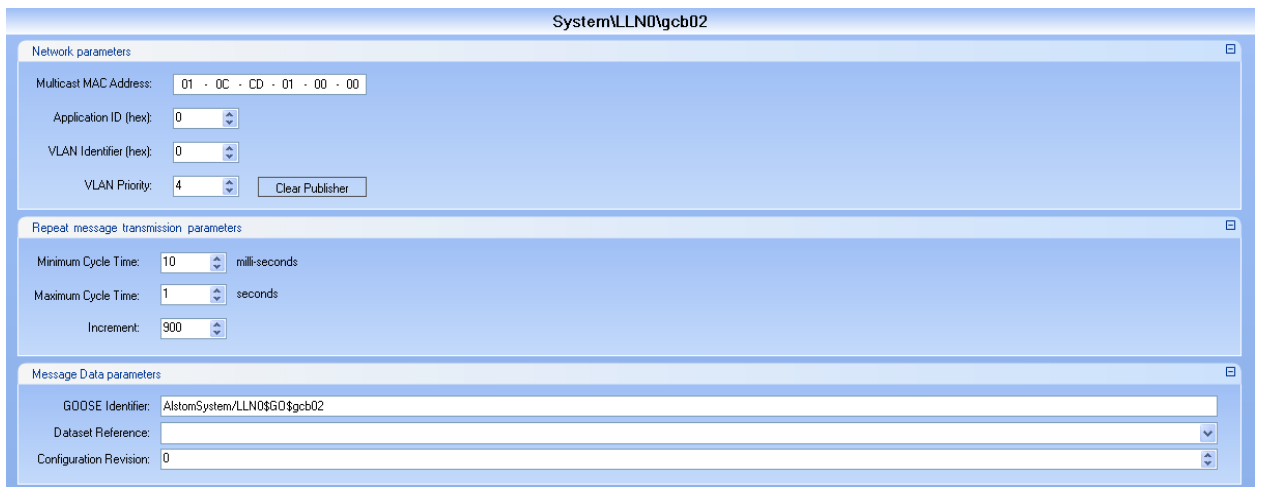
Figure 6.106: GOOSE control block

Click on dataset reference for a drop down menu and select the dataset that has been configured for publication as illustrated in Figure 6.107.

Figure 6.107: GOOSE control block

Note by hovering above the dataset reference, this shows the data attributes enclosed in the dataset as shown in Figure 6.108.
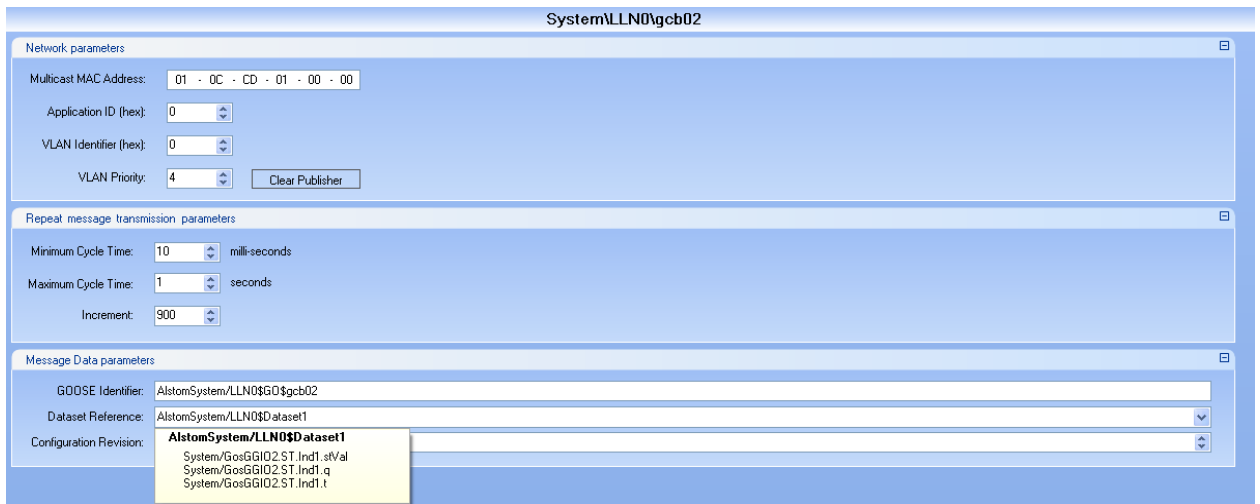
Figure 6.108: GOOSE control block

The Figure 6.109 below illustrates that GOOSE message are partial configured and to complete the configuration the validation of configuration needs to be done in the tool

Figure 6.109: GOOSE publishing summary

This completes the configuration of GOOSE publication as indicated in Figure 6.110.

Figure 6.110: IED configurator

6.3.6 Substation Configuration Language (SCL) Integration

The integration of the communication for the case study is quite simple but becomes rather complex due to the lack of file management as it becomes rather cumbersome. The integration of the system is as follows:

- Create SCD file in Digsi 4 (Siemens ICD only)
- Import this SCD file into Architect (SEL)
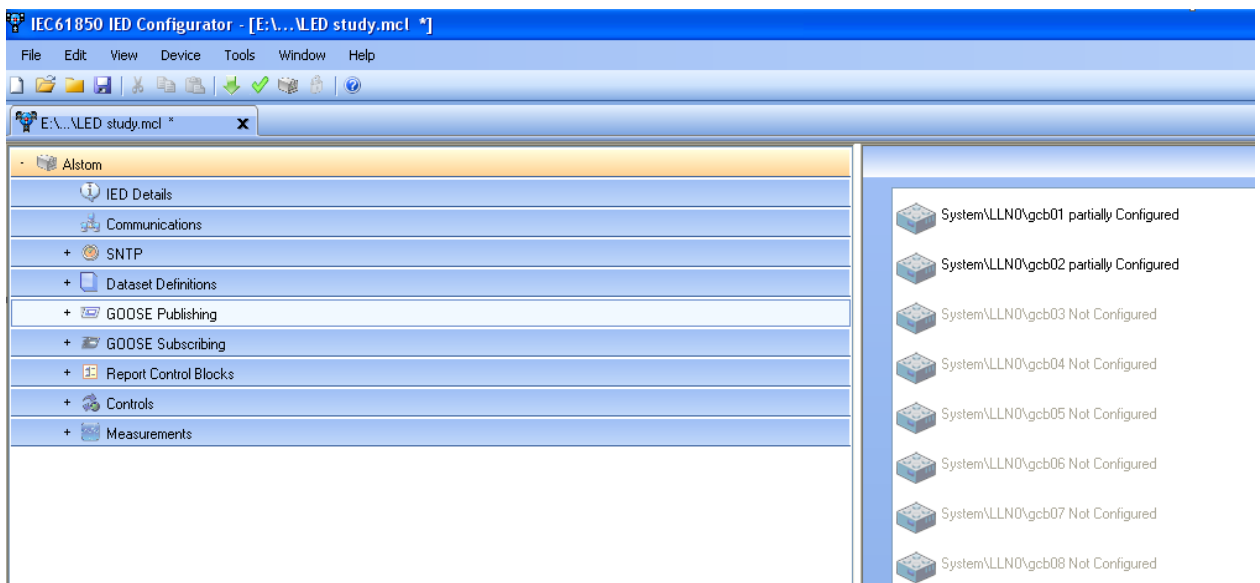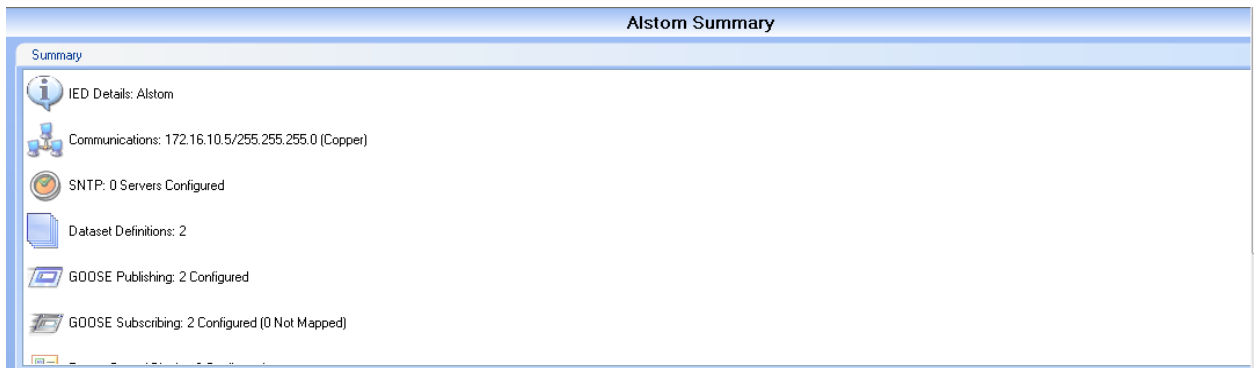- Map required signals for SEL (Architect)
- Export SCD Architect
- Subscribe to SEL GOOSE message in Micom S1 studio
- Load all CID files from the respective tools (Architect, Micom S1 Studio and Digsi 4)

The procedure outlines one of the biggest interoperability challenges when all mapping is done on various vendor proprietary tools. Note that SEL ICD file has pre-configured GOOSE messages thus the ICD file is exported and then imported to Digsi 4. This allows the Siemens device to subscribe to SEL GOOSE messages if required to do so. Digsi 4 based Siemens device will publish GOOSE messages thus an SCD file is created although the SCD file only contains a single ICD file. Exporting the SCD file out of Digsi 4 allows the use of the Siemens CID file to enable subscriptions to the other IEDs. The Siemens SCD file gets imported into Architect as individual CID file (for this case study there is one CID file). Architect creates an SCD consisting of Siemens and SEL CID files. Note there are two SCD files in the process of integrating the system namely:

- SCD 1 in Siemens IED – Siemens CID

- SCD 2 in SEL IED – Siemens CID and SEL CID

Exporting the SCD file from Architect allows the Schnieder device to subscribe to SEL device GOOSE messages. Due to the procedure in Micom S1 Studio to subscribe to GOOSE messages no full system SCD file ever exists.

The system can communicate effectively but the file management is an oversight thus this situation alone will sway utilities and municipalities from even considering IEC 61850 interoperable systems. This would mean that a protocol developed with the view of promoting interoperability has been hampered by the vendor specific configurations tools

6.3.7 Results

Wireshark is utilised to monitor the GOOSE message network to ascertain interoperability functionality. The evaluation of the results entails scrutinising the normal/initial and the new state of GOOSE messages. The Siemens device GOOSE message pay load, note difference before and after event as per Figure 6.111. The SEL device GOOSE message pay load, note difference as per Figure 6.112. The Schneider device GOOSE message pay load note difference as per Figure 6.113. The difference of the payload on the abovementioned figures refers to the payload of the GOOSE messages respectively. The difference is illustrated by the sequence number, status number and the payload.

The event change for the Siemens device occurs on the 8th packet of the GOOSE message as all the packets before the 8th have the same status number and the sequence number is chronological. The payload on the Siemens device changes to True. The status number changes from 33 to 34 and the sequence number changes from 246 to 0. The 16th packet belongs to SEL device GOOSE message which has also changed the status number from 34 to 35 and the sequence number from 492 to 0. The 19th packet belongs to the Schneider device GOOSE message whose status number changes from 17 to 18 and sequence number from 495 to 0.

The Schneider device payload is immaterial to this case study. This also shows that if a device just publishes a GOOSE message the effect is minimal as they are no subscribers in the network.

Figure 6.111: Siemens GOOSE message

Before Event Change	After Event Change

Figure 6.112: SEL GOOSE message

Before Event Change	After Event Change

Figure 6.113: Schneider GOOSE message

The round trip time for the SEL device can be calculated by setting the Siemens device GOOSE message as the reference point on Wireshark as per Figure 6.115. The round trip time for the Schneider device can be calculated by setting the Schneider device GOOSE message as the reference point on Wireshark as per Figure 6.115. The round trip time is as follows:

- SEL Device – 3.75ms
- Schneider Device – 9.357ms

Note the round trip times are only available for SEL device and Schneider device because only the two device receive a GOOSE message and respond with a GOOSE message as indicated in Figure 6.114.
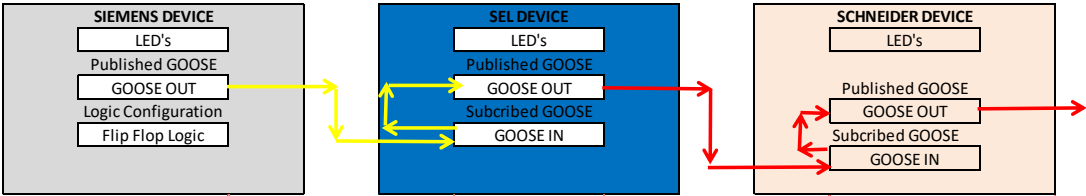
Figure 6.114: Case Study GOOSE messaging
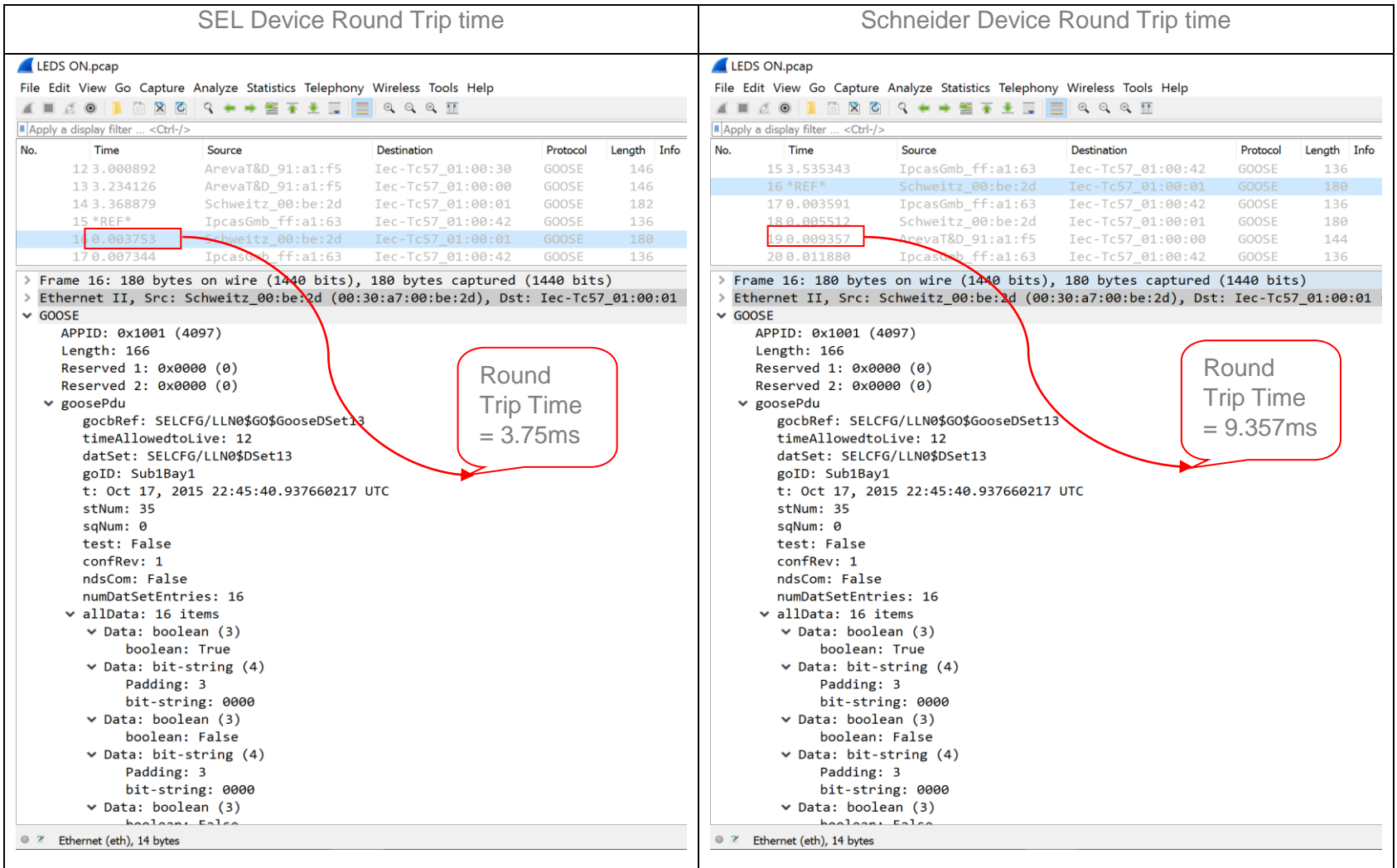
Figure 6.115: SEL and Schneider Roundtrip Times

6.4 Case Study 2: Interoperability Proof of Concept

6.4.1 Case Study Aim

The purpose of this case study is multi-faceted namely:

- GOOSE message performance measured against the bar set by the IEC 61850-5 standard.
- Provide proof of interoperability

Typically, both facets are equally important because if either is not met then the system cannot be referred to as an IEC 61850 compliant. The measurement of transfer time between two devices is not possible in commercially available devices. The case study is not set up to enable the measurement of transfer time. The case study merely illustrates the interoperability of the devices in the system and set-up/configuration of multi-vendor systems.

6.4.2 Case Study Operation

The case study operation is as represented by Figure 6.116.
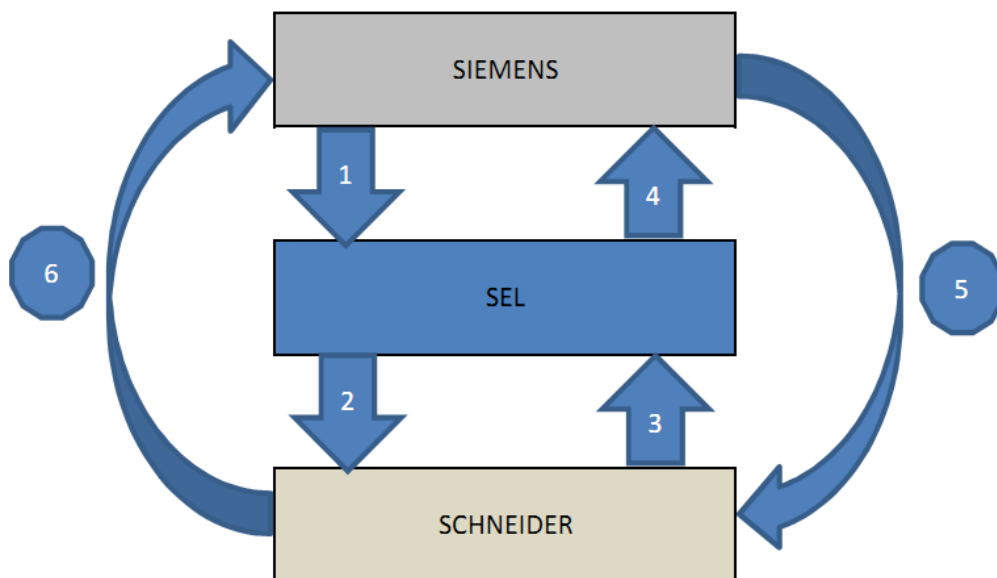
Figure 6.116: GOOSE flow diagram

The interfaces in Figure 6.116 are defined as follows:

1) Siemens IED publishes to SEL IED

   o   SEL IED subscribes to Siemens IED

2) SEL IED publish to Schneider IED

   o   Schneider IED subscribes to SEL IED

3) Schneider IED publishes to SEL IED

- o   SEL IED subscribes to Schneider IED

4) SEL IED publishes to Siemens IED

- o   Siemens IED subscribes to SEL IED

5) Siemens IED publishes to Schneider IED

- o   Schneider IED subscribes to Siemens IED

6) Schneider IED publishes to Siemens IED

- o   Siemens IED subscribes to Schneider IED

The Substation developed and implemented Substation Configuration Language (SCL) integration flow chart is depicted in Figure 6.117.
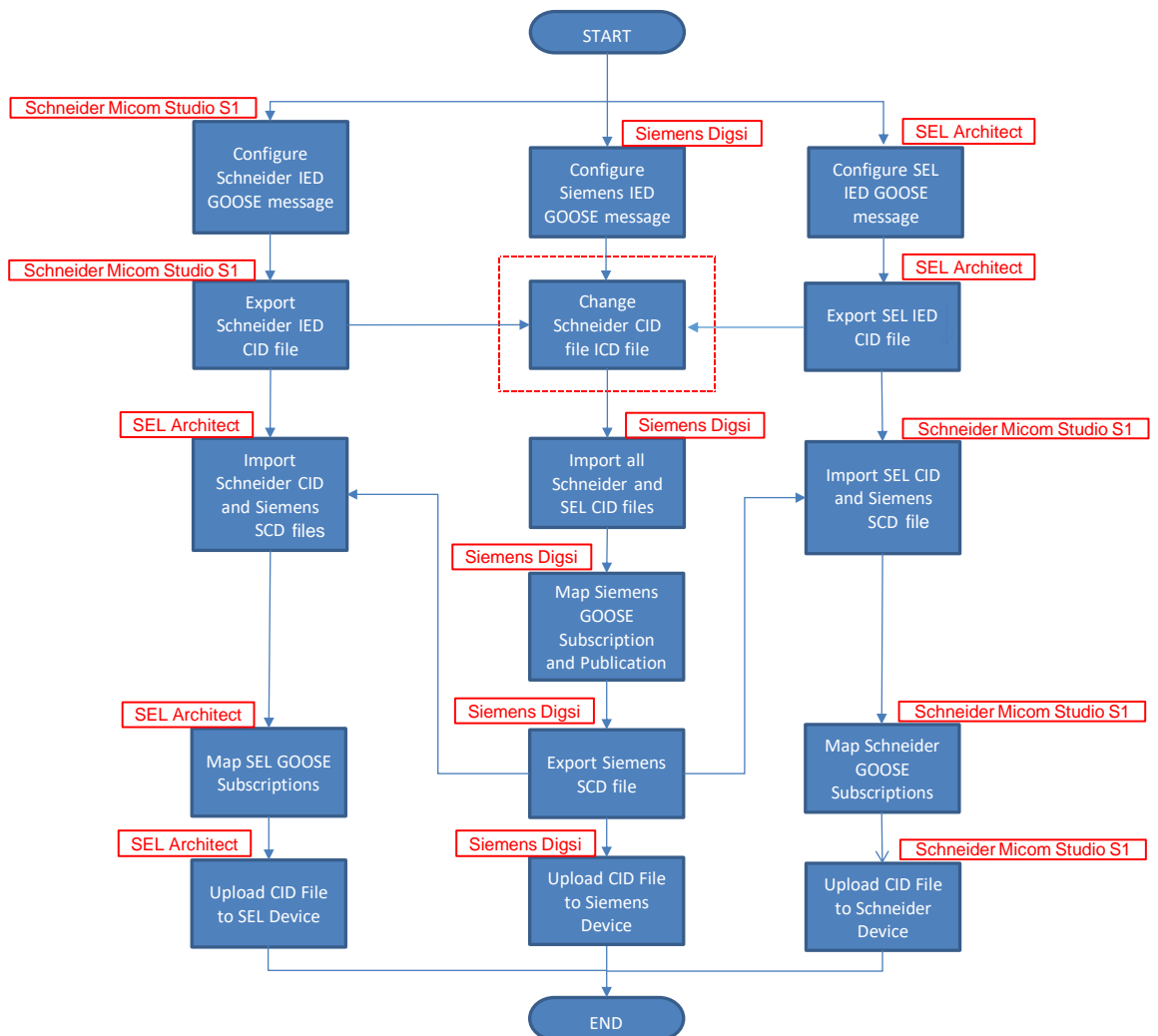
Figure 6.117:SCL Integration Flow Chart

Figure 6.118 illustrates the SCL integration of the case study note the is shift as the concentration is on the configurations tools.

6.4.3 Results

The case study proves that interoperable GOOSE messaging is possible. Naturally the next step is to evaluate the transfer time defined in IEC 61850-5. The case study is setup in a GOOSE ping pong manner between the three IED devices.

The evaluation of transfer time is only possible if the user has access to internal data of the device as defined in the IEC 61850-5 standard. The Figure 6.118 below illustrates the flow path of GOOSE message and process thereof.
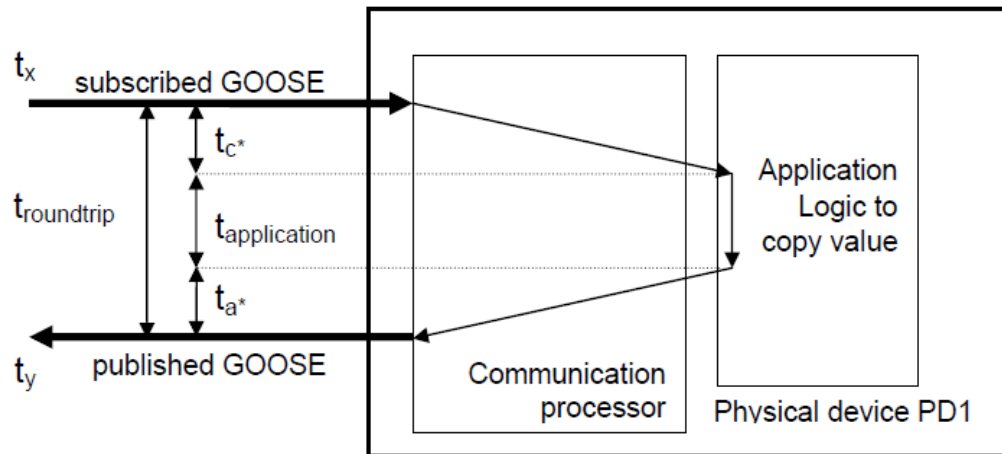
Figure 6.118: GOOSE message Roundtrip (UCAIug Testing Procedures)

t_{a*} = GOOSE publish communication processing time

t_{c*} = GOOSE subscribe communication processing

t_x = Arrival of subscribed GOOSE message time

t_y = Departure of published GOOSE message time

$t_{application}$ = application time

The round trip is defined as follows:

- $t_{roundtrip} = t_y - t_x$

Transfer time can be defined in relation to roundtrip time as follows:

- $t_{transfer} = t_{roundtrip} - t_{application}$

Note network delay is ignored and the application time is documented in PIXIT documents as a scan cycle. Note IEC 61850 edition 1 devices do not document the scan cycle thus this does not allow the case study to provide the transfer time of the device. Below are the different round trip times measured on the equipment.

The measurement of round trip time is calculated using the following tools namely:

- Siemens IED – Publish and Subscribe to GOOSE messages
- Schneider IED – Publish and Subscribe to GOOSE messages

- SEL IED – Publish and Subscribe to GOOSE messages
- Wireshark - Captures GOOSE message packets

Round trip measurement is taken from when Wireshark captures a GOOSE message. The time of capture is used as reference/start point and then time elapsed for GOOSE message reaction is measured through the three IED vendors. The results are tabulated on Table 6.2, Table 6.3, Table 6.4 and Table 6.5.

Table 6.2: GOOSE Message Round Trip Time

Device	1st state change		Packet / Line No	Round Trip Time	Refer to Figure 6.116 Interfaces
Siemens	stNum	2	51	START	1
	sqNum	0			
SEL	stNum	3	52	5.70ms	2
	sqNum	0			
Schneider	stNum	2	55	8.88ms	3
	sqNum	0			

Table 6.3: GOOSE Message Round Trip Time

Device	2nd state change		Packet / Line No	Round Trip Time	Refer to Figure 6.116 Interfaces
SEL	stNum	4	57	4.23ms	4
	sqNum	0			
Siemens	stNum	3	60	5.70ms	5
	sqNum	0			
Schneider	stNum	2	55	15.26ms	6
	sqNum	0			
Siemens				LED switched ON(End)	N/A

Table 6.4: GOOSE Message Round Trip Time

Device	1st state change		Packet / Line No	Round Trip	Refer to Figure 6.116 Interfaces
Siemens	stNum	6	12	START	1
	sqNum	0			
SEL	stNum	23	13	4.85ms	2
	sqNum	0			
Schneider	stNum	12	16	9.82ms	3
	sqNum	0			

Table 6.5: GOOSE Message Round Trip Time

Device	2nd state change		Line No	Round Trip	Refer to Figure 6.116 Interfaces
SEL	stNum	24	19		4
	sqNum	0		5.95ms	
Siemens	stNum	7	22	15.47ms	5
	sqNum	0			
Schneider	stNum	12	26	15.46ms	6
	sqNum	0			
Siemens	stNum	8	44	134.54ms (End)	1
	sqNum	0			

The results in Table 6.2 to Table 6.5 illustrate the round trip time of the various vendors when interaction with each other via GOOSE messages. Table 6.2 presents the round trip time for SEL IED and Schneider IED and illustrate initial states of the state numbers and sequence number. The SEL IED round trip is based on the subscription from Siemens IED GOOSE message. The Schneider IED round trip is based on the subscription from the SEL IED GOOSE message.

Table 6.3 presents the round trip time for SEL IED, Schneider IED and Siemens IED. The SEL IED round trip is based on the subscription from Schneider IED GOOSE message. The Schneider IED round trip is based on the subscription from the Siemens IED GOOSE message. The Siemens IED round trip is based on the subscription from the Schneider IED GOOSE message.

Table 6.4 and Table 6.5 present the round trip time for SEL IED, Schneider IED and Siemens IED. This is an additional test to illustrate Siemens IED to SEL IED round trip as indicated in Table 6.5.

6.5 Discussion

This section discusses the format of data in GOOSE messages, system engineering tools, IED naming conventions, Application Identifier (AppID), Configuration Revision (ConfRev); SCL file exchange and General Generic Input Output (GGIO) application.

6.5.1 Format of data in GOOSE messages

GOOSE message data can be sent in two formats namely data objects and data attributes. Due to endless problems by using data objects the recommendation is to use data attributes instead as this allows seamless integration

The format of data in GOOSE messages refers to Data Set (DS) and Data Attribute (DA). The GOOSE data format issue came to light during the early stages of testing interoperability between a Schneider and Siemens device. This was discovered when attempting to map Schneider GOOSE message to the Siemens device. The GOOSE mapping was done in the Siemens IED system configuration. The system configuration produced an error when mapping was attempted see Figure 6.119 below.
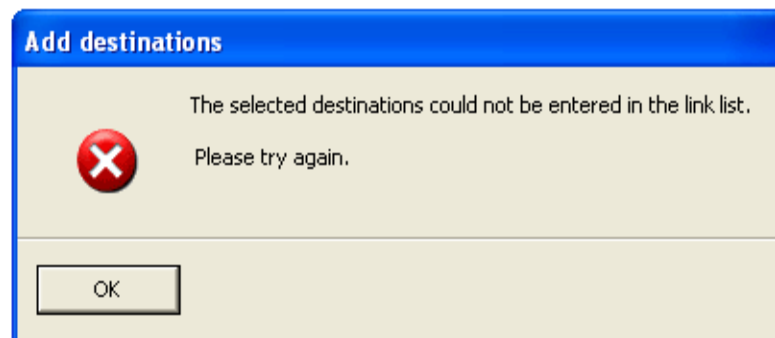
Figure 6.119: GOOSE mapping error message

A query to Siemens was submitted to their customer support centre. Siemens customer support requested all SCL files. Siemens customer support came to the conclusion that there was an additional time data attribute defined as indicated below, Figure 6.120.

Figure 6.120: XML extract Schneider dataset representation

The solution was to delete the time attribute and this was to be done on the XML file format of the Schneider SCL file. The deletion of the data attribute was done on XML mark-up software every single time integration of the system was required. As the research went along experiments with Functional Constrained Data Attribute (FCDA) instead of Functional Constrained Data (FCD) where done. This yielded that Siemens only accepts FCDA datasets rather than FCD data object. This meant that XML editing will no longer be required to achieve GOOSE mapping between Schneider and Siemens devices. The best way to achieve interoperability is to

198

ensure all GOOSE messages are configured with data attributes rather than with data objects as some vendors only accept data attributes

6.5.2 System Engineering Tools

The IEC 61850 tools for the considered IEDs are:

- Ascelerator Architect (SEL)
- Digisi 4 (Siemens)
- Micom S1 Studio (Schnieder)

The use of an independent IEC 61850 engineering tool was not possible. Proprietary IED configuration tools where used to compile CID files. This means that there was no master SCD file. Thus this means that file management may prove to be difficult. Digsi 4 may be used as reference because Digsi 4 is a system configurator as third party GOOSE messages can be mapped. Exporting the SCD file proves fruitless for third party GOOSE message as the mappings information does not carry over to the exported SCD file.

6.5.3 IED name (length/type)

Naming conventions by municipalities and utilities can cause hindrance to achieving interoperability. This is due to vendors imposing various limitations with regards to maximum characters for naming Naming conventions are seldom an impediment in laboratory interoperability tests. It is imperative that vendors expand on the maximum characters that are acceptable for naming conventions.

The below illustrate number of characters permitted by each vendor:

Siemens:

- 8 characters are permitted
- Numbers are not permitted as prefix
- A-Z (upper/lower case) must always be the prefix
- A-Z (upper/lower case), numbers and underscore are permitted

SEL:

- 1 to 29 characters are permitted
- Numbers are not permitted as prefix.
- A-Z (upper/lower case) must always be the prefix
- A-Z (upper/lower case), numbers,$ and underscore are permitted

Schneider:

- 65 characters are permitted
- Supports all characters and any character is allowed to be a prefix

IEC 61850-7-2 edition 1 dictates that IED name / Logical Device (LD) name can be up to 32 characters long including numbers, exclamation marks etc. It should be noted that LD naming did not pose a problem for this research but substation applications may suffer some difficulties in implementation. This is due to the fact that municipalities and utilities have their own naming conventions which may infringe upon vendor naming guidelines. This can impede interoperability drastically as vendors have different naming conventions rules.

6.5.4 AppID

AppID is defines/identifies the application with regards to GOOSE messages. The AppID is illustrated by 0x0000 to 0x3FFF hexadecimal (data type is unsigned16). IEC 61850-8-1 recommends that AppID should be source oriented rather than being assigned randomly. Note this is merely a recommendation rather than mandatory.

The below illustrates the AppID for the three vendors:

SEL

- Provides AppID full complement of identification of 0x0000 to 0x3FFF.
- AppID is entered as a hexadecimal value

Siemens

- AppID is entered as a decimal value

Schneider

- Provides AppID full complement of identification of 0x0000 to 0x3FFF.
- AppID is entered as a hexadecimal value

Each GOOSE message must have a unique AppID to ensure interoperability is possible.

6.5.5 ConfRev

Configuration revision is critical to file management and interoperability. The below indicates how each of the three vendors handle revision iterations:

SEL

- Allows for configuration revision to be entered manually

Siemens

- Increments the configuration revision should there be amendments on the data sets.

Schneider

- Prompts an increment should there be a change in the datasets and also allows manually changing the revision.

The configuration must be noted as there is no master SCD file, thus ConfRev needs to be closely monitored.

6.5.6 SCL file exchange

Substation Configuration Language is the critical part of GOOSE message interoperability. The SCL file exchange between the three vendors is discussed below, as follows:

SEL

- Allows for SCD, CID and ICD files to be imported in to Architect but only in CID format
- This is to merely allow the SEL device to map its subscription to the different vendor.

Siemens

- Allows for only ICD files to be imported in to Digsi 4 System configurator
- This is to merely allow the Siemens device to map its subscription to the different vendor.

Schneider

- Micom S1 Studio does not import different vendor SCL files
- For subscription mapping Micom S1 Studio binds via selecting the relevant SCL and selecting the appropriate dataset

Note Figure 6.117 indicates the GOOSE message integration flow and indicates the software package is indicated on the flow chart.

6.5.7 GGIO Application

IEC 61850 is object data oriented and vendors interpret it differently but within the bounds of the standard, hence it is assumed from different vendors are compliant. The mechanism to subscribe to GOOSE messages is not described in the IEC 61850 standard. This has made it difficult to identify the source of the GOOSE message, but this does not impact on the subscription mechanism. Vendors make use of various methods/syntax to describe/implement input GOOSE messages.

The mechanism to publish a GOOSE message is well documented in IEC 61850. Vendors are determined on implementing of GGIOs (General Generic Input Output). Although the use of GGIOs does not in any way make the device noncompliant to IEC 61850. Vendors make use of GGIOs as virtual inputs and outputs to publish and subscribe to GOOSE messages and utilised various Logical Devices to publish GOOSE message moving away from defined norm in IEC 61850. The Figure 6.121 below illustrates the different vendors use of GGIOs for GOOSE message LD, LN, DO and attribute.
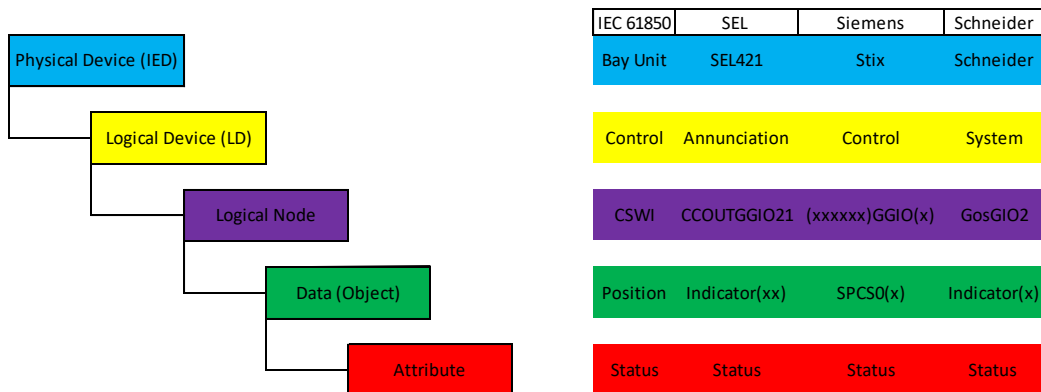
Figure 6.121: Publishing GGIO Illustration

The entire configuration process is composed of all these set of files being the various vendor CID files. No single file exists to describe the communication of the interoperable. This is a big deterrent to supply authorities to makes use of different vendors in a single substation. This causes a difficult document/file management for the technical staff. This issue can be combated with interoperable IEC 61850 configuration tools which are freely available. Note there are interoperable IEC 61850 configurations in the market but these tools are not free. It is in the best interest for all vendors to note that interoperability across the board will not be achieved unless the hurdles/obstacles are dealt with.

6.6 Conclusion

This chapter outlined the concept of GOOSE message interoperability between three vendors. It further discussed areas where improvement on the standard are required ensuring that interoperability is achieved seamlessly. This chapter also illustrates that the proposed methodology to achieve interoperability is functional.

Chapter seven focuses on conclusions, deliverables, and recommendations for the future work on different scenarios of interoperability within a Substation Automation System (SAS).

CHAPTER SEVEN
Conclusion and Recommendations

7.1 Introduction

IEC 68150 standard is being adopted around the world currently and this shows that Utilities and Municipalities have confidence in the communication protocol. IEC 61850 standard ensures that Utilities and Municipalities are not bound to a single vendor due to the use of proprietary communication protocols. IEC 61850 also ensures procurement of IEDs to be seamless and provides a platform for competitive pricing. This is because IEC 61850 standard provides interoperability across all IEC 61850 compliant devices thus ensures seamless integration and migration exercises. The results from the research work in the thesis has shown that to ensure IEC 61850 interoperability careful selection/ specification has to be conducted thoroughly even though devices are IEC 61850 compliant.

The thesis focuses on GOOSE message interoperability with the aim to investigate and develop methods to achieve interoperability with the use of commercially available tools. The evaluation of GOOSE message interoperability is investigated using three different vendors whose IEDs are IEC 61850 compliant.

The research investigates in detail GOOSE message interoperability with GOOSE message applications which are generic in a substation and develops a method to evaluate and achieve interoperability. The proposed methodology is implemented and simulated to illustrate GOOSE message interoperability. A test bed is implemented to illustrate GOOSE message interoperability.

This Chapter summarises the results obtained, key findings and the thesis deliverables. The deliverables of the thesis are presented in 7.2 of the chapter. The thesis research presents the various applications where the thesis deliverables can be utilised in part 7.3. Future work and development of this thesis are discussed in part 7.4. Part 7.5 indicates publications.

7.2 Deliverables

IEC 61850 interoperability is not fully utilised in the industry due to the complex device and system configuration required to be implemented in a Substation Automation System environment. This means that although IEC 61850 is being realised around the world it is still not being used to its fullest. Interoperability of

GOOSE messages is discussed at length and implementation is provided to prove interoperability is possible. The objectives of the research are as follows:

- Analysis of the IEC 61850 standard
  - Review of all parts of the IEC61850 standard
- Evaluate requirements for interoperability
  - PIXIT and MICS documentation review
- Evaluate various vendor interpretations of IEC 61850
  - PIXIT and MICS documentation review
- Evaluation of interoperability using various test methods and test tools.
  - Test methodologies used to assess concepts or test benches.
- Development of a lab scale protection and control scheme for interoperability evaluation
  - Tabulate results and lessons learned

The deliverables of the research are as follows namely:
- Literature Review
- IEC 61850 Standard Review
- Interoperability Methodology Development
- Design and Implementation of test bench to implement the proposed methodology

7.2.1 Literature Review

The literature review focuses on IEC 61850 standard complaint Substation Automation applications. The literature review is presented in Chapter Two with analysis looking at various literature which have analogies to GOOSE message interoperability and Substation Automation System configuration and integration. The literature review revealed that most interoperable applications are implemented by vendors rather than the user client, thus configurations challenges are not explored in depth and instead integration becomes the core of the implementation.

7.2.2 IEC 61850 Standard Review

The IEC 61850 standard is reviewed in Chapter Three to illustrate the various parts of the standard. The review of the standard reveals that various vendors interpret the standard itself differently and this may cause interoperability issues, although devices may be IEC 61850 compliant. The review shows that Substation Automation Systems implementers must have a fully rounded knowledge of the standard. This is

to ensure that it's easier to identify when a vendor has interpreted the standard differently to what was meant. The review also ensures what the IEC 61850 applications and capabilities of the standard are known and understood.

7.2.3 Interoperability Methodology Development

Conformance testing is critical to ensuring IEDs are in compliance to IEC 61850 standard. Conformance testing does not ensure effective communication among different IED manufacturers. This indicates that conformance testing does not ensure interoperability but merely ensures compliance to the IEC 61850 standard.

Conformance testing is an execution of a convention of the system being tried with regard to its particular functionality. The point is to test the functionality, thus to enhance the likelihood that the execution will depict effectively with a known or expected outcome condition. These tests are connected to functionality, and the test results are collated to the function. Based on the results of the examination a decision can be figured about the functionality which, if positive or negative, can be utilized to confirm the conformance of an IED.

The development of the interoperability methodology is presented in Chapter 4. Any testing or experiments were methodically formulated. The development of the methodology is formulated from existing methodologies rather than creating new methods. The proposed interoperability methodology is based on conformance testing process. The methodology provides the foundation to assess interoperability for any IEC 61850 compliant devices with ease. The methodology provides a blueprint on how to assess and implement interoperability of GOOSE messages and other applications in a Substation Automation Systems.

7.2.4 Design and Implementation of a test bench to implement the proposed methodology

The development of the design and implementation to prove GOOSE message interoperability spans across Chapter five and six. The development of a test bench is such that it brings about various scenarios namely publish and subcription capability. It is critical to test the ability of an IED to subscribe and publish to various vendor IED's. This assists in establishing the degree of GOOSE message interoperability. For industry purposes the interoperability methodology is integral as this provides what results should be expected during implementation testing.

Interoperability testing is attempting to discover interoperability among different vendors by methods for experimentation. The experimentation is generally done with basic functions of the IEDs, where typical and functionality is re-enacted. The point of testing is to pick up certainty that amid ordinary utilize the IED will work acceptably.

7.2.4.1 Hardware

Interoperability is the ability of an IED from vendor A being able to communicate with an IED from vendor B. The selection of equipment was to illustrate interoperability of GOOSE messages between two different IED vendors. The equipment comprised of three IEDs from SEL, Siemens and Schneider vendors, Omicron CMC356 and a managed Ethernet switch. The IEDs where installed in a star topology Ethernet network.

7.2.4.2 IED Device Configuration

The configuration of IEDs from different vendors is conducted on their respective proprietary configuration tools. The three IEDs are configured with the use of the software in Table 7.1.

Table 7.1: Configuration Tools

Manufacturer	Configuration Tool	Version
Siemens	Digsi 4	4.83.11
SEL	Ascelarator Quickset	5.0.4.3
Schneider Electric	Micom S1 Studio	3.4.1

7.2.4.3 Integration

Chapter five and six provided the flow of the individual IEC61850-based devices configuration through their vendor proprietary tools. This was followed by system configuration and GOOSE mapping between devices. Block diagrams of all IEDs (subscribers and publishers) were provided to enable users to simply track the functionality of GOOSE messages between IEDs. This is because no single SCD file exists that can describe an interoperable system due to the use of proprietary configuration tools for GOOSE message configuration.

7.2.5 Experiments and Recommendations

Chapter six demonstrated that GOOSE message interoperability in a multi-vendor system is possible. The GOOSE message interoperability or peer-to-peer communication between SEL, Siemens and Schneider IEDs was achieved and demonstrated using Wireshark as a network analyser.

The Table 7.2 illustrates the items/situations that can impede interoperability and solutions thereof.

Table 7.2: Interoperability Functionality

Item	Description	Comment
GOOSE Message Data format	Refers to the data set or data attribute	Use of data attribute rather than data set to achieve interoperability
System Engineering Tools	Refers to IED specific configuration tools	Create block diagrams to scope GOOSE message communication as no single file exists to describe the an interoperable system
IED Name Length	Length of Name of IED	Review length minimum characters across all IEDs that are to be used an interoperable system
AppID	Identifies the GOOSE application	Ensure all IEDs in the network have a unique AppID
ConfRev	Refers to configuration revision	Ensure configuration
SCL File Exchange	File Management	Lack of file management of SCL files due to the lack of one master SCD file

7.3 Application of the Thesis Deliverables

The research thesis deliverables provide the foundation for complex interoperable SASs. The research can be expanded and used for factory acceptance tests for interoperable SASs being done by:

- Municipalities
- Utilities
- Independent Power Producers (IPPs).

The proposed interoperability methodology evaluation can be used as procurement tool to ensure bids have IEDs which are interoperable. The methodology can further be of use to investigating vertical communication in SAS.

7.4 Future Work

This research project targeted interoperability at the bay level of a substation and narrows down to peer to peer messaging. For future interoperability research various

scenarios of GOOSE messaging can be explored and the following devices can be investigated using different combination of vendors at the process and station level:

- o Merging Units

- o IED's

Further research is required to explore interoperability for IEC 61850 devices with regards to the edition (Edition 1 and 2) they conform to. Engineering Configuration for this research project was achieved with great difficulty due to file management of SCL files was not possible due to vendor proprietary configuration tools. A review of third party tools is imperative for the implementation of interoperability.

7.5 Publications

- Mguzulwa NR, Tzoneva R (2018) Formulation of GOOSE message Interoperability Evaluation Methodology, Sent to Journal of Electrical Engineering and Technology (JEET), August 2018

- Mguzulwa NR, Tzoneva R (2018) IEC 61850 GOOSE Message Interoperability Case Study: Circuit Breaker Failure, Sent to Journal of Electrical Engineering and Technology (JEET), August 2018

- Mguzulwa NR, Tzoneva R (2018) Review of PICS, MICS and PIXIT documentation for Interoperability capability, Sent to Journal of Electrical Engineering and Technology (JEET), August 2018

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