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IEC16850 standard-based islanding detection algorithm for distributed generator integrated power systems

by

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DECLARATION

I, Abuyile Mpaka, 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.

24/02/2023

Signed **Date**

ABSTRACT

The integration of DGs in power system network is related with several protection and security challenges. The islanding detection is one of major problems, when the power grids' service is disconnected while the DGs are still in use. As a result of this phenomena, stability and power quality may worsen as the DGs may not be able to maintain voltage and frequency. The security of the utility employees may also be at risk during the islanding stage. Due to the harmful effects of unplanned islanding brought on by high DG penetration. Technical standards like UL 1741, IEEE 1547, and IEEE 929 have all addressed the islanding phenomena.

Load shedding and island detection systems are used if the synchronized generator is unable to meet demand according to the literature. The distributed energy resources were used in this study to concentrate on the islanding detection scheme for distribution systems. The load flow is examined under various system operating conditions of the distribution system. The fault analysis is carried out to determine the protective configuration settings for the case study under consideration and to analyse the breaker capacity. For the distribution systems under consideration, the research looked into voltage-based protection mechanisms. In order to test the protection functioning of the micro grid system, a lab-scale protection test bench is set up at the CPUT CSAEMS laboratory utilizing a generator protection relay and test injection device.

The IEC 61850 engineering configuration based on GTNET-GSE protocol using ICT600 tool is performed within RSCAD simulation environment. The project implemented the hardware-in-the-loop simulation using real-time digital simulator to evaluate the voltage and frequency-based protection functions of the considered distribution system. Simulations were used to carry out the performance evaluation of the hardwired and GOOSE simulations. The simulation's findings show that the simulated distribution system satisfies the protection requirements for both hardwired and IEC61850 GOOSE applications.

Keywords: Distribution system, Renewable energy resources, Islanding, Power Loss detection, Voltage protection, Frequency Protection, HIL Simulation and IEC61850 GOOSE Application.

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- Throughout the thesis preparation phase, I would like to thank laboratory technicians from the Centre for Substation Automation and Energy Management System for their assistance.
- The final thing that I would like to mention is I am grateful for the financial assistance I have received from CPUT.

DEDICATION

As a gesture of gratitude to my mother Nobuhle Princes Mpaka and my siblings, this thesis is dedicated to them. In addition, I would like to dedicate this thesis to the memory of my later father Zama Obed Mpaka, and to my entire family for their patience and lastly, I would like to dedicate this thesis to my supervisor Dr. Senthil Krishnamurthy for support me throughout this thesis.

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GLOSSARY

Algorithm - A step-by-step procedure for solving a problem using a computer.

Busbar – A common connection point in a distributed network substation.

Distribution – The conveyance of electricity through a distribution network.

DigSilent – Power systems modelling, analysis and simulation software for applications in generation, transmission, distribution and industrial systems.

GOOSE – is a high performance multi-cast messaging service for inter-IED communications, and is used for fast transmission of substation events.

IED – Intellectual Electronic Device describes microprocessor numerical based controllers used in power system equipment and performs a power system computation based on the inputs received and produced an output signals for the operation of the circuit breakers.

Interoperability – Ability of two or more IEDs, regardless of the vendor, to exchange information and use that information for correct execution of specified functions.

IEC 61850 – The standard for communications network and systems in substations, it provides an internationally recognized method of local and wide area data communications for substation and system-wide protective relaying, integration, control, monitoring, metering and testing.

Logical nodes – Used by IEC 61850 as a key element to define the information of a device to be communicated.

Numerical Relay – A relay capable of acquiring instantaneous samples of voltage and current and process them using mathematical algorithm.

Protection system – A system, which includes equipment, used to protect facilities from damage due to an electrical or mechanical fault or due to certain conditions of the power system.

Relays – Multifunctional devices using numerical algorithms that can easily duplicate any of the protection functions with simple software modifications.

Reliability – The possibility of a system, performing its function sufficiently for the period intended, under the encountered operating conditions.

Stability – The quality or attitude of being firm and steadfast, reliable and balanced power system.

SCL – Substation Configuration description Language is the language defined by the IEC 61850 standard used for the configuration of substation devices/apparatus.

Supervisory Control and Data Acquisition – is a process control system that enables a system operator to monitor and control processes distributed among various remote sites.

Substation Configuration description Language – is a description language for communication in electrical substations related to the IEDs.

Voltage Transformer - A device that transforms voltage from one magnitude to another magnitude.

Nomenclature

ADA	Advanced Distribution Automation
AC	Alternating current
A/D	Analogue to Digital
CT	Current Transformer
CM	Condition Monitor
DC	Direct current
DG	Distributed Generation
DSP	Digital Signal Processing
EFPIOC	Instantaneous Residual Overcurrent Protection
GOOSE	Generic Object Oriented Substation
HV	High Voltage
IdM	Islanding detection method
IM	Impedance measurement
IEC	International Electrotechnical Commission
IEDs	Intelligent Electronic Devices
IPDN	Integrated power distribution network
IFD	Internal Fault Detector
IEEE	Institute of Electrical and Electronics Engineers
LAN	Local Area Network
LV	Low Voltage
O/UVP	Over/Under voltage protection
O/UFP	Over/Under frequency protection
PLC	Power line communication
PLL	Phase-Locked Loops
RTDS	Real Time Digital Simulator

ROCOF	Rate of change of frequency
ROCOP	Rate of change of power
SCADA	Supervisory control and data acquisition
SAS	Substation Automation System
SCL	Substation Configuration Language
SHR	Second harmonic ratio
VDM	Vector Diagram Monitor
VT	Voltage Transformer
UCA	Utility Communication Architecture
PIOC	Instantaneous Phase Overcurrent Protection

CHAPTER ONE

INTRODUCTION

1. Introduction

The increase in technological advances, improvement in the standard of living, and population growth have led to energy demand increase. The economic growth has been fuelled by fossil fuels in the 20th century by being less expensive and are in abundance. Fossil fuels are still the primary energy provider globally but produce a lot of greenhouse gasses that degrade the environment. There is a quest to reduce the carbon footprint by employing clean renewable energy in the utility network. They improve efficiency, provide energy security, and reduce emissions and are less energy-intensive which is critical for sustainable development goals(Rakotomananandro, 2011; Shi et al., 2020a).

The power system industry is progressing towards distributed generation hence the increase in microgrids implementation (Ustun et al., 2013). A microgrid is a small easily operatable grid that comprises of microgenerators, loads, and storage systems. The challenge of microgrids is coping with the power-imbalance especially in islanding operations which leads to the uncontrolled island. It is of paramount importance to quickly detect and have swift measures to mitigate the hazardous situation and have the microgrid in stable operation. Failure to detect results in poor power quality, reverse power flow, and system instability. Once the isolation is discovered, the disconnection must occur in 2 seconds which is endorsed by IEEE at the point of common coupling (PCC) and transit to isolated mode. This mitigates against unwanted power injection to the grid which may destroy equipment and even endanger lives(Shi et al., 2020a; Ustun et al., 2012).

DG must be disconnected from the power systems network once there is a detection. Islanding can be deliberate or accidental. The shutdown of the grid due to maintenance on the utility can trigger generator islanding. Since the grid loss is voluntary, the islanding is referred to as non-intentional islanding due to accidental shutdown of the grid is of greater concern. Since there are a variety of challenges concerning unintended islanding. The operation of island mode concerns power plants that operate in standalone from the national or local grid. Generators that are parallel with the grid can generate independently in case there is a power failure from the grid.

A lot of researchers implemented many ways of mitigating the islanding but none have ever implemented the method of new algorithm using voltage elements and frequency elements protection scheme on DigSilent and RTDS. This new algorithm has proven that islanding can be detected in a faster way than before, the implementation of IEC61850 on RTDS for GOOSE messaging shows that operating time for Hardwired is not faster than GOOSE messaging and that is why this research has closed the gap on the islanding.

This chapter is outlined as follows: Part 1.1 introduces the Awareness of the problem to be mitigated on this research. Part 1.2 is the problem statement. Part 1.3 is the research aim and objectives. Part 1.4 is the hypothesis. Part 1.5 is the delimitation of research. Part 1.6 is the assumptions of this thesis. Part 1.7 is the research design and methodology. Part 1.8 covers the Data collection. Part 1.9 is the thesis chapters and the conclusion.

1.1 Awareness of the problem

Modern grid complexity and increasing climatic change have resulted in more extreme grid power outages caused by natural calamities and human interruptions, and therefore that is why we need to have a connection to operate the micro grid system both grid connected and islanded modes of operation. The development of new algorithm using voltage and frequency protection elements. The assumption is that IEC61850 GOOSE communication is faster than hardwired signals.

1.2 Problem statement

The islanding method involves disconnecting dispersed generators from the main electrical network but allowing them to deliver load independently of the grid. DG mitigates the absence of active power production sources in distribution networks and the loss of electricity in the event of a transmission line breakdown.

1.3 Research Aim and Objectives

The fundamental goal of this research is to investigate the micro grid system both grid connected and islanded mode operation with the wind turbines connected to the micro grid system and the investigation includes the protection functionality of the micro grid system.

1.4 Objectives

- To conduct an extensive literature review on islanding detection methods.
- Model and simulate the considered feeder network in Digsilent and RSCAD software simulation.
- Develop a new Islanding detection algorithm using Overvoltage, Under voltage, Over frequency, Under frequency protection elements, with distributed energy resources.
- To implement the lab-scale setup to test the Islanding detection for the DG integrated power systems.
- To implement the Hardware-in-the-loop simulation using RTDS, and test the Islanding detection condition with DG integrated power systems.

1.5 Hypothesis

- Modelling the micro grid system with wind turbine renewable energy sources to operate the micro grid system with both grid-connected and islanded modes of operation.
- Hypothesis to validate islanding protection function by using SEL700G protection relay considering voltage and frequency protection elements for stage 1 and stage 2 islanding detection.
- The IEC 61850 implementation on RTDS using GTNET-GSE to validate the GOOSE messaging application for the micro grid system both grid-connected and islanded modes of operation.

1.6 Delimitation of research

The thesis focuses exclusively on the islanding detection in micro grid system with the use of IEC61850 application.

Research investigations of this thesis do not include the following protection schemes:

- Overcurrent Protection scheme excluded because project focuses on the voltage protection which is more sensitive in comparison with current-based protection schemes.
- Differential Protection and Busbar Protection scheme is excluded and the project focus on microgrid system.

1.7 The motivation of the research project

The research motivation is to operate the microgrid system with both grid-connected and islanded modes of operation. The literature provide evidence for different current-based protections scheme applied for the microgrid system; however, the focus of the project is investigating the voltage-based, frequency-based protection schemes. The digitalization is other major motivation, this project implemented the IEC61850 GOOSE application for the microgrid protection system and tested the scheme with hardware-in-the-loop simulation. This yields a reliable power system, better control, monitoring, and protection functions.

1.8Assumptions

The following assumptions are taken in the development of an algorithm to enhance the reliability of Islanding detection.

- The engineering configuration for testing islanding voltage waveform protection and islanding frequency protection with the use of SEL vendor relay, this protection can be done with ABB or any other vendor, but the assumption is, I consider the SEL 700G relay to implement and validate the islanding protection scheme.
- The type of DG that is considered is wind turbines.
- The Hardware-in-the-loop simulation utilized Real Time Digital Simulator devices at CSAEMS laboratory at CPUT.
- Reduce copper wiring using the IEC61850 standard-based protection schemes.
- Overall to improve the reliability, better control, monitoring, and protection functions of the electricity network.

1.9 Research Design and Methodology

In distribution networks, it's critical to be able to identify islands. Utilizing such sources has also raised a number of problems, including the islanding problem, as a result of the significant improvement of renewable energy supplies in distribution grids. It is also used to maintain an island that has been planned by switching the controls on the DERs. The protection system's dependability is improved by the use of protective relays do detect islanding, and the most common functions are: under/over frequency

(ANSI 81U/O), rate of change of frequency (ANSI 81R), vector surge (ANSI 78) and under/over voltage (ANSI 27/59). Therefore, in this project lab-scale setup is established to test the distribution system protection functionality for the both gird-connected and islanded modes of operation. Hardware-in-the-loop simulation is performed to evaluate the performance of the hardwired and IEC 61850 GOOSE applications for the considered distribution system using voltage and frequency-based protection functions. The following are the details of the research methodology presented in this section:

1.10 Literature review

Several systems are utilized in the context of islanding detection; however, IEC 61850 is the primary topic of a thorough investigation. Active and passive Islanding detection methods are reviewed in detail. Information is collected via reading IEEE publications, related books, speaking with engineers at Eskom, and using online resources.

1.11 Protection scheme

The main goal of this research is to develop a new algorithm that will use overvoltage, undervoltage, overfrequency, and underfrequency protection elements to mitigate an islanding detection. This algorithm will then be programmed into a SEL 700G protection relay for an Islanding detection condition that operates in both grid connected and islanded mode.

1.12 Implementation

The distribution network is modelled in DigSilent and the power flow is investigated for different system operation conditions. The faulty study is conducted in DigSilent and the voltage and frequency-based protection is tested in the DigSilent Simulation environment.

The lab scale setup is established at CPUT, CSAEMS lab and the protection functional testing is conducted to evaluate the performance of the system. Protection Hardware-In-the-Loop simulation is conducted using RTDS and SEL700GT generator protection relay. The ICT600 tool within RSCAD software environment using GTNET-GSEv5 protocol is used to evaluate the protection performance using IEC61850 GOOSE application.

1.13 Data collection

The case study considered in the simulation is adopted from the(Abdulhadi et al., 2011). The data of the distribution system given in Chapter 4, Table 4.1 consists of a 220/33/11kV step down transformer (T1) linked to the medium voltage 33kV Bus and the Low voltage 11kV Bus.

1.14 Thesis chapters

This section provides a synopsis of the research, which is followed by the chapter content summary and two appendices that provide the documentation of the research findings. Following are thorough summaries of each chapter's contents:

1.14.1 Chapter One

Introduction to the concept and background of islanding detection on distributed networks. The aims and objectives of the research, the motivation behind it, the scope and limitations of the research, as well as the background of the research are presented in this overview.

1.14.2 Chapter Two

This chapter's objective is to review the material on islanding detection strategies for distribution systems that rely on voltage and frequency protection. The review study scope is investigated thoroughly with regards to the relevant topics: a) IEC 61850-based HIL protection simulation; b) active and passive islanding approaches; and c) protection system for DG integrated power systems.

1.14.3 Chapter Three

Theoretical concepts of islanding detection methods utilized in power system distribution networks are presented in this chapter. Additionally, the chapter provides theoretical information about the techniques for islanding detection that use voltage- and frequency-based protective mechanisms.

1.14.4 Chapter Four

In this chapter, DigSilent simulation software is used to analyse the distribution network. The load flow is examined under various system operating conditions of the distribution system. The fault analysis is carried out to determine the protective configuration settings for the case study under consideration and to analyse the breaker capacity. The voltage and frequency-based protection is tested in the DigSilent Simulation environment.

1.14.5 Chapter Five

The islanding protection scheme's lab-scale testing is covered in this chapter. The lab scale setup is established at CPUT, CSAEMS lab and the protection functional testing is conducted to evaluate the performance of the system. This chapter also covers the configuration options for the SEL 700GT generator protection relay, which use the following elements as the primary protection: (27) under-voltage and (59) over-voltage elements. The appropriate voltages for testing the islanded protection system have been provided by Omicron CMC 356.

1.14.6 Chapter Six

Protection Hardware-In-the-Loop simulation is conducted using RTDS and SEL700GT generator protection relay. The ICT600 tool within RSCAD software environment using GTNET-GSEv5 protocol is used to evaluate the protection performance using IEC61850 GOOSE application.

1.14.7 Chapter Seven

This chapter provides thesis deliverables, publication, conclusion, and future recommendations.

1.14.8 Appendix A

This Appendix contains information about the SEL 700G Generator Protection Relay and the protection components that it supports.

1.14.9 Appendix B

The DigSilent Power Factory results are included in this Appendix.

1.14.10 Appendix C

This appendix describes the engineering configuration of the IEC61850 datasets used to test the protective functionality. Appendix provides the overview of the datasets configured in ICT 600 Engineering configuration suite.

1.14.11 Conclusion

The chapter provides project aim, objectives, problem statement, assumptions, hypothesis, project delimitations, research methodology, data collection, overview of the thesis chapter, and summary of the appendices.

The literature review on active and passive islanding detection techniques is covered in the following chapter.

CHAPTER TWO

LITERATURE REVIEW

2. Introduction

It is of critical importance to force the islanding under frequency and/or under voltage by tripping all the breakers from the source to isolate DG from the grid. A distributed generation (DG) network requires complex safeguards to protect it. DGs have become more and more popular in recent years due to their installation at the low and medium voltage level of distribution networks all over the world(Vasquez-Arnez et al., 2015). Protection schemes for distribution networks are often designed without DGs from the beginning(Ngaopitakkul et al., 2013)(John & Ebenezer, 2022). There are two types of distribution networks: radial and mesh. Interconnected regulations apply to distribution utilities as a means of protecting distributed networks from the penetration of DGs(El-Zonkoly, 2011). It is for this reason that protection schemes are required, which can identify and isolate faults immediately after they occur(Merino et al., 2015). As a result of these schemes, the requirement for the disconnection of DGs is more easily met as protection coordination is assured and power islands can be intentionally created with ease(CARDENAS et al., 2009), . Power generation at the distribution level is on the rise, fossil fuel consumption is decreasing, and it is becoming more crucial to ensure high power quality and reliability(Shahzad et al., 2017). Due to the much lower magnitude of fault currents in islanded systems than in grid-connected systems, the protection system of an islanded system must be more sensitive(Muangchareon et al., 2013), (Rugthaicharoencheep & Chalangsut, 2013).

A further distinction is made between passive methods (methods that depend only on local measurements) and active methods (methods that directly interact with the power system operation by introducing small perturbations(Abd-Elkader et al., 2018), (Habib et al., 2022). In addition to introducing disturbances into the power system, active islanding detection methods also negatively impact the quality of the power(Anudeep & Nayak, 2018), (Anudeep & Nayak, 2018). There are passive techniques that check for deviations in certain parameters, such as voltage magnitude, frequency change rate, harmonics, and phase angle change(Kim et al., 2019). All grid-connected PV inverters must meet the under/over frequency (UOF) and under/over voltage (UOV) protection requirements.(Abokhalil et al., 2018). In order to determine whether islanding has occurred, these parameters are compared to a threshold value(Shi et al., 2020b). Because passive techniques are cost-effective and reliable, they are suitable for practical implementation, but their main limitation is their large Non-detection zone(Younas & Raza, 2019), (Pandit et al., 2019).

The capability of sending messages to shed some of the load, receive information about the load or generation is through the IEC GOOSE(Adamiak et al., 2009). The frequency fluctuation by +/- 0.5 Hz of the specified 50Hz then islanding mode of operation will be triggered. With the increasing number of DGs installed, several negative impacts have also emerged, including increased thermal constraints on utility assets, voltage level control issues, reversed power flows, and network protection issues, which pose serious challenges to future deployments of DGs(Berni et al., 2014),(Ali et al., 2012). GOOSE messages are used by the central controller to send tripping commands to the distributed generators when the circuit breakers are tripped. Known as the IEC 61850, this international standard is designed to improve the efficiency of electrical power systems and is likely to have a major impact in the future(Ozansoy & Frearson, 2016), (Bayrak & Cebeci, 2016).

In this paper, a range of aspects of the IDLS-based IEC 61850 scheme are discussed, including the design of the communication network, Generic Object Oriented Substation Event (GOOSE) messaging, and the development of two discrete control schemes for island detection and load shedding(Silos et al., 2017), (Bhushan et al., 2022). The communication link of a modern line differential protection allows islanding protection to be developed in a fast, reliable, and selective manner(Lloret et al., 2007), (Yeh et al., 2015). An application of the transfer-trip scheme based on the generator protection relay communication channels is used(Zhao et al., 2011), (Silos et al., 2017). In order to enhance the accuracy and reliability of the anti-islanding protection, high-speed BST (Binary Signal Transfer) signaling at the substation level is combined with IEC 61850 GOOSE messaging(Etxegarai et al., 2011).

This chapter is outlined as follows: Part 2.2 Grid integration and protection impacts of DGs on distribution network. Part 2.3 Background of Islanding detection and the techniques used for islanding detection (Passive, Active and communication based). Part 2.4 presents the IEC61850 based HIL protection simulation. The final section 2.5 is the conclusion of this chapter based on the review discussions.

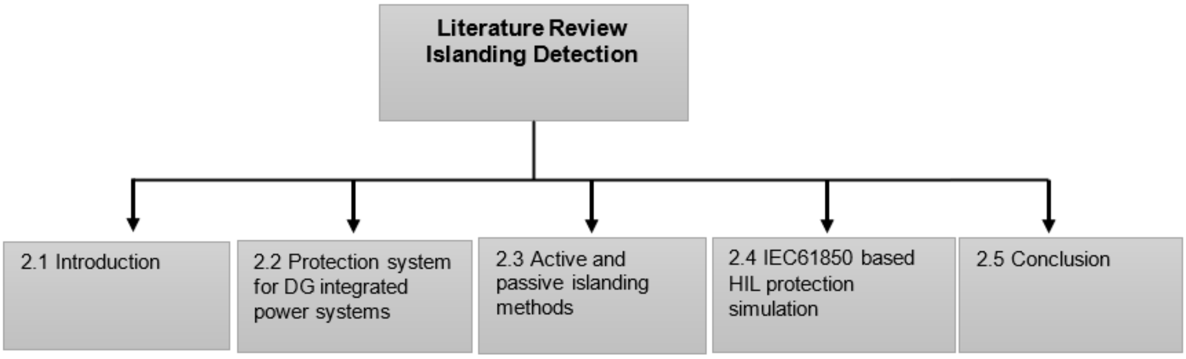

Figure 2. 1: Literature Review block diagram for chapter two

An overview of the number of papers reviewed from 2005 to 2022 is provided in Figure 2.2. In this series of papers, papers focusing on the history of detecting islanding have been selected to represent the field of protection in power systems.

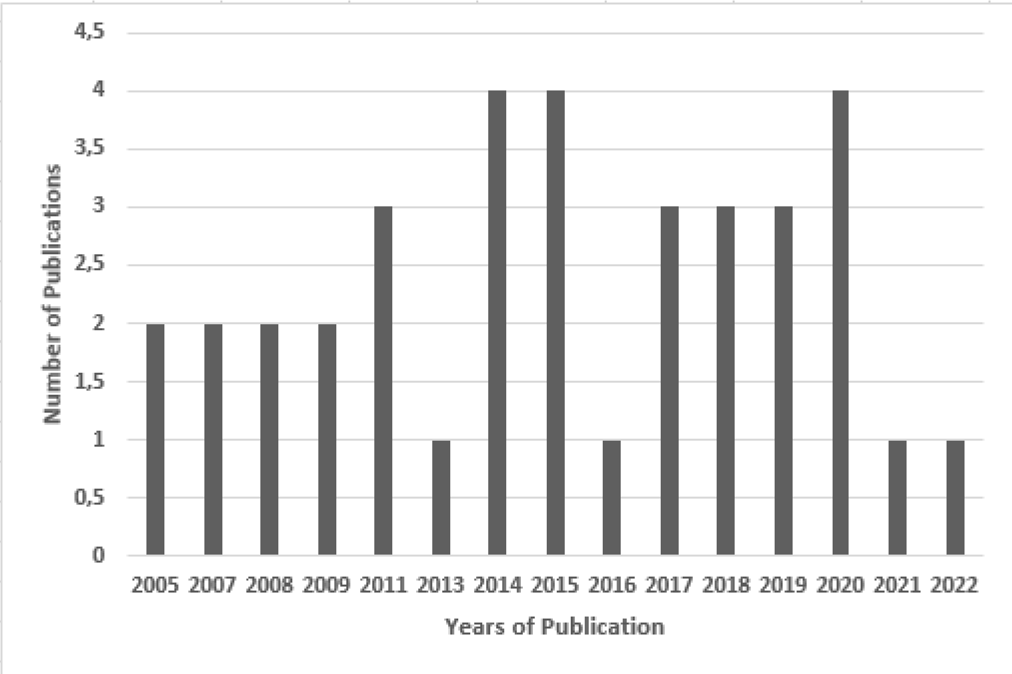

Figure 2. 2: Bar-graph for paper reviewed Publications Vs Year

According to the graph above, there are three topics covered; protection systems for DG integrated power systems, active and passive islanding methods, and the simulation of HIL protection based on IEC61850. As can be seen from the literature review list, there are 37 papers on the topic of generator protection from the year 2005 through 2021, only covering chapter 2 and user manuals. In addition to this, the graph also shows that many papers were published in 2014, 2015 and 2020.

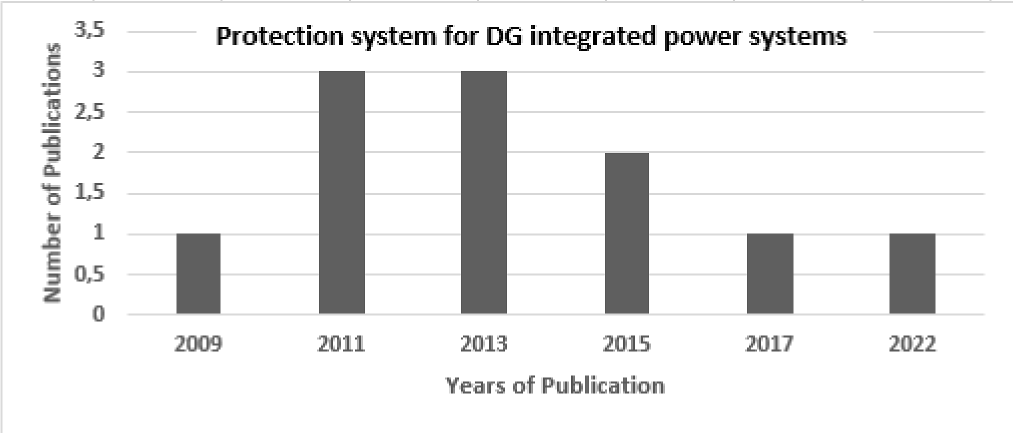

Figure 2. 3: Publications on protection system for DG integrated power systems

Based on figure 2.3, which shows the number of publications related to protection systems for distributed generators integrated power systems, a greater number of papers have been published.

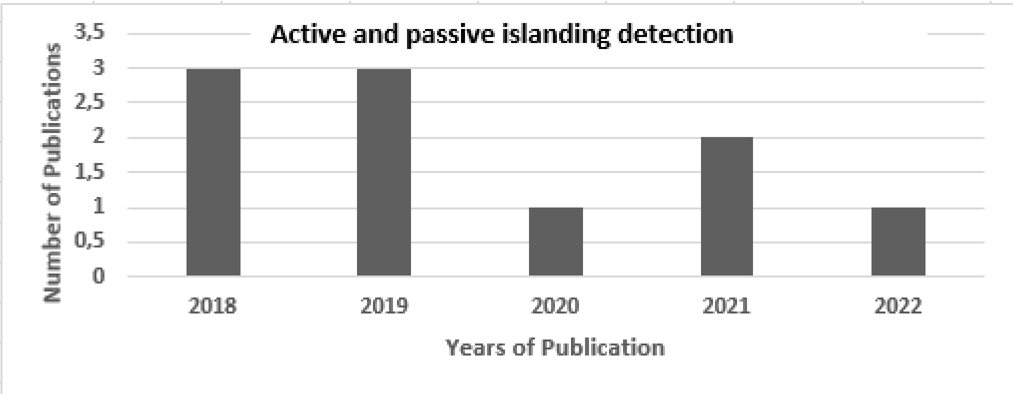

Figure 2. 4: Publications on Active and passive islanding detection

A figure 2.5 below depicts the number of papers on IEC61850-based HIL protection simulation published

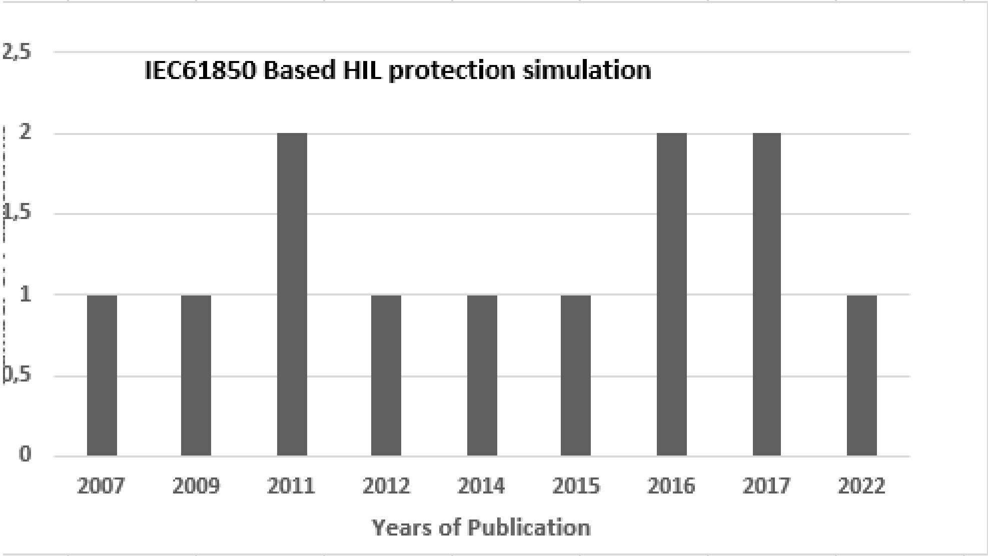

Figure 2. 5: Publications on IEC61850 based HIL protection simulation

2.1 Grid integration and protection impacts of DGs

Radial topologies are used in traditional distribution networks, assuming a single source of in-feed and radial current flow. Due to the fact that DG connections generate an increase in the fault levels near them, the total fault level may exceed the designed fault level for the distribution equipment due to an additional fault level from the generator. The plant will suffer damage and failure at fault levels above the level of protection, which could result in plant failure and worker injury. Since different distributed generation methods contribute to different levels of current faulting in different configurations, it is crucial to ensure proper protection of the distributed generation system. (Cui et al., 2018).

A solar power system has various components distributed throughout the system. On the other hand, wind energy system components are being assembled close to the tower. Power is transferred from the shaft of the rotor to the collector by the drive system (Akhtar et al., 2022).

Reliability, security, technological improvements, regulatory concerns, and needs for emission reduction are a few of the elements influencing the rise in the penetration levels of renewable energy (RE). Distributed renewable energy systems have the ability to provide reactive power, which system operators can use to mitigate voltage spikes brought on by the addition of active power to the grid. With reactive power injection, voltage rises become neutralized, allowing renewable energy systems to operate on the network more effectively(Yeh et al., 2015).

In recent years, distributed generators have generated increasing attention as a source of DC current for distribution networks. Transformer less inverters are causing distribution transformer saturation by injecting sufficient current into distribution circuits. As a result, there is a chance that a DC component (offset in voltage or current) will manifest and flow into the grid. (Wasiak & Hanzelka, 2009).

DES interconnection should be developed as a modular global architecture offering common features for power conversion, power conditioning and quality, protection, DES and load management, communication, auxiliary services, and metering. The ability of distributed generators to resist shocks without triggering false grid interface protection trips, experiencing under- or overvoltages, or experiencing any other problems is crucial. (Wasiak & Hanzelka, 2009).

2.1.1 Techniques for mitigating issues with DG penetration

As DG penetration rises, it is also required to boost grid flexibility. The locations where DG is being implemented in utility systems and the significant challenges it faces have been covered in the previous sections. A distribution system that is capable of fault detection can be enhanced by upgrading existing equipment such as circuit breakers. Multiple DG units and their controllers should be kept apart to minimize control interactions. When distributing electricity throughout large networks, some precautions should be taken, such as coordinating controllers and keeping DG plants at a minimum distance from one another(Chiradeja et al., 2018).

By employing DG to support the system during a prolonged outage brought by by a network failure, islanding entails restoring a portion of the load until the fault is fixed. Parts of the distribution network are electrically isolated from the rest of the electricity distribution system as part of this approach, and they are locally managed by a power controller. The detection of faulty network portions, the rapid disconnection and automatic reconfiguration of the network are vital for turning this theoretical possibility into an everyday practice(Celli et al., 2005).

It is the main concern of the power system industries to maintain high levels of reliability of their power supplies. Power utilities must ensure that new connected loads and supplies do not affect their network or protection system. When reverse and forward current flows are smaller than the threshold value for the protection setting, the trip may fail. It is possible for two adjacent feeders to experience protection miscoordination when DGs are used in distribution networks(Norshahrani et al., 2017).

Unintentional islanding prevention is a key issue with microgrids. A condition known as an island occurs when DERs are used to power a network in a microgrid system and are cut off from the utility grid. In islands, power generation continues despite the isolation. This method of operation has a number of drawbacks, including asynchronous reclosing, power quality reduction, and potential risks to personal safety. (Ganivada & Jena, 2020)

2.1.2 A study of the islanding phenomenon in power systems

Electricity islands occur when distributed generation units are involved in the power distribution system. There is a situation in which DG units continue to energize a portion or the entire load within an area that is isolated from grid supply for any reason. That occurs when DG units are running independently of grid supply. Therefore, the distribution utility can't guarantee quality or stability of supply on the island as a result of losing control over supply on the island(Ekonomou et al., 2016) and (Mustafa Bhutto et al., 2014)

The distribution networks were passive in nature, therefore there was no power source infusing power into them in the past. Because of this, utilities' protection plans took care of any network faults that arose. This presumption is no longer accurate as a result of the introduction of DG at the distribution level, and additional analysis and research are needed to solve the problem of islanding in power systems. (CARDENAS et al., 2009).

2.1.3 Review discussion on Grid integration and protection impacts of DGs

In this study, we examine the effects of DG integration on protection systems as described in other research works and analyze some of the approaches provided by academics in other research works. It is found that integrating distributed generation can improve the operation of power grids (DG). Even though DG units have a real impact on electrical grids, there are many issues and worries about how faults should be separated and recognized as a result of their perceptible impact on power network protection systems. With increasing energy demands, DG units are being integrated into distribution networks as a reasonable alternative to costly network expansions. Although the integration benefits consumers and power grids, it also poses challenges in terms of control and protection(Meskin et al., 2020). This section discusses the benefits of converting a distribution network into an active electrical system, as well as potential difficulties protection systems may encounter.

A change in the fault current level within the power system would impact power distribution units, which are a part of the protective systems that are impacted by DG units. This section examines the potential harm that DG unit integration may have on PDs. (Meskin et al., 2020). These causes may cause the power flow to reverse;

Untrue tripping, protection blinding, unwelcome islanding, asynchronous closing, and major power outage.

Within the reviewed papers on Table 2.1, different methods and implementations indicated that there can be still a better way of detecting islanding at low Remote is the most expensive of these techniques compared to passive and active techniques.

Table 2. 1: Review of the Protection for DG integrated systems

Paper	Aim	Methods	Communication & Protocol	Simulation or Implementation	Benefits	Protection
U.Shahzad, S.Asgarpoor.,2017	should reevaluate all preventative measures and broaden them to include larger systems that have a significantly higher proportion of distributed generation	Application of drone technology in protection of active distribution systems	Not mentioned	DigSilent Power Factory and MATLAB	Bidirectional power flows in distribution networks connected to DGs are increasing the reliability of the power system.	DG Protection
A.Ngaopitakkul, C. Pothisarn, S. Bunjongjit, B. Suechoey., 2013	To study the reliability due to employment of DG's integrated to distribution system	Method to analyse and evaluate the reliability of the transmission equipment in electrical system	Not mentioned	DigSilent Power Factory	increasing system average interruption duration and frequency metrics, which measure customer reliability	Not mentioned

G. Bayrak, M. Cebeci., 2014	When connected to an electrical grid, PV-based Synchronous Generators must have certain electrical link requirements	A hybrid methodology that combines efficient methods of communication and passive methods.	IEEE 929-2000 standard	Simulation using MATLAB/SIMULINK	The approach is powerful and offers a practical islanding solution so that grid-tied PV systems can be easily implemented and used in real device applications.	Not mentioned
N. Rugthaicharoencheep, A. Chalangsut.,2013	To investigate the impact of distribution system reliability	Tabu search algorithm and reliability worth analysis	Not mentioned	DigSilent Power Factory	An indirect measure for cost implementation association with power failure	Not mentioned
S. Muanghareon, A. Ngaopitakkul, S. Bunjongit, A. Nawikavatan., 2013	to research how protective equipment is coordinated	Using the rate of change of phase angle difference, a new passive islanding technique	IEC 609090	DigSilent Power Factory	Improved coordination setting of protective device	Generator protection
Vasquez-Arnez, J.A Laghari, H. Mokhlis., 2015	This method is effective at detecting islanding phenomena and has a comparatively narrow non-detection zone in comparison to previous	Remote technique Communication between DG and utility system	VDE 0126-1-1	PSCAD/EMTDC	Detecting islanding with DG hybrid resources using an efficient detection strategy	Not mentioned

	islanding detection methods.					
S. Varghese, M. Ebenezer., 2022	The main aim of this research was to improve feeder protection using overcurrent protection	Active method	Not mentioned	Arduino UNO	With ETAP, the relay coordination is confirmed in a four bus system, Ethernet network, IEEE 14 network, and IEEE 13 network	Feeder protection

Table 2. 2: The impact of distribution generation on the protection system for integrated(Meskin et al., 2020)

Method	Advantage	Disadvantage
As soon as a fault occurs, all DGs have to be disconnected	Application is simple	The temporary nature of the fault makes this unreasonable
Connect DGs to unfaulted areas after disconnecting them from the faulted area		All CBs need to be monitored and controlled remotely. Communication channel is needed
The recalculation of protective devices	Easy to implement	The higher time setting results in increase of fault-clearing time only if the DG units are not in service.
Limiting Distribution generator size	Maintains coordination	This restricts customers
Detect the location for the DG connection	Easy to apply. There is no need to install new devices	It is not feasible for all networks and customers

2.2 Islanding detection

Islanding is the isolation of a proportion of the electrical energy from the electrical network but remains operating, supplied by one or more DG units catering for the load in the islanding condition. This research work investigates an Islanding detection and initiation algorithm based on IEC61850 standard for the DG integrated South African power system network.

The smart IDLS scheme needs to identify fast and quickly then execute a reliable grid separation event by using CB status signals or line current measurement, or both to detect line outage(Wester & Adamiak, 2008). This relies on CB signals alone is not ideal because not every instance is due to the source CB that leads to disturbances. CB located in the upper stream could open during network disturbances and it might be unlikely to get the status data of all CB in the vicinity. The monitoring of either voltage or frequency needs an IED12 source relay which is incorporated in the incoming line and sheds the load when they move out of prescribed limits. The prescribed control is in charge of the CB data to detect islanding timely, monitor, and processing of the frequency and line current(Zhao et al., 2011).

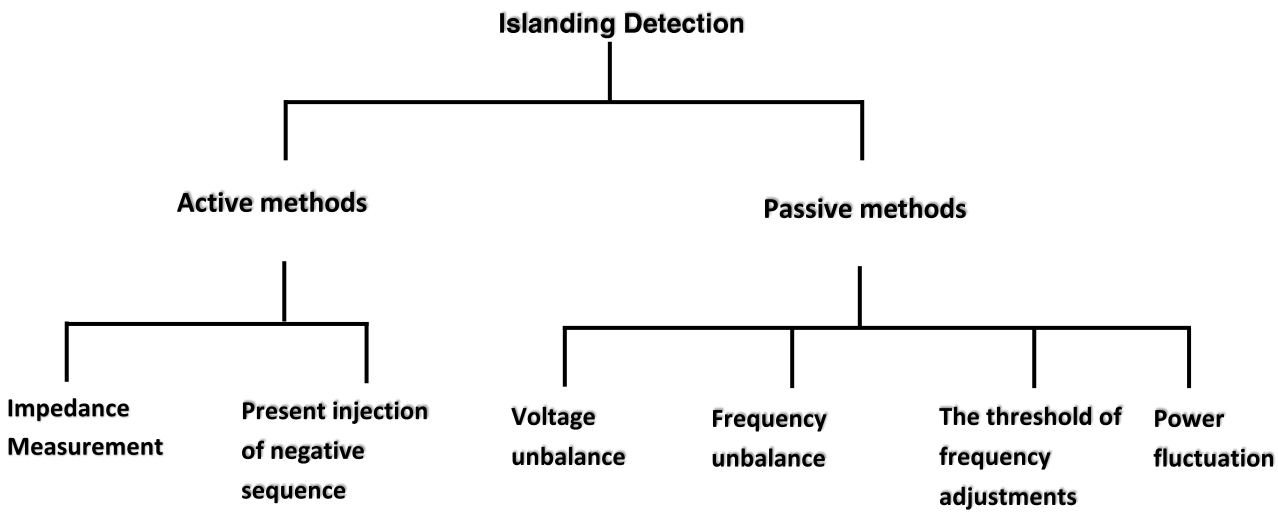

Figure 2. 6: Block Diagram for islanding detection methods (Active and passive)

2.2.1 Classification of Islanding detection using Active method

2.2.1.1 Impedance Measurement

With this method, the grid-connected synchronous generator supplies power to the factory, and when the grid is disconnected, the impedance difference at the point of common coupling is determined. In the event that the grid is no longer reachable, the impedance alternative is significantly greater than the predetermined threshold value. To distinguish the island, this variation is sufficient. (Xie et al., 2020).

The short circuit current is used to measure the source impedance of the system, and a shunt inductor is connected via a thyristor switch to measure the inductance of the system. Currently, the voltage variation is being monitored. There is a certain delay in response when using this system and it is more expensive(Abarrategui et al., 2007).

Based on the fact that the utility grid has a smaller source impedance than the local load, this method involves monitoring the source impedance. Thus, the measured impedance of a grid-connected device will be much lower than that of an island-connected device, allowing this condition to be detected. A near short-circuit with low impedance applied during a close to zero-cross is typically used to assess the source's impedance. (for example, from 358 to 360)(Cebollero et al., 2022).

2.2.1.2 Present injection of negative sequence

This case is considered to be balanced by the grid voltage and however, the shortcoming of being unable to differentiate between the island and the momentary sag or swell. Moreover, since the injection of the negative-sequence current creates an imbalance in the supplied load voltage(Tuyen et al., 2017).

According to some grid codes, reactive current injection only includes positive sequence currents under balanced (symmetric) and unbalanced (asymmetric) fault conditions. To address these issues, grid codes now include criteria for both positive and negative sequence injection.

Relay Time Data System (RTDS) creates currents and voltages that relays see during a fault and records relay behavior by modeling electrical power systems in RSCAD software. (Daboul & Orsagova, 2018).

Following an islanding event, the injected negative sequence current components of DG units can interact with each other at some PCCs. A radial feeder does not exhibit significant interaction between the DG units when they are located close together electrically. Efforts aimed at detecting active islanding do not stop at the proposed method, which is not an exception to this interaction phenomenon(Karimi et al., 2008).

2.2.2 **Classification of islanding detection using Passive Active method**

2.2.2.1 Voltage unbalance

This method uses the measurement of the output voltage of DG locally and operates if the parameter is not within a standard range of a certain duration of time.

An unbalanced voltage occurs when the magnitude of the phase voltage, line voltage or both are different from the balanced conditions, or both. This section's goal is to offer three definitions of voltage unbalance from three different communities, analyze the discrepancies between them, and show how they differ numerically. Three-phase induction machines perform better when voltage unbalance is considered, for instance. The RMS voltage values or the phase angles of three phases becoming non-equal between three phases result in voltage and current unbalances in three-phase systems(Ahmadipour et al., 2019).

Through voltage transformers and protection relays, the voltage unbalance of a system is analysed and the power system is controlled. A voltage transformer's accuracy when switching from primary to secondary depends on the transformer's type (class).

Depending on the type of distribution network, voltage unbalance indices would be stored. The type would depend on a variety of parameters, such as the load balance among phases, the length of the network, the cable characteristics, voltage drops, and the number of customers in each category. A voltage unbalance index could be estimated by the software after a network attribute and corresponding load are known(Lloret et al., 2007).

2.2.2.2 Frequency unbalance

The islanding output frequency of DG varies considerably as it cannot alone support the entire load of the grid it is connected to(Ma et al., 2020).

Under or over frequency relays are used if the grid frequency strays from the target range to allow some loads to be shed or generation plants to be shut down, respectively. It is therefore necessary to develop suitable DSP techniques for the rapid and accurate estimation of real-time fundamental frequencies from distorted grid voltage waveforms(Reza et al., 2014).

The frequency estimation algorithm can become very complex if all those effects need to be compensated for. It is also important that the same algorithm is not overly complex to consume too much processor power or to use additional sensors or inputs, since its application could potentially increase the price of the overall system. In the modern world, there are many different methods for measuring frequency, most of which are based on digital techniques. Detectors that detect zero crossings, discrete Fourier transforms, etc. for fundamental frequency tracking can all be implemented using digital signal processors (DSPs)(Marčetić et al., 2014).

2.2.2.2.1 The threshold of frequency adjustments

Island, a large power imbalance between the powers delivered for the distributed generator and load on the island occurs, this will lead to a change of frequency level dynamically. As a result, island detection can be done using the frequency shift rate. Faster detection is offered by this type of anti-islanding as compared to frequency imbalance.

In addition to providing insight into how different levels of threshold adjustments and noise uncertainty affect primary user signal detection, the simulations also reveal how different levels of detection threshold adjustments are affected by the level of noise uncertainty. Increasing the signal-to-noise ratio has been shown to improve the accuracy. In the presented analyses, different combinations of operating parameters were exploited to help understand how energy detection operates and how they can improve its efficiency in detecting spectrum changes(Lorincz et al., 2022).

2.3 Power fluctuation

The output power fluctuation on the DG in standalone mode is higher than during the grid connection for the equivalent load change(Cebollero et al., 2022).

When distribution generation is connected to the grid, it will have an impact on the grid's power quality, system protection, and schedule. As distributed generation is connected to the grid, a new method of power flow calculation will be needed. the Synchronous generators are a common type of distributed power source used by combustion engines and gas turbines. Synchronous and distributed generators may be transformed into PV nodes as long as the voltage inverter is coupled to the grid. (Song et al., 2015).

When grid-connected distributed PV generation in large amounts is combined with uncertainty characteristics, the supply and demand of power are asymmetric and the power fluctuation is intensified, which can lead to voltage fluctuations exceeding the safe operating range. In the end, this results in frequency instability, which could be hazardous. In addition, the voltage fluctuations may be within the voltage range, but because of the rapid frequency change, they may also interfere with the normal operation of equipment or load(Li et al., 2021).

2.3.1 Review and discussion of islanding detection techniques, both active and passive

This section discusses and contrasts a number of islanding detection techniques. Fast and accurate islanding detection is one of the main challenges in today's power system because many distribution networks have DG penetration now and there aren't many problems to fix with islanding. Also important for islanding detection is the possibility of islanding operation of distributed systems in the future, as this would enhance supply reliability and quality. During islanding, a distribution system becomes electrically isolated from the rest of the power system, but continues to be energized by the DG that's connected to it. Voltage, frequency, and harmonic distortions are all measured passively in a system. As a result of landing, these parameters change significantly. The thresholds set for these parameters determine whether there is an islanding condition or a grid connected condition. To distinguish islanding from other disturbances in the system, special care should be taken when setting the threshold value. In comparison to passive techniques, passive techniques are fast and do not introduce disturbance in the system, but they fail to detect islanding conditions because they have an extensive non-detectable zone (NDZ) (Anudeep & Nayak, 2018).

Passive detection schemes cannot detect islanding even when generation and load are perfectly matched. Active methods can detect islanding even when generator and load are perfectly matched. Active methods can be able to directly interact with power system operation by introducing perturbations(Abokhalil et al., 2018).

Table 2.3 below shows the comparison of the presented papers for the purpose of reviewing the existing active and passive methods for islanding detection. Active methods provide faster responses.

Table 2. 3: Review of the Active and passive methods

Paper	Aim	Methods	Communication & Protocol	Simulation or Implementation	Benefits	Protection
P.B. Pandit. G. Chaudhari., 2019	Active methods that would help in reducing Non-detection Zone for Passive Methods.	Active Methods, these methods do not perturb the system, are easy to understand.	Not mentioned	Simulation using MATLAB/SIMULINK	Ensuring proper working, active methods should be applied to all the new systems.	Relay on the OFP/UFP or OVP/UVP
R. Haider, Gyu-jung Cho, Chung-Yuen Won., 2019	Main utility network response for a smooth operation in coordination with the protection and control units	Classification of various IdMs	IEEE 1547-2003 standard	MATLAB	IdMs have reduced the detection time and improved the overall performance and minimized the implementation cost	Not mentioned

A.G. Abokhalil, A.B. Awan., 2018	The main aim was to improve the tripping time during islanding detection	Active islanding detection techniques	IEEE standard	PSIM software	Active method provide faster response, results showed that islanding detection time was about 0.1 s, which is very faster than the required detection time of 2 s.	Not mentioned
B. Anudeep, P.K. Nayak., 2021	DG should be disconnected within 2 s after the loss of the main utility grid	Fast and reliable islanding detection	IEEE standard 399-1997 model	PSCAD/EMTDC	Islanding detected even zero power mismatch at the DG terminals and secured operation during non-fault transients such as heavy load switching	Line differential protection

B. Indu, Dr. Subhash, Dr. Aravind., 2022	Aim of this research to improve the islanding detection time in microsecond	Active method and Hybrid	Not mentioned	Matlab	In order to distinguish proof of islanding conditions, a variety of latent islanding procedures, including Under/Over Voltage, Under/Over Recurrence, Voltage Phase Jump Detection, Harmonic estimation, and Voltage Unbalance are conducted.	Voltage and Frequency Protection

2.4 Communication-based method for HIL protection simulation

Articles about islanding detection, Communication-based methods have been chosen as the best methods for islanding, comparison between passive and active methods, all circuit breakers are controlled by the control system because of these techniques. Since they are employed in high-powered systems with important loads and are utilized to prevent power quality changes and ensure system dependability, communication-based approaches are unique techniques. Additionally, these techniques are employed for the system's cost and are insignificant in terms of the power efficiency of the system. (JohnSundar & SenthilKumaran, 2015).

An intelligent electronic device (IED) platform for testing and validating protection schemes through Hardware in the Loop (HIL). A special feature of the platform is the capability to support the GOOSE protocol for fast peer-to-peer communication as well as the MMS protocol for client-to-server communication. In order to model power system contingencies in real time, the platform incorporates a Real Time Digital Simulator (RTDS), and plug-in capabilities enables the incorporation of IEDs that apply protection schemes. With it, IEDs can be configured more flexible and data can be exchanged between them through GOOSE(Cui et al., 2017).

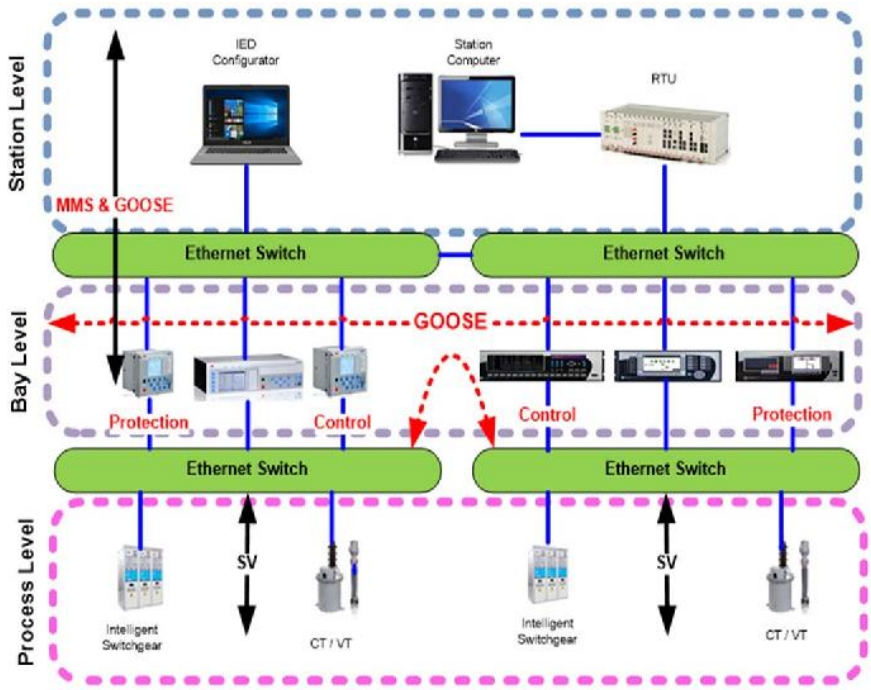

Figure 2. 7: Communication network architecture (Kulkarni et al., 2015)

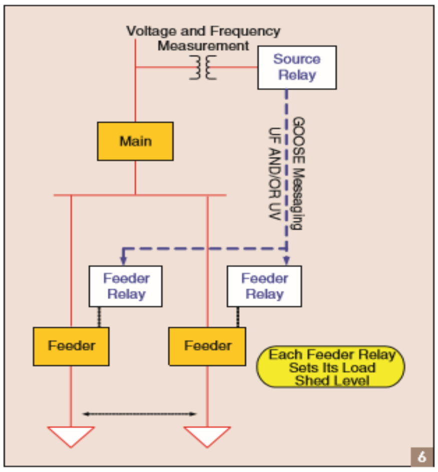

Figure 2. 8: A load scheme with GOOSE messaging (Sevov et al., 2013)

Zhao et al., (2011) recommend a quick and robust LS scheme that can detect under frequency or under-voltage incidents that could be harmful during conditions of system overloading. For radial feeders on a main-tie-main line-bus configuration when the tiebreaker is available, a GOOSE messaging-based LS system is favoured. To exchange load motion, voltage, and frequency values and to trigger commands to open/close feeder breakers, GOOSE messaging is used between the feeder and main source relays

2.4.1 Review discussion on IEC61850 communication methods for HIL protection simulation

Substation communication networks (SCNs) are being increasingly used by industry to automate processes at substations, which is leading to increased digitalisation of substations. As a result of the system, system diagnostics are more straightforward, copper wire is reduced, less installation time is required, monitoring is increased, and the process to alter system design is simplified. Communicates critical interlocking and protection messages between Intelligent Electronic Devices (IEDs) at a faster pace. As well as supporting bay distributed functions, the IEC 61850 standard also supports cluster distribution functions. As a result, intra-bay schemes remain operational if the station switch fails, ensuring high reliability. IEC 61850-based SCNs are still regarded with caution by the industry for implementing mission-critical functions in power distribution centers for industrial facilities in case of abnormal processes.

Based on IEC 61850 based HIL protection simulation, the papers in Table 2.4 below demonstrate how this test bench can be set up, as well as demonstrating how the power system protection can be tested based on IEC 61850.

Table 2. 4: Review of the IEC61850 based HIL protection simulation

Paper	Aim	Methods	Communication & Protocol	Simulation or Implementation	Benefits	Protection
A.Etxegarai, P. Eguia, I. Zamora,.2011	Fast and reliable islanding detection to avoid issues	Remote islanding detection method	IEC61850 GOOSE messaging	Not mentioned	Technical good performance and operating times	Not mentioned
J. Payne, A. Kulkani, P. Mistretta., 2013	Integrating three primary electrical control systems into one Ethernet Network at a refinery.	Implementation of an Ethernet communication network in a ring that links substations at a large industrial facility in a closed communication loop.	IEC 61850 communication standard	Not mentioned	The refinery was able to improve the flexibility of electrical safety and control systems by introducing an ICT communication network.	Not mentioned
A. Apostolov, B. Vandiver., 2007	To improve the hybrid implementation of IEC 61850	Communication-based hybrid implementation	IEC 61850 communication standard	Not mentioned	Operating fast and cost effective	Feeder protection

P. Eguia, A. Etxegarai, I. Zamora., 2011	The concepts that are used for underlying remote islanding detection methods and the current state of implementation of remote islanding communication-based detections to be used in distributed power generation systems.	Communication-based islanding detection systems and Remote islanding detection operating principles are used recently.	IEC 61850 communication standard	Not mentioned	The smart solutions can be economically feasible; They are easily adapted to alterations in the network topology. If the communication connection is down or communication latencies are high, local systems may rely on anti-islanding security.	Line differential protection

C. Ozansoy, K. Frearson., 2016	A comprehensive system design strategy for the development of an IEC 61850-based smart ID and LS model.	An IEC 61850 GOOSE fast LS system is based on messaging, where the final LS decisions are made in real-time by a fast load-shedding controller.	IEC 61850 communication standard	Simulation using MATLAB/SIMULINK	A governor advantage factor-based LS scheme, which is anticipated to save costs by eliminating excessive quantities of LS in the possibility of islanding situation in industrial substations	UF/OF and UV/OV

F. Hany, T. Pate, S. Brahma., 2022	Aim to investigate the protection system In order to provide a suitable backup solution in the event of breaker and relay failure, and have the healthy feeders continue to operate during abnormal conditions.	IEC61850	GOOSE messages	RTDS simulator	A successful co-simulation of communication and power systems enhances credibility	Under voltage-based protection scheme

2.5 Conclusion

In addition to still being underdeveloped technologies, islanding detection methods present severe deficits. In the same way that some active methods adversely affect the grid, this kind of use would be better avoided. Compared to some active and traditional systems, their implementation costs are very high. The methods used on one system could affect the effectiveness of the methods used on another system if the latter uses multiple embedded methods.

For islanding, to be mitigated an IEC 61850-based scheme of high quality was chosen as a critical factor of industrial systems. The core quality of this lookup paper setting apart it from in the past published works(Ozansoy & Frearson, 2016b). Design of the dissemination network, improvement of the islanding detection and initiation algorithms, and configuration of GOOSE messaging illustrated, however focus on this research will be based on communication-assisted methods. The proposed new algorithm for islanding detection is clear and it requires fame sign for the circuit breaker only from the utility grid such as the transformer, isolators, or line protection time out signals, but will be based on the following protection elements; Overvoltage, Under voltage, Over frequency, and Under frequency. The IEC61850 communication-assisted algorithm for Islanding detection and initiation with DG integrated power systems to eliminate the Non-Detection Zone (NDZ) found in a local method and Reduce copper wiring and troubleshooting using the IEC61850 standard. Overall to embellish the system reliability, control, monitoring, and protection performance of the power systems.

The next chapter is the theoretical aspects of islanding detection schemes in power systems distribution network.

CHAPTER THREE

THEORETICAL ASPECTS OF ISLANDING DETECTION SCHEMES IN POWER SYSTEMS DISTRIBUTION NETWORK.

3.1 Introduction

Throughout the history of electricity, testing and validation have been essential to power system protection. As engineers have been practicing electrical engineering for many years, the transmission system level protection has always been the focus of reliability testing. Very detailed and stringent type testing procedures and regulations have been developed to ensure this level of reliability.

A loss of mains condition (LOM) is usually detectable by a relay that detects under/over frequency and/or voltage and/or current. DERs measure load changes and time durations during utility system failures to determine how much load is changed. Detecting LOM conditions can be achieved using the simple methods listed above if the load exceeds the capacity of the DER. It is recommended, however, to include dedicated LOM protection in the case of small load steps and when DER is well suited to handle them.

As a result of low power imports and exports at the point of common coupling (PCC), the nondetection zone defines a performance limit for most commonly used methods. The most commonly used LOM protection techniques can also trigger spurious tripping due to severe network disturbances.

This chapter explain the Islanding detection methods in part 3.2. in part 3.3. Blackout. 3.4. Relay Description. 3.5. Instrument Transformer. In part 3.6. Voltage Transformer. In part 3.7. Synchronous Machine. In part 3.8. Distribution Generator connection arrangements. In part 3.9. Protection performance predisposing factors. In part 3.10. 3.10. Islanding Detection scheme using local area measurement solutions. The section 3.15. Is the conclusion based on the methods used for islanding detection.

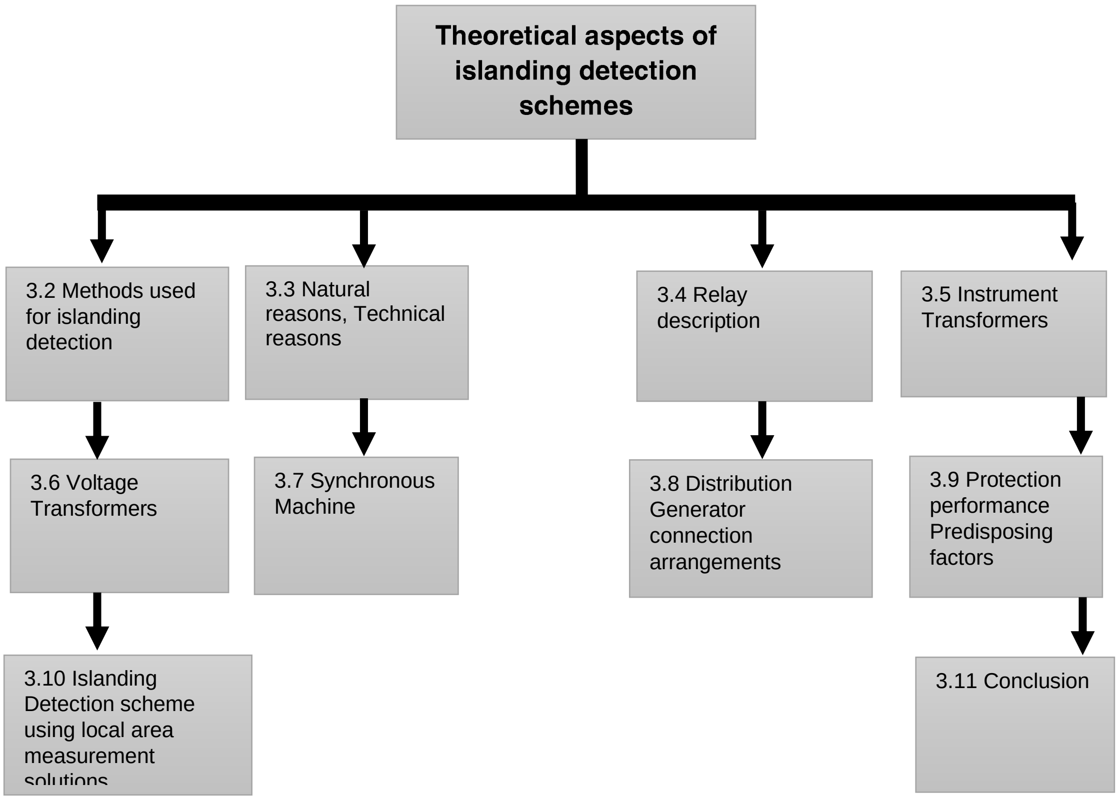

Figure 3. 1: Block diagram for chapter three structure

3.2 Methods used for islanding detection

3.2.1 Under frequency load shedding scheme

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Under frequency load shedding scheme is need for maintaining frequency within permissible limit, with issues of moreover output of Distribution Generators also the change during load shedding process that effect in performance and reliability decreases. In South Africa, we actually experience stage 6 load shedding, which has negative economic effects on power generation. Load shedding occurs when there is not enough electricity available to meet the demand from all Eskom customers.

Supply to some regions could need to be interrupted. In case of worst possible contingency results in highest initial rate of decay in frequency, and this scheme ensures that amount of load shed do not fall below. Control frequency it is not a trivial task it has to be done very precisely and accurately otherwise results in undesirable damage black outs and serious cost.

Under Frequency Load Shedding Scheme uses frequency first derivative, only one parameter that effect power deficit is H

In first step estimated H is used, & in the next step updated H will be used

Power deficit is calculation by swing equation $Pd = \frac{2Heq}{fN}$ (3.1)

Where fN is the Nominal frequency of system in Hz

$2Heq$ is the equivalent inertia constant in sec

Since this scheme is based on frequency first derivative it will account for all the sudden change of power due to DG's.

Under frequency load shedding scheme is successful in determination of load shed and maintain the frequency within limit for various scenarios for hybrid and multi area power system(Rudez & Mihalic, 2011).

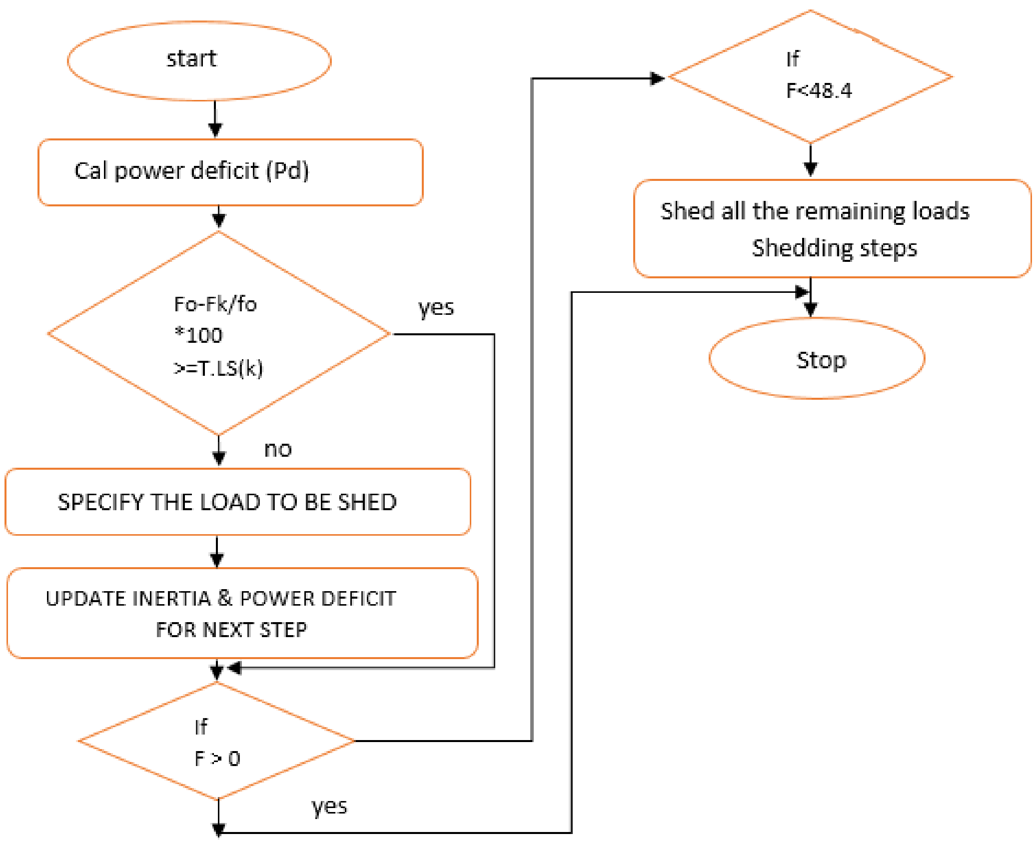

Figure 3. 2: Under frequency diagram (Rudez & Mihalic, 2011)

The examples below show how frequency coordination can be used to highlight limitations in passive detection techniques that prevent them from distinguishing between islanding and anti-islanding events when the reactive power mismatch is near to zero.

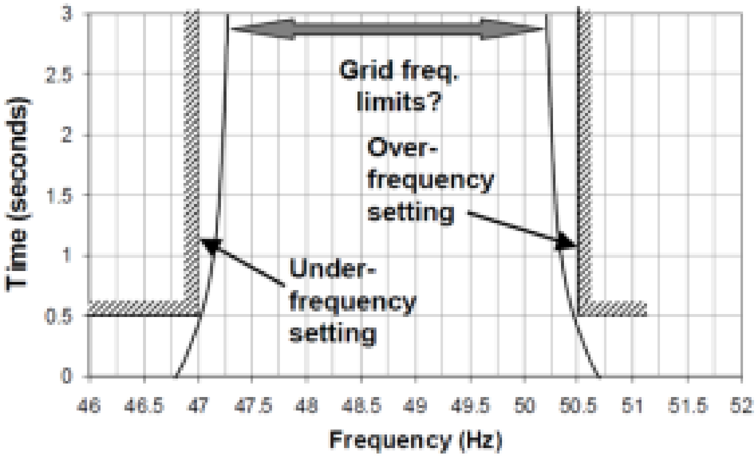

Figure 3. 3: Frequency co-ordination (Chowdhury et al., 2008)

3.2.2 Under voltage load shedding scheme

Protection engineers and system planners must work together to develop an under voltage load shedding scheme program. Together, they can determine the amount of load and time delay necessary for the various areas of the shedding program, but system planning engineers must conduct numerous studies using P-V (nose curves) and other analytical methods to determine the amount of load that must be shed to maintain voltage stability under plausible contingencies.

Voltage collapse is more likely to occur in situations of high load, such as when a significant quantity of power must be transmitted from distant generation sites and a considerable portion of the system load is made up of motors.

Table 3. 1: Summary of Related Work

S. No	Author	Technique	Strength	Weaknesses	Journals/Yrs of Publish
1	Abbas Ketabi	A sensitivity-based method for UFLS	Hybrid and Multi area Power Systems	Voltage stability is ignored	IEEE Trans.on smart grid 2015
2	Ahmad Ahmadi	New Integer-value modelling	Minimizing total amount of load shed and the amount of interruption cost	Hybrid Power system not considered	Journal ELSEVIER 2014

3	M.M Hosseimi	A techno economic multi-objective optimization	Consider social welfare and smart market	Hybrid Power system not considered	Journal ELSEVIER 2013
4	Alireza Saffarian	Designing the 3-D combinational load shedding method	Adaptive combinational LS methods are proposed	Traditional LS schemes are not capable of dealing with combined instabilities	IEEE Trans.on power systems, 2011
5	Urban Rudez	Frequency of center of inertia (COI) in adaptive LS schemes	Only under frequency load shedding considered	Under voltage load shedding not considered	IEEE Trans.on power systems, 2011
6	M.H.A Hamid	UVLS based on voltage stability index	Dynamic simulation	DG's were not considered	IEEE innovative Smart grid technologies Proceedings 2014
7	Arief Ardiaty	Trajectory sensitivity factor (TSF)	Reduce the amount of LS by 15MW by using DFIG	Fail to reduce asynchronous power generator from DFIG	Journal ELSEVIER 2012
8	Tamree Ranjbar Mozafari	Modal predictive control	Can be implemented on entire Power System	Sensitivity of the modal were ignore	Journal ELSEVIER 2011
9	Y.W ang I.R	Modal analysis method	Non-linear problem into a series of linear programming problems	Only N-1 Contingency has considered	IET Generation Transmission and distribution 2010
10	K. Uma Rao	Round Robin Technique	Novel grading scheme for loads to minimize the impact of load shedding by taking revenue loss, social factors into consideration factors into consideration	Dynamics were ignored	IEEE ISGT Asia 2013 proceedings

11	Md. Qamrul Ahsan	Traditional, semi-adaptive and adaptive	Auto load shedding and islanding scheme developed in a well manner	Voltage stability problem ignored	IEEE Trans. On power systems, 2012
12	Zhichao Zhang	New adaptive load shedding algorithm based on WAMS	Consider frequency and voltage both at the same time	Load Dynamics were ignored	International Journal of control and automation 2014
13	Junjie Tang	Power flow tracing algorithm	He considered both frequency and voltage stability	Transmission line outage is not considered	IEEE Trans. On power systems, 2013

Voltage stability is a significant issue that is frequently taken into consideration in the context of a power system, which can be extensively defined according to various operating situations.

Voltage stabilization is a crucial component of power system regulation that involves keeping a constant, acceptable voltage under typical operating and distributed situations.

Why do we need voltage stabilization, one would ask? The potential for instability manifests as a gradual decrease or increase in some buses' voltages.

Loss of load in a region or tripping of transmission lines and other components by their protective systems, which results in cascade outages, are potential effects of voltage instability. These interruptions or operational conditions may also cause certain generators to lose synchronism.

3.2.3 Principles of UVLS

There are three main principles of under voltage load shedding, the first one is the amount of load curtailment, the appropriate location for load curtailment and the timing to execute load curtailment event.

3.2.4 Meta-Heuristic techniques for UVLS

These Meta-Heuristic techniques in order for them to work some adjustments are to be done including reducing of the amount of the load shed, enhanced reliability, less power failure, reducing of the possibility of blackouts by applying such techniques, we may easily handle large, complicated power systems and highly stable

3.3 Blackouts

A blackout in a power system refers to the unavailability of Electric power in area for a short or long duration. These power blackouts occur due to natural and Technical reasons and sometimes the animal contact with live conductor, vehicle accidents that also resulting damages on transmission poles, and whether conditions that causes tress failing on transmission lines.

These blackouts are also caused by human error operating in a substation, overloaded transmission lines, faulty equipment due to year expansion and stability issues

Table 3. 2: Comparison features of Conventional and computational intelligence techniques(Rudez & Mihalic, 2011)

No	Feature	Conventional Technique	Computational Technique
1	Optimum load shedding	Do not provide optimum load shedding	Have a ability to provide optimum load shedding
2	Complex Power System	Cannot deal efficiently with modern and complex Power System	Can deal efficiently with modern and complex Power System

Due to the shortage of electricity, load shedding is extremely common in South Africa. To overcome drastically decreasing frequency of the system, usually load shedding is performed. Automatic load shedding is required to anticipate and relieve the overloaded equipment before there is loss of generation, equipment damage or a chaotic random shutdown of the system.

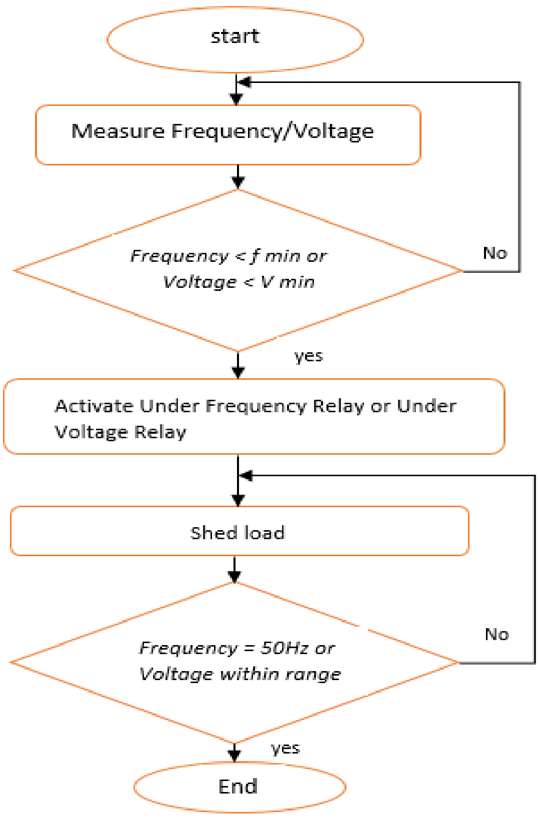

Figure 3. 4: Flow chart of conventional load shedding techniques(Rudez & Mihalic, 2011)

3.4 Relay Description

The relay utilized throughout the network performs the relatively straightforward operation of sensing the frequency, voltage, and comparing each phase to a predetermined value. It then starts a timer when the voltage dips below the predetermined value across three phases. The SEL700GT generator protection relay features a permissive that limits operation if frequency or voltage falls too low, which has been demonstrated during lab-scale testing, to prevent operation on a line that is purposefully de-energized. In the studies it is found that positive sequence voltage measurement it is not optimal for application with the reason of voltages are depressed during any type of fault occurs on the network and under the loss of just one voltage transformer. This may lead to possibilities to supervise the under voltage relay with an overcurrent relay.

The relay operates by using a voltage instrumental transformer to gather data on the network infrastructure in case there is a failure that can also be located. The protective relay must be connected to the circuit breaker in order for it to function, and CBs that are configured and positioned between network zones can be used to isolate or disconnect the fault components. Using the strength of these protective relays, information on the kinds of failures that have occurred and the location of the fault can be provided.

3.4.1 Relay Settings

The relay operating settings should be high enough to prevent the relay from operating under normal conditions but not so low to certain extent that the function never operates in abnormal or overload conditions. Nominal voltage typical settings ranges between 85% - 90% and this setting is not too hard to guesstimate from a fuzzy analysis of how a system typically operates. The DigSilent Power Factory Software has been used to run the system load flow under all normal contingency conditions in verifying the settings are not too high.

The studies for system load flow under serious abnormal conditions are run in order to determine if the relay would operate abet to mitigate the problem. This operation has a maximum time delay that needs to be considered during network fault in the event and after an event when generation is lost, the remaining generation picks up the load but there are some possibilities to cause some generation go into mode of field current boost, and in that case there are generators that have protective equipment in order to limit this high excitation current after 1 to 2 minutes(Narasimhan & Maradana, 2017).

3.5 Instrument Transformers

Voltage and current transformers referred to as instrument transformers are those created especially for metering or protection needs. The primary functions of instrument transformers are to convert currents or voltages from a typically high value to a value that relays and instruments can handle, to create an insulating barrier that isolates relays, metering, and instruments from primary high voltage systems, and to provide opportunities for standardizing relays, instruments, and other devices to a small number of rated currents and voltages.

3.6 Voltage Transformers

The solely electro-magnetic type (often referred to as a VT) and the capacitance type are the two voltage transformer kinds utilized for protective devices (referred to as a CVT). The only way the electro-magnetic voltage transformer differs from a power transformer is in how different attention is given to mechanical, insulation, and cooling factors.

The principal winding is connected either phase-to-phase or phase-to-neutral and has a significant number of turns. Less voltage and larger currents are attained because the secondary has fewer turns and the volts per turn remains constant.

3.7 Synchronous Machine

The majority of conventional thermal generators, along with CHP microgeneration powered by reciprocating cylinder engines, use three-phase synchronous machines under steady state operation, excitation is provided by a DC source.

In synchronous generators, the output power and mechanical input power are always correlated with the rotor angle. Multiple parallel synchronous machines require synchronization of their rotating speeds and output frequencies.

3.7.1 Dynamic response of Synchronous Machine

Since the field current supported by the excitation system endures and delivers a constant fault current while the electric power output is lowered, the voltage in the stator winding is maintained even under transient fault situations. In this instance, a persistent short-circuit current is produced together with a DC offset.

As the system's short circuit current moves through it, the machine winding equivalent impedance rises. The fault current so decays more quickly as a result. Three types of reactance variables have been introduced by the IEEE Standard (subtransient, transient, and synchronous). Synchronous machines can output up to three times their full load after a relatively brief fade when a problem occurs thanks to their excitation mechanisms.

If the grid is unable to absorb enough levels, a synchronous machine becomes unstable. In this case, suitable protection should be provided to detect this instability and disconnect the DER from the utility network (e.g. pole slip protection). This instability should be detected and the DER disconnected from the utility network through appropriate protection, for example, pole slip protection.

3.8 Distribution Generator connection arrangements

3.8.1 Connection arrangements

Varied utility system topologies, rated power levels, voltage levels, and DER installation goals necessitate different DER connection configurations. For connections between different countries, there are typically various arrangements.

3.8.2 Interface connection

A major influence on the dynamic behaviour of the DER is the power connection method. In most cases, utilities require a transformer to connect DER to their networks, although direct DER connections may be possible in some cases. The circuit design and protection coordination of DER connections can differ significantly from one type to another. As such, there is no universally accepted best example of DER connection.

(a) High Voltage Delta (Grid side) and Low Voltage grounded Wye (DG side)

The utility side of this connection is generally not preferred in transmission systems and LV distribution systems because of possible high voltage potentials. As a result, existing protection relays are not negatively affected on the ungrounded utility side.

Table 3. 3: High Voltage Delta (Grid side) and Low Voltage grounded Wye (DG side)(Vasquez-Arnez et al., 2015)

	Grid side High Voltage	**Advantages**	**Disadvantages**
Delta **Dnd-Wye** **Delta**	Delta Delta Wye	Through zero sequence isolation between the DER and grid, fault currents from the utility side won't be fed into the DER in the event of DER winding problems. without any faults, backfeed grid faults from the DER side.	The potential of high voltage during utility faults
Delta	Gnd-Wye	The voltage being reduced and potential for grid faults. Zero sequence introduced between DER and Grid.	An unwanted grounding source is created for remote

		Easy to detect faults at grid side.	faults in utility network
Dnd-Wye	Gnd-Wye	In this connection there is no overvoltage for both grid faults and DER winding faults	There are no isolation for third harmonics. No isolation between Grid and DER.
Directly connected		Cost-effective	No isolation between Grid and DER. There missing effective grounding system during islanding.

When implementing this arrangement, there main parts that need to be taken into consideration, for multiple grounding is forbidden in distribution systems with DERs for example in High Voltage distribution system below 132kV in United Kingdom. An industrial system can be exported to a utility by adding a DER to an existing transformer connection.

(b) High Voltage grounded Wye (Grid side) & Low Voltage Delta (DER side)

This connection is frequently utilized in actual installations and is advised for use in transmission systems and LV distribution systems. It is similar to the arrangements used in large-scale generating facilities.

It provides a reliable grounding source for the utility grid, which can withstand high fault currents in the event of a single-phase fault (the most typical fault type in practice). Relays can thus quickly identify issues.

Due to the zero sequence isolation between HV and LV windings, there won't be any additional fault current infeed from the utility side when DER winding defects happen. Additionally, this connection separates third harmonics entering the grid, which can destroy some delicate machines. However, this connection configuration adds a second zero sequence grounding source. Thus, the connecting transformer can detect a remote grid ground fault.

The selectivity and range of protection relays may be impacted if the ground impedance is low. Additionally, the utility grounding transformer and the DER connecting transformer will divide the unbalanced load current during unbalanced operation, which occurs frequently in low voltage distribution systems. As a result, with a significant unbalance, the connecting transformer's load carrying capability is decreased.

3.9 Protection functional testing

This chapter provides a description of the key performance on protection functional testing which covers the voltage-based protection function, frequency-based protection, the lab-scale protection testing of under/over voltage and under/over frequency protection scheme and lastly, the hardware-in-the-loop testing.

1.9.1 Voltage-based protection function

In this paper, we present a voltage-based backup protection function that makes use of busbar voltages without the need for current measurements, demonstrating a future wide-area backup protection scheme without the need for current measurements. As a result of the scheme’s accuracy and applicability, as well as its robustness, it has performed well under a variety of scenarios. Voltage-based systems exploit this fact as fault currents are caused mainly by dynamic generators (DGs). Consequently, the fluctuating fault current affects the system's bus voltage indirectly.

1.9.2 Frequency-based protection function

This protection function it has been tested in DigSilent simulation with two different scenarios. UFLS (based on existing settings) during the loss of large infeed contingency, frequency-based protection during loss of large infeed contingencies, malfunctioning renewables that support the load are more likely to cause more interruptions of service in a weak system where natural low inertia renewables support the load(Cao et al., 2014).

1.9.3 Lab-scale protection testing

The lab-scale protection testing implemented at the lab testing voltage-based protection functions and frequency-based protection functions using CMC Omicron device for injecting voltages and SEL700G relay. This testing is done to verify the protection functions and the relay operation.

1.9.4 HIL protection testing

Hardware-in-the-loop protection testing is done on RTDS simulator implementation done on RSCAD, and tested protection function for under-voltage stage 1 and stage 2, over-voltage stage 1 and stage 2 protection elements, hardwired-in-the-loop using CMS and SEL700G IED.

3.10 Islanding Detection scheme using local area measurement solutions

The Islanding Detection Scheme uses conventional protection elements which are Voltage elements and Frequency elements. The table below shows the thresholds and the pickup timer values for these conventional elements.

Table 3. 4: Relay settings for Undervoltage and overvoltage protection study (Faiek et al., 2012)

Protection function	Symbol	Recommended settings	
		Setting	Time
Undervoltage 27Stage 1	U<	0.87 Un	2.5 s
Undervoltage 27 stage 2	U<<	0.80 Un	500 ms
Overvoltage 59 stage 1	U>	1.10 Un	1.0 s
Overvoltage 59 stage 2	U>>	1.13 Un	500 ms

Additionally, the islanding detection method local area makes use of special elements that respond more quickly than traditional frequency elements. The scheme blocks the characteristic's output for 30 cycles when there is a problem. Its fault detection algorithm include components that deal with undervoltage. The characteristic with defect detection and blocking logic is depicted in the figure below.

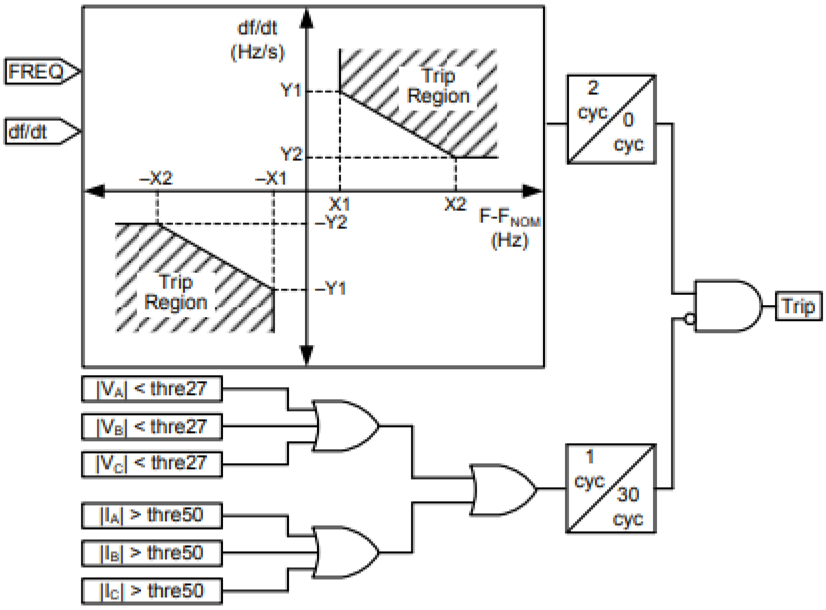

Figure 3. 5: IDS using local measurements (Mulhausen et al., 2010)

3.10.1 The slip frequency & acceleration characteristic

The characteristics of the two systems' slipperiness—both how slowly and quickly—against one another are being compared. The definition of acceleration is the rate at which the slip frequency changes with regard to time, hence the characteristic below is based on both slip frequency and acceleration. Figure 3.6 shows the characteristic's islanding and normal operating zones.

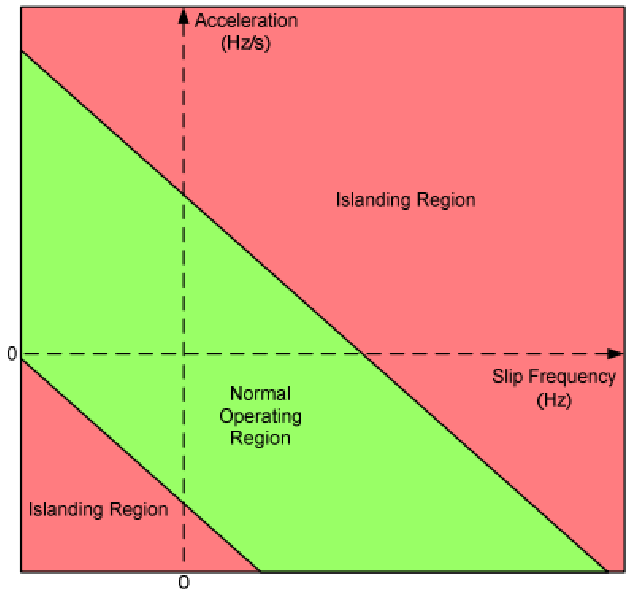

Figure 3. 6: Islanding detection characteristic using wide area measurements (Mulhausen et al., 2010)

3.10.2 Under-voltage logic

This logic has three input voltages and one output, the 27A1 bit is asserted when the magnitude of the A-phase voltage falls below the 27P1P setting. The 27B1 and 27C1 bits work similarly and the output of the AND gate, 3P27, is only asserted when all three phase voltages have dropped below the 27P1P setting.

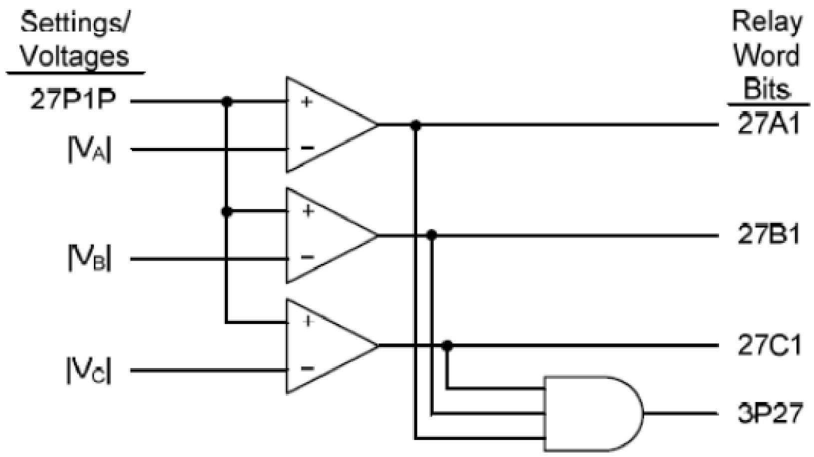

Figure 3. 7: Under-voltage logic (SEL-700G Instruction manual, 2015)

3.10.3 Frequency logic

This logic has the bubble on the top input of the AND gate performs a NOT function on the 27B81 input before it goes into the AND gate. The output of the AND gate (81D1) will not be allowed to assert if 27B81 is asserted, regardless of the state of the bottom input of the AND gate. In this application, the frequency element (81D1) is blocked from operating when an under voltage condition (27B81) is declared.

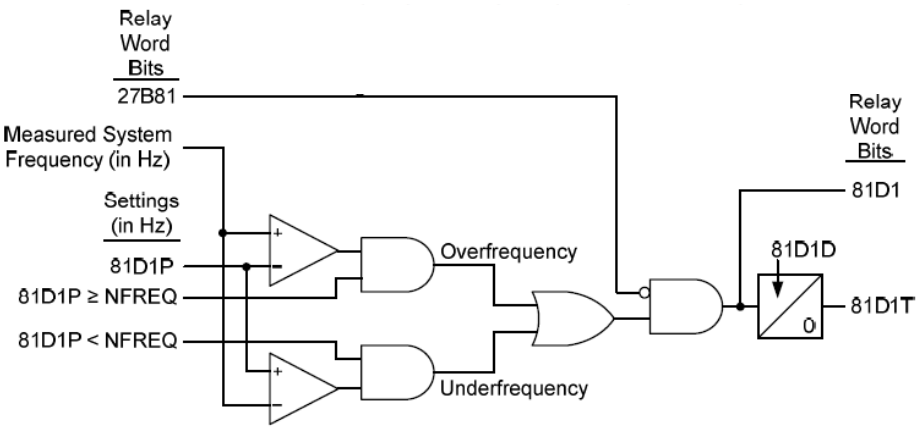

Figure 3. 8: Frequency logic (SEL-700G Instruction manual, 2015)

3.11 Conclusion

This chapter's goal was to give an overview of electrical theory. It also addressed the fact that different countries use various standards and approval processes, which highlights the urgency of finding better standardized solutions in the near future.

This chapter lays the foundations for the simulation and real-world applications of islanding detection systems and offers a strong framework for their implementation.

The implementation of islanding detection strategies using the DigSilent Power Factory simulation tool is covered in the section that follows.

CHAPTER FOUR

Modelling and Simulation of the Islanding protection scheme

4. Introduction

Islanding is a situation where a distributed generator (DG) keeps a place lit even when the electrical grid is down. This remote area of the Grid is referred to as the island. A similar disruption might result in a blackout. As a result, the islanding strategy provides a way to maintain power supply to critical services in a zone or area. We understand that the Grid is a network of interconnected generators and transmission lines.
All of the interconnected Generators operate in synchronization. However, if significant disruptions occur, the transmission lines may trip, resulting in a cascade impact. The DigSilent Power Factory software is employed in this project; since it is an appropriate tool that is used for simulation study. To configure the settings of the protective relays, various types of faults are applied in the network to determine protection element pickup settings. The simulation is built using Schweitzer relay models from the DigSilent library. The network's stability and the influence of fault levels on fault clearing times are explored. The under/over voltage and under/over frequency and ROCOF protection elements are investigated in order to provide effective protection for islanding detection.

This cascading impact may finally cause the entire Grid to fail, resulting in a blackout. The power system's islanding technique is built such that, in the event of a substantial Grid disruption detected by the protection element, a segment of the system is separated by tripping the pre-defined tie lines of transmission lines. As a result, the system is cut off from the rest of the Grid. As a result, the influence of Grid disruption is no longer affecting this Island. There are several methods for detecting Grid disturbances and initiating the Islanding Scheme. The Grid Frequency is one such approach. Grid frequency is proportional to load. The frequency will decrease as the demand on the grid grows. In the case of a decrease in load, however, the Grid frequency will increase. Unbalanced generation and load are two significant causes of grid disturbance.

This chapter is outlined as follows: Part 4.2 introduces the simulation software utilized in this investigation. The network in the case study, as well as the description of the test network system in 4.3 Part 4.4 depicts the component model and network data. Part 4.5 presents the protection configuration settings and their parameter design. Part 4.6 discusses the DigSilent protection simulation findings for the explored varied fault level situations. The final section 4.7 of this chapter is the conclusion based on the simulation results reported in 4.6.

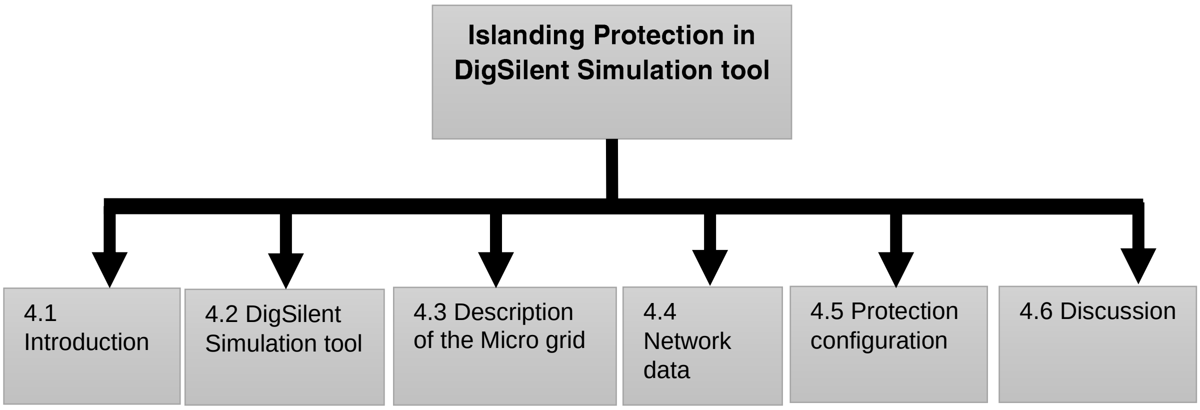

Figure 4. 1: Block diagram for the chapter structure

4.2 The simulation software

In this study, the DigSilent (Digital Simulator for Electrical Network) calculation tool was utilized to examine how different factors impact the association between power imbalance in power systems and islanding detection. For more than 25 years, DigSilent power factory software's total functional integration has set standards and trends in power system modelling, analysis, and simulation(Researcher, 2018)(Electromagnetic et al., 2022). Power Factory's all-in-one solutions support highly optimal workflow. Protection selectivity study using cutting-edge analytical methods that include quasi-dynamic simulations, voltage plan optimization, and much more. The extensive model library allows you to utilize ready-made models for single and three-phase loads. This program is mostly used to perform a simulation and analyze the results as part of the commission testing at simulation environment, and also be able to conduct the data in an integrated graphical environment.

4.3 Description of the test system

The aim of this section is to create a distribution network model. The test network system (Faiek, n.d.). utilized in this work is schematically represented in Figure 4.2 below; the system model is an infinite bus that depicts a distribution network upstream 220kV network from the Grid side. The network segment consists of a 220/33/11kV step down transformer (T1) linked to the Medium voltage 33kV Bus and the Low voltage 11kV Bus. The network consists of two feeders: Feeder B on the right side of the Low Voltage Bus and the variable load (load B) connected to the loadbus B. Feeder A and variable load (load A) on the 11kV side of the transformer (T2) 33/11kV with a distributed generator are located on the Load Bus A. The distributed generator is linked to T2 on the LV side at the end of feeder A and is protected by a circuit operated by the SEL700G protection relay.

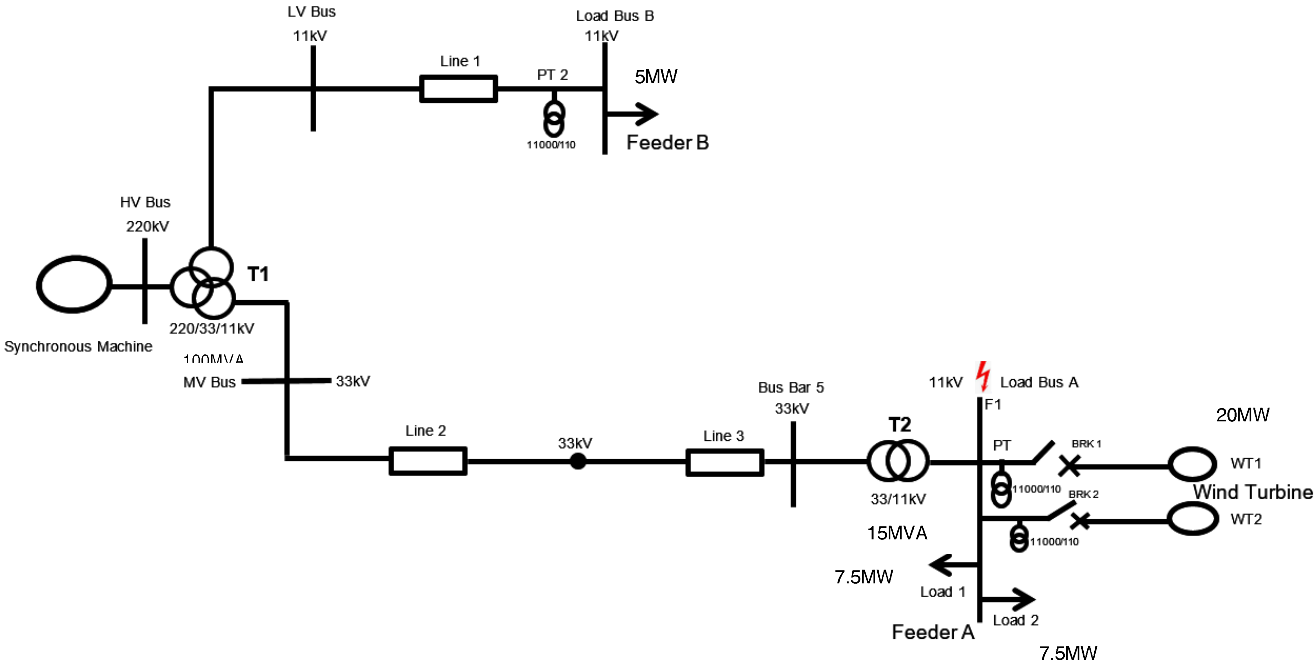

Figure 4. 2: Network considered in the case study

4.4 Components model and data

For the purpose of simulating dispersed systems, load flow calculations are performed collectively. Calculations are required in order to determine the network system's steady-state performance for the control and operation of this distribution network. Because this research is primarily concerned with islanding detection, the purpose of this load flow calculation is to identify the voltage magnitude, frequency fluctuation, voltage angle of the nodes, as well as the active and reactive power on all branches. In this case study, the calculation approach is an AC load-balanced positive sequence done using the Newton-Raphson method.

4.4.1 Network data

The specified distribution network was modelled and simulated using the parameters listed in Table 4.1. The utility is keeping the balance between utilized and generated electricity in the island grid, implying that an energy storage technology can be deployed. The wind turbines are normally attached to feeder A, and it is extremely capable of supporting an island.

Table 4. 1: The parameters of the synchronous machine

Equipment: Synchronous Machine													
Name	Busbar	Type	Num-bet	Sn [MVA]	Un [kV]	Cos phi	Xd" [p.u.]	Xd"sat. [p.u.]	R2	x2	R0	X0	Re
100MVA	HV Bus	DG	1	100MVA	220	0.80	0.14	0.20	0.00	0.20	0.130	0.002	0.00

Table 4. 2: Busbar voltage ratings

Busbars			
Name	Un [kV]	System Type	No. of Phases
HV Bus	220,00	AC	3
MV Bus	33,00	AC	3
LV Bus	11,00	AC	3
Load Bus A	11,00	AC	3
Load Bus B	11,00	AC	3
Bus 5	33,00	AC	3
DG Bus	11,00	AC	3

Table 4. 3: Loads parameters

Loads						
Parameters for Load A	Name	Description	Value	Name	Description	Value
	Type	Type of Load	RL	Pinit	Initial Real Power	10 MW
	Vbus	Rated Line to Line Bus Voltage	11 kV	Pmin	Minimum Real Power	0.1 MW
	Vmin	Minimum Bus Voltage(L-L)	0.8 p.u.	Pmax	Maximum Real Power	10 MW
	Freq	Base Frequency	50 Hz	Qinit	Initial Reactive Power	0.0 MVAR
Parameters for Load A (B)	Name	Description	Value	Name	Description	Value
	Type	Type of Load	RL	Pinit	Initial Real Power	7.5 MW
	Vbus	Rated Line to Line Bus Voltage	11 kV	Pmin	Minimum Real Power	0.1 MW
	Vmin	Minimum Bus Voltage(L-L)	0.9 p.u.	Pmax	Maximum Real Power	7.5 MW
	Freq	Base Frequency	50 Hz	Qinit	Initial Reactive Power	0.0 MVAR
Parameters for Load B	Name	Description	Value	Name	Description	Value

	Type	Type of Load	RL	Pinit	Initial Real Power	5 MW
	Vbus	Rated Line to Line Bus Voltage	11 kV	Pmin	Minimum Real Power	0.1 MW
	Vmin	Minimum Bus Voltage(L-L)	0.9 p.u.	Pmax	Maximum Real Power	5 MW
	Freq	Base Frequency	50 Hz	Qinit	Initial Reactive Power	0.0 MVAR

Table 4. 4: Transformer parameters

Transformers						
Parameters for T1	Name	Description	Value	Name	Description	Value
	Tmva	Transformer MVA	100 MVA	WINDING #1		
	CoreS	Transformer core construction	3 – Limb	V1	Primary voltage (L-L, RMS)	220 kV
	F	Base operation frequency	50 Hz	YD1	Winding #1 connection	Delta
	Xl12	Pos.seq.leakage reactance	0.0001	V2	Primary voltage (L-L, RMS)	33 kV
	Xl13	os.seq.leakage reactance	0.0001	YD2	Winding #2connection	Y
	Xl23	os.seq.leakage reactance	0.0001	V3	Primary voltage (L-L, RMS)	11 kV
	Rot	Winding Rotation	Lags	YD3	Winding #3 connection	Y
Parameters for T2	Name	Description	Value	Name	Description	Value
	Tmva	Transformer rating (3 Phase)	15 MVA	WINDING 1		
	F	Base operation frequency	50 Hz	YD1	Winding #1 connection	Y –Gnd
	xl	Leakage Inductance	0.001 p.u.	Pol1	Primary Winding Polarity	+ve
	NLL	No load losses	0.0 p.u.	Rot1	Winding Rotation	ABC
	VL1	Winding #1 Base Voltage (L-L, rms)	33 kV	Im1	Magnetizing Current	1 %
	WINDING 2					
	YD2	Winding #2 connection	Y –Gnd	Im2	Magnetizing Current	1 %
	Pol2	Primary Winding Polarity	+ve	VL2	Winding #2 Base Voltage (L-L, rms)	11 kV

Table 4. 5: Wind Turbines parameters

Wind Turbines								
Name	Type	Loading	Busbar	Active Power [MW]	Reactive Power [Mvar]	Power Factor	Current [kA]	[p.u.]

						[-]		
WT Type 4A	Genstat	28.6	WT Type 4A LV	10.00	0.000	1.00	49.841	0.993
WT Type 4A 2	Genstat	28.6	WT Type 4A LV 2	10.00	0.000	1.00	41.534	0.993

Table 4. 6: Line parameters

Line Parameters	Name	Description	Value	Name	Description	Value
L1, L2 and L3	F	Line frequency	50 Hz	Rz	Zero sequence series resistance	0.0004 ohms
	Rp	+ve sequence series resistance	0.001 ohms	Xz	Zero sequence series inductive react	0.0004 ohms
	Xp	+ve sequence series inductive react	0.0001 ohms	Xcz	Zero sequence shunt cap.react. of line	0.0004 Mohms
	Xcp	+ve sequence shunt cap. Reactance of line	0.0003 Mohms	V Line 1	Rated voltage	33 kV
	Rp	+ve sequence shunt cap. Reactance of line	0.0003 Mohms	V Line 1	Rated voltage	11 kV

The data presented above is in table 4.1 to 4.6, and it is performed on the distribution network system model in the DigSilent Power factory, as illustrated in Table 4.7 to 4.8. The simulation below depicts the active power, reactive power, apparent power and load flow calculation magnitudes. The load flow was completed successfully, and the results for three-phase currents and voltages in p.u. The distribution network depicted below is balanced with a 120-degree phase shift and balanced voltages and currents. These results are obtained under normal circumstances. The many network scenarios are performed in order to analyse and construct the network system chosen for this study's protection.

Table 4. 7: Load flow calculation for the considered distribution network when CBGRID open and CBWT closed

Load flow calculation			
Name	Actual power	Reactive power	Active power
Generation	18.9 MW	-1.1 Mvar	20 MVA
External Infeed	0.0 MW	0.0 Mvar	0.0 MVA
Load A	6.5 MW	1.0 Mvar	7.5 MVA

Load A (B)	6.5 MW	1.0 Mvar	7.5 MVA
Load B	5 MW	0.0 Mvar	5 MVA
Grid losses	0 MW	0.0 Mvar	0 MVA
Transformer 1	100 MW	0.1 Mvar	100MVA
Transformer 2	25 MW	0.0 Mvar	25 MVA

Table 4. 8: Load flow calculation for the considered distribution network when CB_{GRID} closed and CB_{WT} open

Load flow calculation			
Name	Actual power	Reactive power	Active power
Generation	0.0 MW	0.0 Mvar	0.0 MVA
External Infeed	20 MW	0.0 Mvar	20 MVA
Load A	7.5 MW	0.0 Mvar	7.5 MVA
Load A (B)	7.5 MW	0.0 Mvar	7.5 MVA
Load B	5 MW	0.0 Mvar	5 MVA
Grid losses	0 MW	0.0 Mvar	0 MVA
Transformer 1	100 MW	0.0 Mvar	100MVA
Transformer 2	25 MW	0.0 Mvar	25 MVA

Table 4. 9: Voltage levels within micro-grid and installed capacity of renewable energy resources

Voltage levels within microgrid (or stand-alone microgrid) (kV)	Installed capacity of renewable energy resources (MW)
30/34.5/35	≤100
20/22/23	≤50
6.9/10/11/13.8	≤20
0.4/0.48/0.69	≤2

4.4.2 Islanded mode operation

In a distribution network, distributed generators (DG) provide power to islands that are disconnected from the rest of the network. As soon as a fault has been cleared and isolated, islands are usually formed. When a grid is lost, DGs within islands must disconnect within 0.1 seconds to 0.2 seconds. Grid codes impose strict restrictions on distribution networks. The total load of this network is 20MW.

4.4.2.1 Case study A: Grid-connected islanded operations

The figure 4.3. Below is an illustration of grid-connected island operations. As soon as the circuit breaker on the external grid is closed, the two Wind Turbines on the microgrid side will be isolated as well. The purpose of this case study was to demonstrate in detail how islanding occurs on networks. The results below show that, the utility connections for a microgrid are made through the use of a point of common coupling (PCC) which is represented by HV Bus in this instance and two Wind Turbines are out of service.

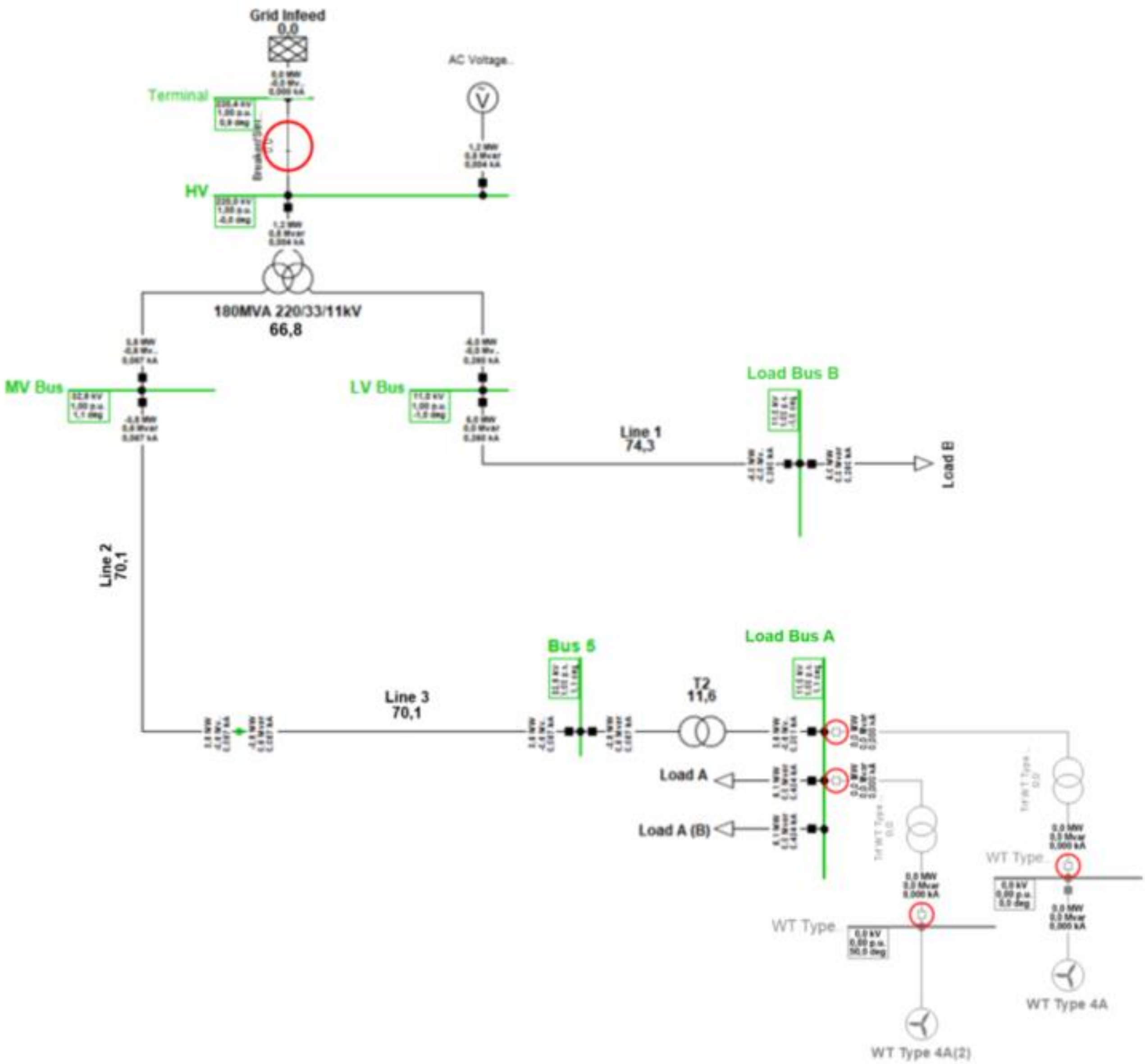

Figure 4. 3: Grid-connected islanded operations

The below figure 4.4. Illustrates the system response during changeover from grid-connected system to microgrid connected system. In terms of frequency graphs, the system remained stable during the changeover, whereas in terms of voltage graphs, there was a slight change that did not affect the operation of the network.

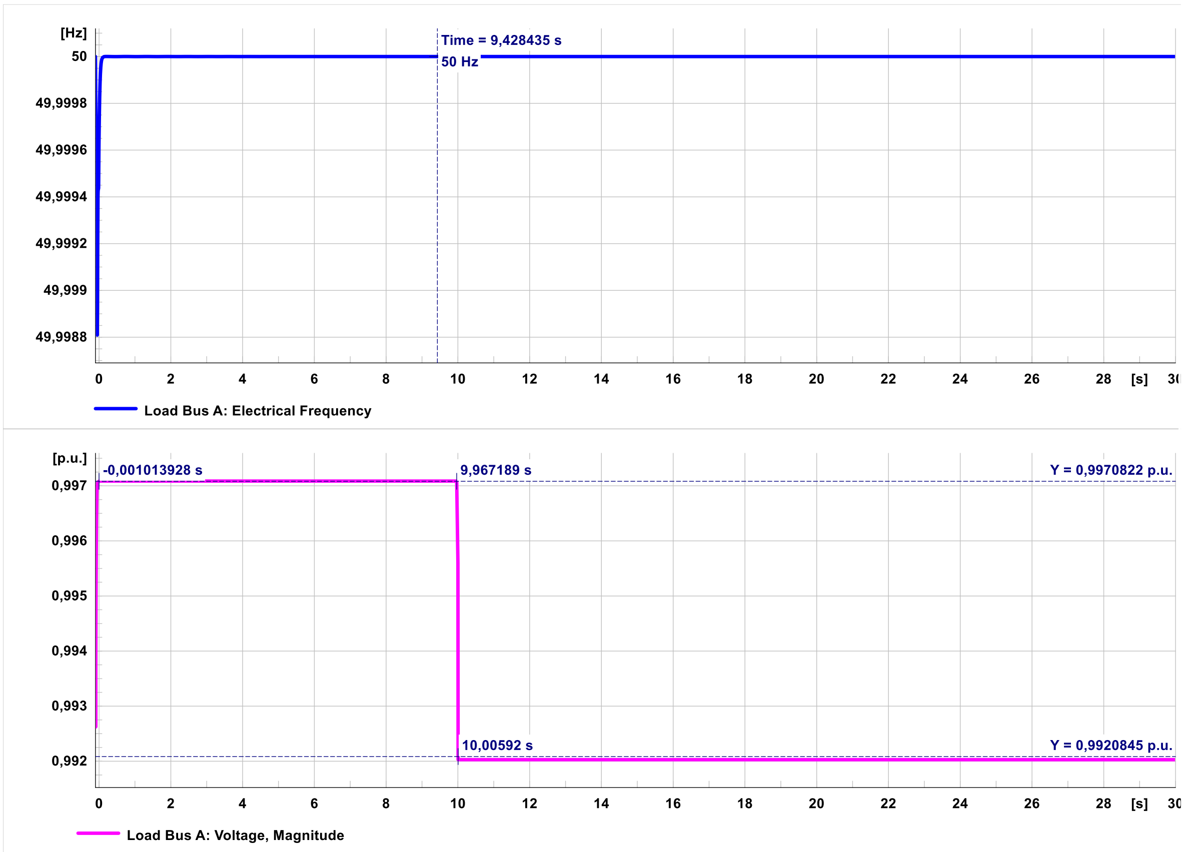

Figure 4. 4: Network response when Grid Circuit breaker closed

4.4.2.2 Case study B: Microgrid-connected island operations

The figure 4.5. below represent the microgrid-connected island operations. When the grid-connected system is uncoupled, the circuit breaker opens, and the Wind Turbines supply the microgrid-connected system, but only one wind turbine supplies the microgrid system, and the other wind turbine tripped because of the spike in frequency and voltage during changeover from grid-connected to microgrid-connected system (see figure 4.6). This case study emphasizes the importance of protection on microgrid-connected systems, in this instance, SEL700G protection relay is used to monitor voltage and frequency protection elements. This is why one wind turbine tripped during changeover due to overvoltage. Furthermore, to ensure equipment and personnel safety, the voltage protection elements and frequency protection elements are tested.

In addition to operating as an independent island or a distribution network that is connected to the utility grid, microgrids can also operate as a distribution network that is operated by a utility company. It will be possible for DGs to maintain grid connections after islanding procedures are complete by using the algorithm. In a microgrid, islands are predefined and distributed across the network.

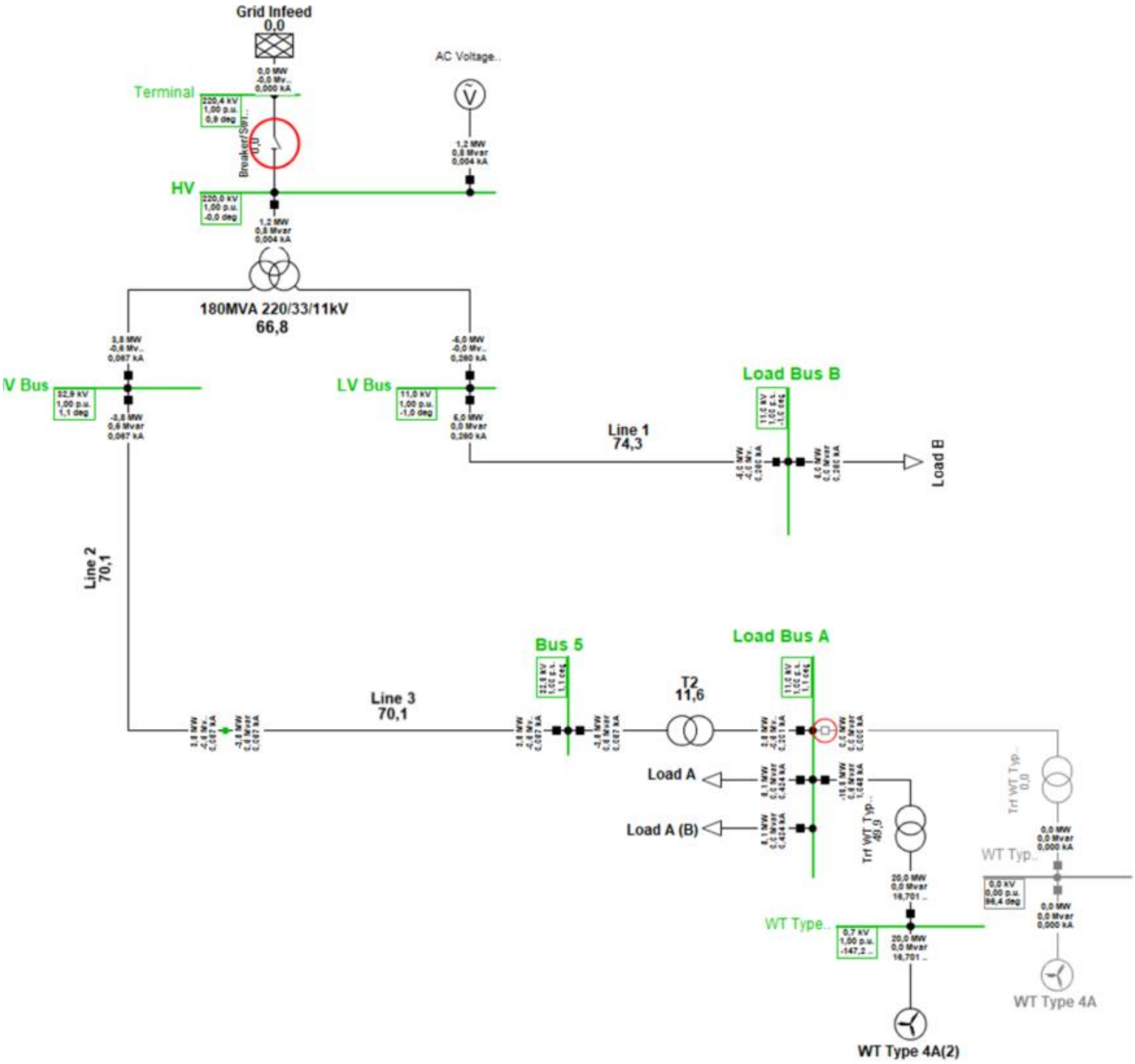

Figure 4. 5: Microgrid-connected islanded operations

The figure 4.6. below illustrates the system response when the grid-connected system isolates and wind turbines supplying microgrid connected system. According to the two graphs, both frequency and voltage fluctuated during changeover, resulting in one turbine tripping. As seen in the frequency graph, the spike was observed but the system returned to normal, but as seen in the voltage graph, there was an over voltage on the system during this change, which was monitored and the voltage protection was activated, which then returned to normal.

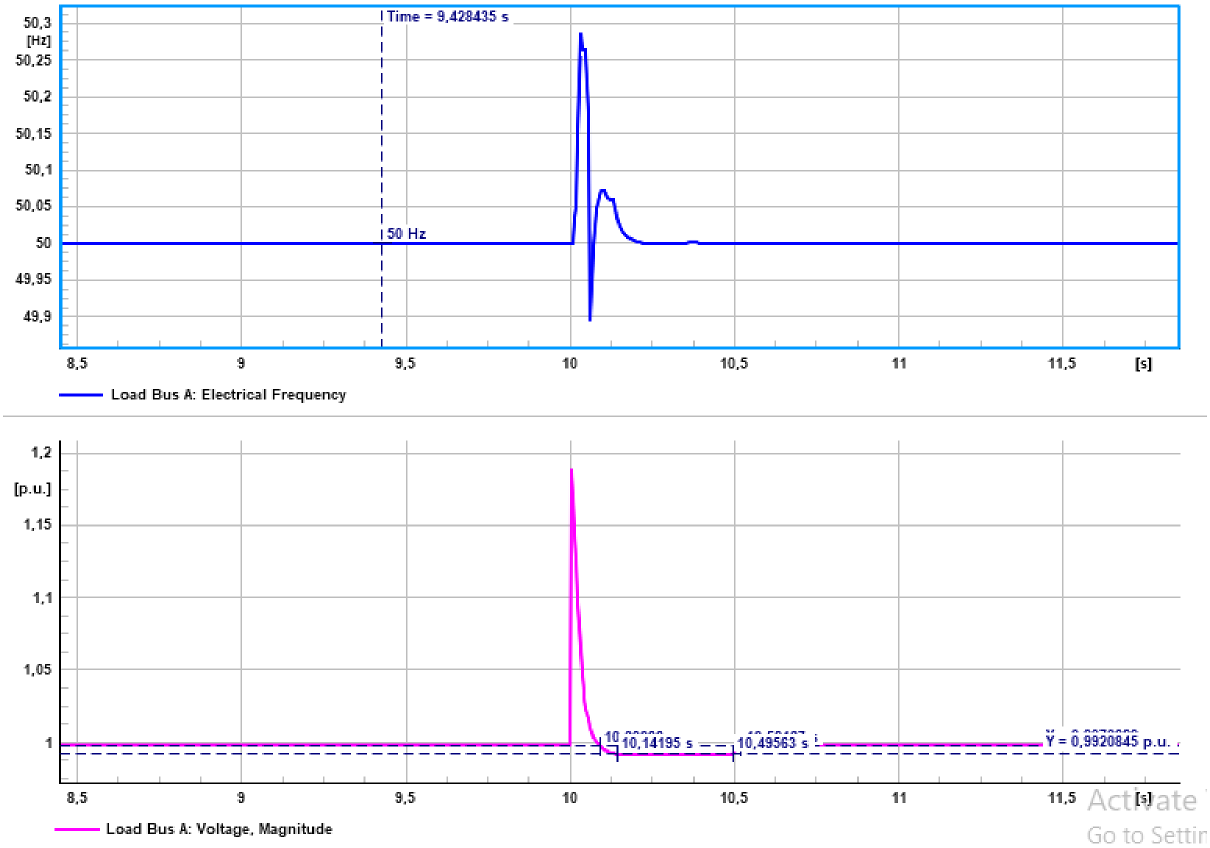

Figure 4. 6: System response when the grid-connected system isolates and wind turbines supplying microgrid connected system.

Grid: Islanding Detection System Stage: Islanding Detec | Study Case: Study Case | Annex: / 3

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
Bus 5	33,00	1,001	33,05	1,50	
HV	220,00	1,000	220,00	0,00	
LV Bus	11,00	1,000	11,00	-0,22	
Load Bus A	11,00	1,001	11,02	1,50	
Load Bus B	11,00	1,000	11,00	-0,23	
MV Bus	33,00	0,989	32,63	1,07	
WT Type 4A LV	0,69	1,007	0,70	-145,80	
WT Type 4A LV(1)	0,69	1,007	0,70	-145,80	

Figure 4. 7: Three phase voltages and currents on Load Bus A and Load Bus B

Table 4. 10: Active and reactive power of the simulated distribution network

Load Flow Calculations								
Name	Type	Loading	Busbar	Active Power [MW]	Reactive Power [Mvar]	Power Factor [-]	Current [kA]	[p.u.]
WT Type 4A	Genstat	49.6	WT Type 4A LV	10.00	0.000	1.00	0.4984	0.993
WT Type 4A 2	Genstat	49.6	WT Type 4A LV 2	10.00	0.000	1.00	0.4134	0.993
Load A	Load		Load Bus A	10	0.00	1.00	2.620	0.999
Load B	Load		Load Bus B	5.0	0.00	1.00	2.620	0.999
Synchronous Machine	Syn	72.6	MV	-100	100	-0.59	0.018	0.057
Line 1	Line	74.99	LV Bus	1.5	0.00	1.00	0.262	0.750
Line 2	Line	70.1	33 kV node	-1.5	0.00	0.87	0.186	0.186
			MV Bus	1.5	-1.5	-0.87	0.186	0.186
Line 3	Line	70.1	Bus 5	1.5	-1.5	-0.87	0.186	0.186
			33 kV node	-1.5	1.5	-0.87	0.186	0.186
T1	Tr1	66.8	HV	-100	-0.56	-0.59	0.018	0.025
			MV Bus	100	0.56	0.86	0.186	0.118
T2	Tr2	60.1	Bus 5	15.00	0.00	-0.87	0.186	0.193
			Load Bus A	15.00	0.00	-0.87	0.186	0.193

The load bus voltages are generally at the average of 1.00 per unit, and the loading on transformers, cables are within the normal working capabilities. The generator selected output power and the reactive outputs are ranges within the limits that are defined within the generator capability curves.

The Negative Power Factor presented in Table 4.12 is the cosine of the angle between voltage and current when electrical power is flowing in the opposite direction. A negative Power Factor arises when the DG (Wind turbine) power flows from the load Bus A to the source. The negative power factor primarily denotes the leading power factor in terms of the primary power source. In this scenario, the negative power factor is caused by the DGs (Two parallel wind turbines) connected to load Bus A.

4.4.2.3 Short circuit currents calculation and simulation

The major goal of the short circuit in this distribution network is to employ a calculating approach to choose fault ratings for all devices used to design the protection settings. As a result, the three-phase short circuit was implemented on the network to determine the fault current capacity. These forms of failures, which can be phase to phase short circuit, phase to neutral, two phases to neutral, and the most frequent failure of the three phases with neutral or earth, are highly prevalent in three-phase power systems. The system's operating frequency is influenced by how the equipment operates under normal and fault circumstances.

4.4.2.4 Short circuit simulation

A short circuit analysis's major goals are to determine the system protective device configuration parameters. The effects of fault currents on various system components such as lines, transformers, and generators are determined. Short circuits are categorized into five categories, which are as follows: Three-phase line to the Ground fault, Three-phase line to Line fault, Single line to the Ground fault, The line to Line fault, and Double line to the Ground fault.

Table 4. 11: Types of short circuit faults in the three-phase distribution network (Faiek et al., 2012)

S.no	Type of faults	Short-form	Symmetrical or Unsymmetrical	Probability of occurrence
1.	Three-phase line to Ground fault	3LG	Symmetrical	2 to 3%
2.	Three-phase line to line fault	3LL	Symmetrical	<1%
3.	Single line to the Ground fault	1LG	Unsymmetrical	70 to 80%
4.	The line to Line fault	1LL	Unsymmetrical	15 to 20%
5.	Double line to the Ground fault	2LG	Unsymmetrical	<10%

During the islanding and planning stages, the short circuit was used in several locations to assess the actual fault rating of the equipment in the power system network. The most intriguing aspect of this study is based on the maximum and minimum predicted fault currents to correspond with the protection scheme design. The security system provides dependability, sensitivity, and selection.

When three-phase faults occur in the power system network, the symmetry is generally under fault state, and any other sort of fault, such as a single line to ground fault, is defined as unsymmetrical.

4.5 Islanding Protection configuration setting

Islanding occurs when a distributed generator (DG) continues to power an area despite the absence of external electrical grid power. Island mode operation refers to power plants that operate independently of the national or local energy distribution network. The most frequent passive islanding detection techniques as shown in Fig 4.5 have over/under voltage and over/under frequency (OF/UF).

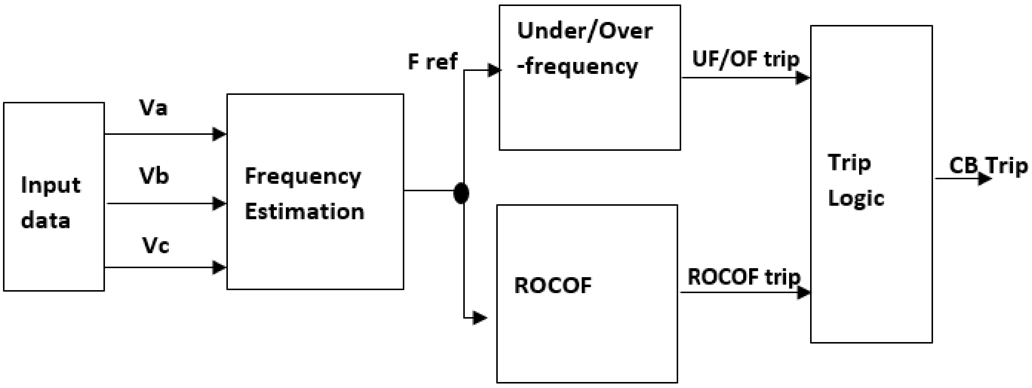

Figure 4. 8: Structure diagram for the protection functions (OF, UF and ROCOF)(Elvis et al., 2020)

4.5.1 Voltage protection function

The voltage-based protection function is set up to test for undervoltage and overvoltage. Table 4.15 shows the voltage relay settings; they are present in the SEL700G protection relay.

Table 4. 12: Undervoltage and overvoltage protective relay settings(Faiek, n.d. et al 2012)

Protection function	Symbol	Recommended settings	Time Setting
Undervoltage 27Stage 1	U<	0.87 Un	2.5 s
Undervoltage 27 stage 2	U<<	0.80 Un	500 ms
Overvoltage 59 stage 1	U>	1.10 Un	1.0 s
Overvoltage 59 stage 2	U>>	1.13 Un	500 Ms

Sections 4.6.1 and 4.6.2 offer the simulation results of the case studies for overvoltage and undervoltage protection investigations, respectively.

4.5.2 Frequency protection

The frequency-based protection function is designed for under frequency and over frequency testing of stages 1 and 2 as shown in Table 4.16; the relay determines if the system frequency is above or below the setting thresholds and sends a tripping order to the breaker. The difference between the two will cause a shift in frequency from the nominal 50 Hz (assuming Grid voltage to be 50 Hz during normal conditions). As a result, before islanding, an under frequency relay is used to detect a large Grid disruption and commence load shedding by opening circuit breaker on a feeder.

Table 4. 13: Relay settings for under frequency and over frequency protection study (Faiek, n.d. et al 2012)

Protection function	Symbol	Recommended settings	
		Setting	Time
Underfrequency 81U Stage 1	f<	47.5 Hz	10 s
Underfrequency 81U stage 2	f<<	47 Hz	500 ms
Overfrequency 81O stage 1	f>	51.5 Hz	10 s
Overfrequency 81O stage 2	f>>	52 Hz	500 ms

Sections 4.6.3.1 and 4.6.4.1 offer the simulation results of the case studies for underfrequency and over frequency protection investigations, respectively.

4.6 Introduction to the DigSilent protection simulation results

Various test scenarios were performed to evaluate the voltage and frequency protection on a distribution network with DG interconnected system. Under/overvoltage protection refers to circuits that safeguard downstream components from over/under voltage damages. The over/under voltage; Over/under frequency protection elements are considered for the microgrid system presented in Figure 4.6. The relay protection settings are implemented on the SEL700G relay, with the standard maximum time delay for the relay set to 10 seconds. Those simulation cases results are presented in details in sections 4.6.1 through 4.6.5.

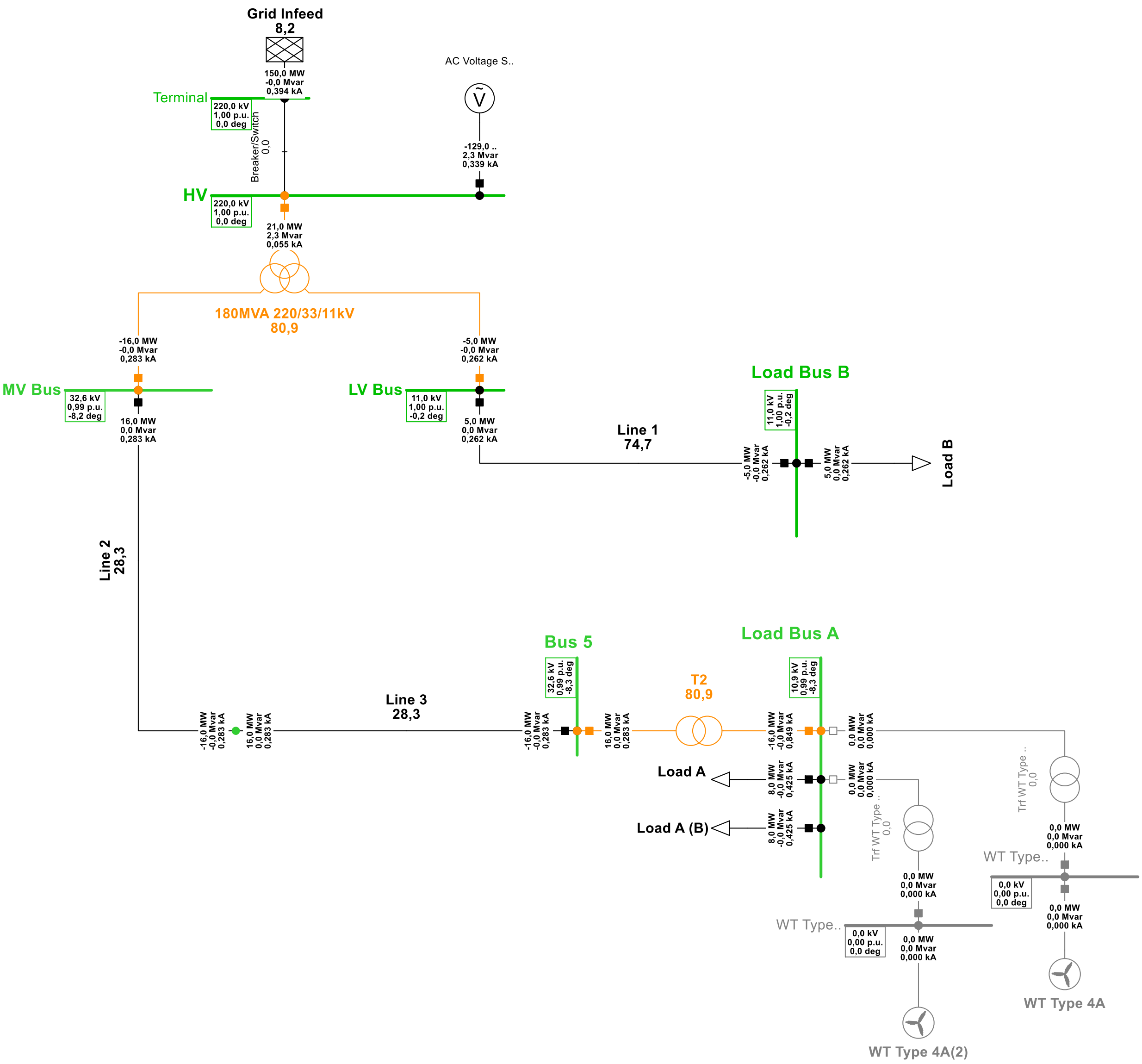

Figure 4. 9: Distribution network at normal state

4.6.1 Scenario 1 to 4 as follows:

- Over-voltage protection testing
- Under-voltage protection testing
- Under-frequency protection testing
- Over-frequency protection testing

4.6.1.1 Scenario 1: Over-voltage protection testing

4.6.2 Overvoltage protection testing by load reduction on feeder A (Load A2)

Load reduction on feeder A (Load A2) is used to test the overvoltage protection feature. The performance test was carried out to assess protection sensitivity over a 60-second period. The voltage in p.u. was initially 0.9786892 p.u. and increased to 1.249824 p.u. following load decrease as shown in Figure 4.11b, which is above the voltage scale referred to in Table 4.17.

Table 4. 14: Voltage scale (Shaimaa et al., 2016)

Voltage level	**Normal Conditions**		**Voltage Deviation**
	Vmin (pu)	Vmax (pu)	Normal
220 kV	0.95	1.05	± 5%
33 kV	0.95	1.05	± 5%
11 kV	0.95	1.05	± 5%

As a result, Figure 4.11. depicts the distribution network's behaviour after adopting load deduction on LoadbusA (load A2), which is separated from the network, and feeder B (load B), which is likewise isolated from the network during overvoltage conditions.

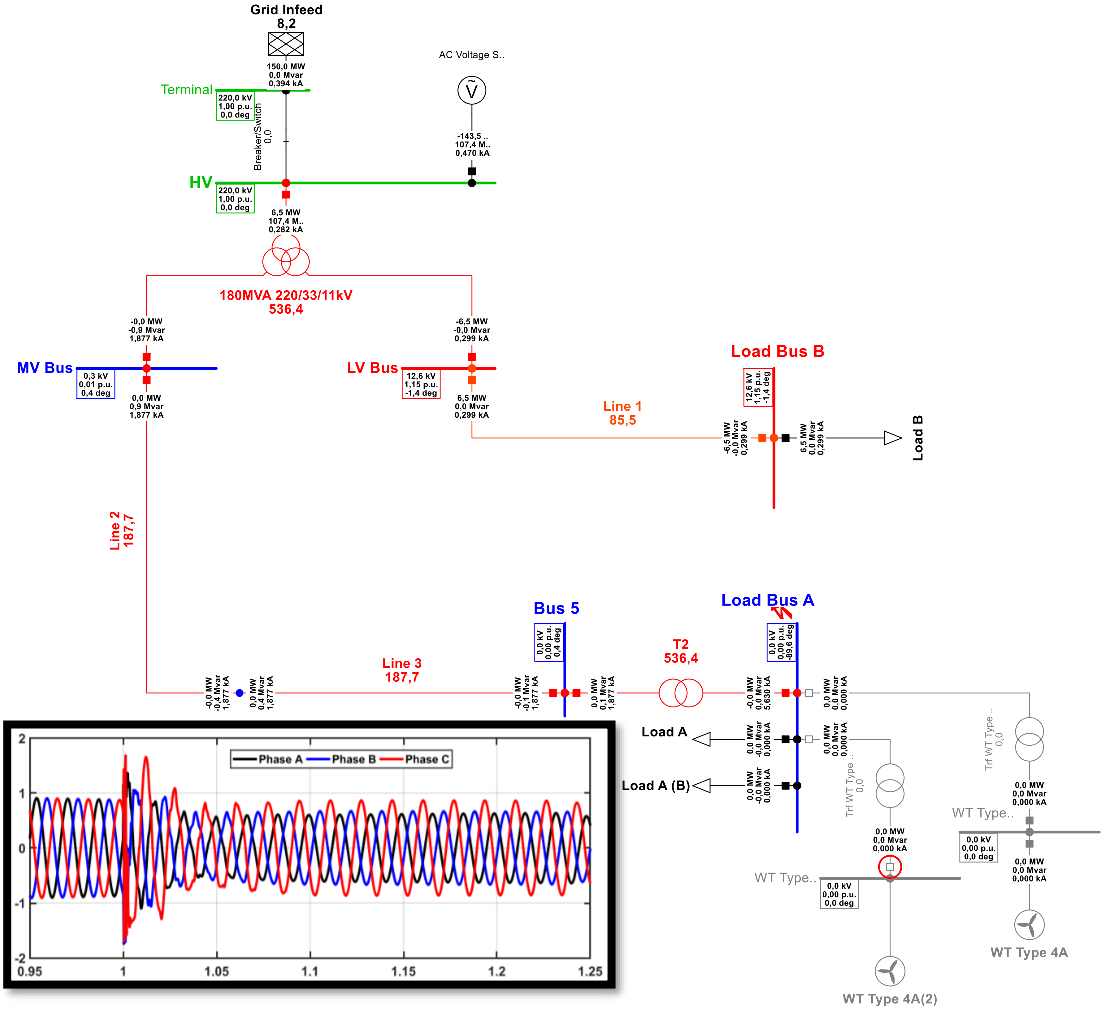

Figure 4. 10a: Network behavior following load decrease

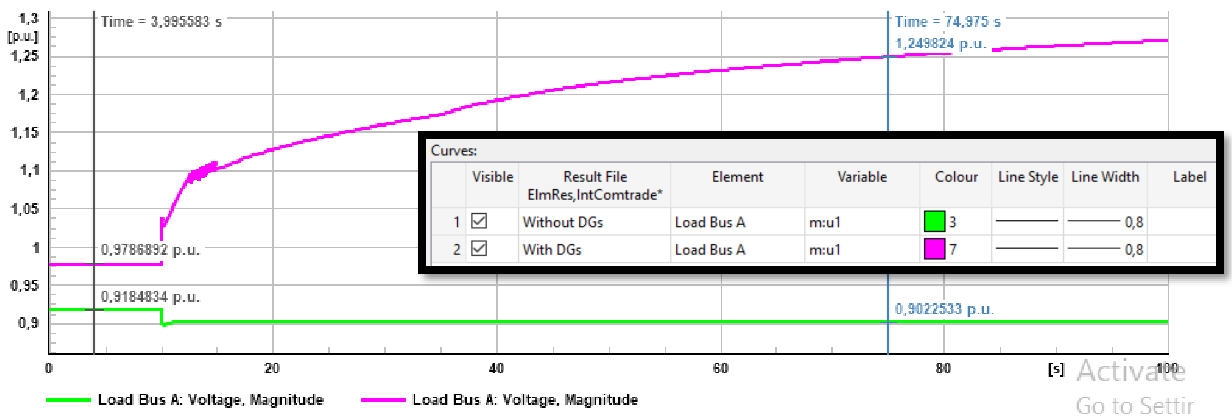

Figure 4. 11b: Overvoltage simulation test results

Table 4. 15: The relay response after Overvoltage implemented

	rtd V [kV]	Phase	Voltage [kV]	[p.u.]	[deg]

Bus Load A	11.00	A	14.0	1.27	-0.02
		B	14.0	1.27	-120.0
		C	14.0	1.27	120.04

4.6.2.1 Scenario 2: Under-voltage protection testing

4.6.3 Under-voltage protection testing by applying single phase to ground fault on Bus Load A.

The second test performed is **Under-voltage protection**. This function is tested in the islanded mode of the distribution network section whereby a single phase to ground fault applied in Load Bus A to create under-voltage.

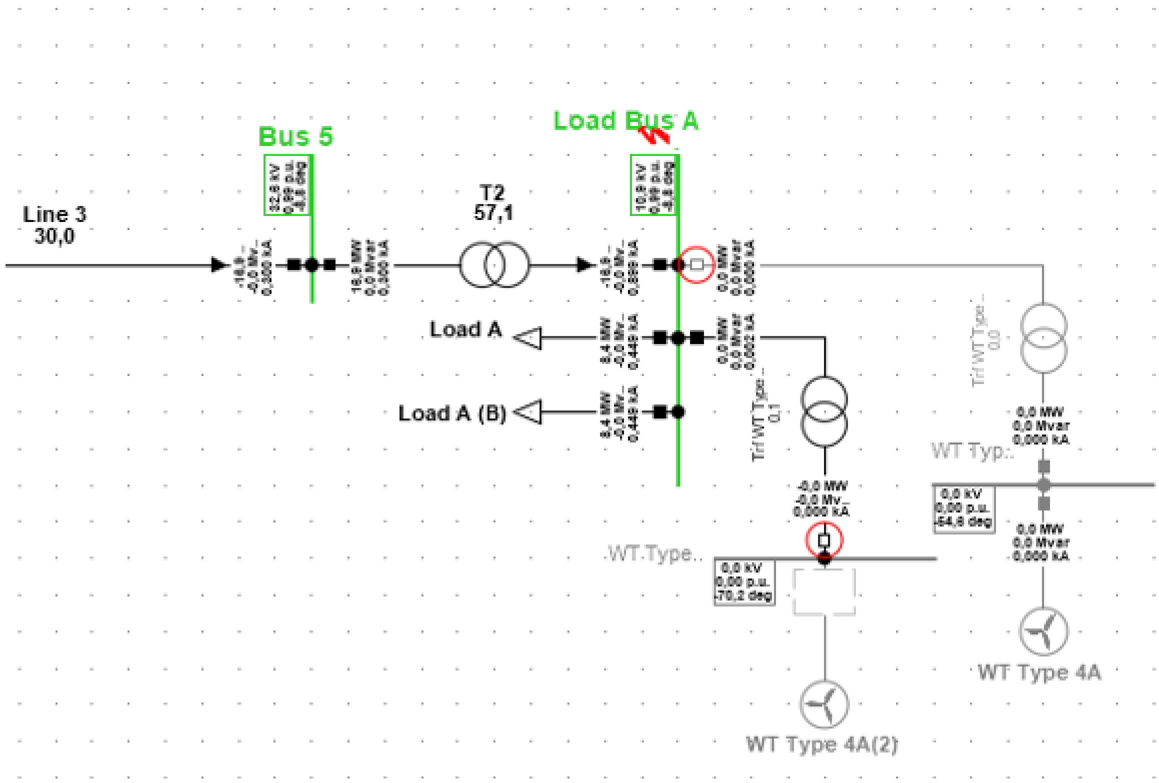

Figure 4. 12a: Phase A to Ground fault initiated on Load Bus A

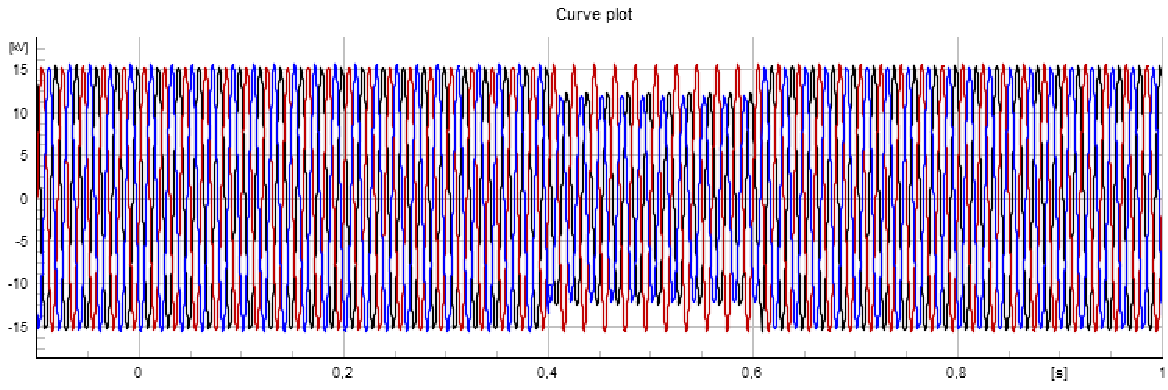

Figure 4. 13b: Voltage waveform during Under-Voltage

The above figure 4.14a and 4.14b shows the results of under-voltage after a single phase to ground fault applied on load bus A. The equipment is protected by an under-voltage SEL700GT relay that monitors the voltage supply and switches off the supply in the event of an Under-voltage condition and protection responsiveness is illustrated by how the voltage protection relay responds to this fault.

4.6.4 Frequency Protection

In power system relaying, frequency protection plays a crucial role. One aspect of its function is to protect other frequency-sensitive apparatus from possible damage or extensive wear. Another aspect is to protect the system during load shedding. An overview of the power system frequency definition, frequencies measurement algorithms, and fundamentals of frequency relaying are presented in this session. Synchronous machine as reference has been used instead of external grid in order to get exact results on the network study. It is vital to control and monitor frequency stability in power systems.

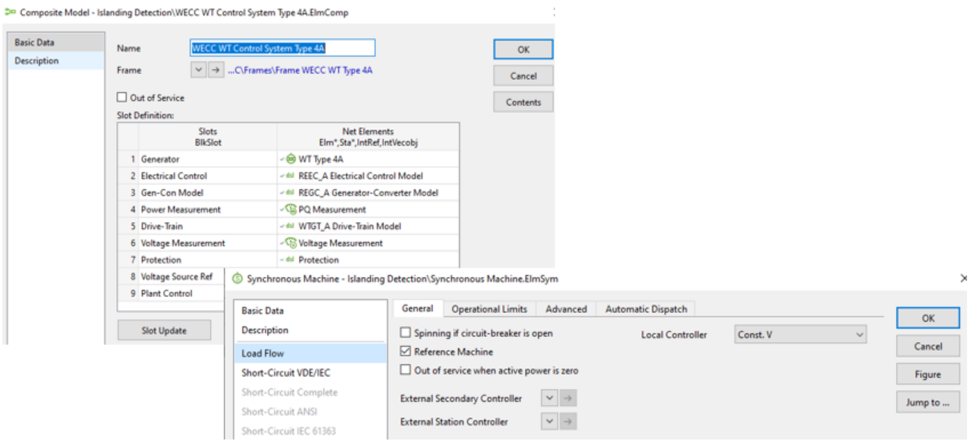

Figure 4. 14: Synchronous Machine as reference instead of External grid

4.6.4.1 Scenario 3: Under-frequency protection testing

4.6.4.2 Under frequency protection testing by disconnecting the generator DG at t = 10 s to create under frequency conditions

The third test performed is **under frequency protection**. This function is tested in grid-connected operation mode of the distribution network.

The aim of the test case study was to compare the under frequency load shedding elements that are used in the DigSilent power factor.

The thoroughly investigations were done by implementing various conditions on the Network System in order to fully understand the performance of the two elements.

Performance of under frequency elements in the software environment of DigSilent power factory. The starting point after all the above was considered the simulation was performed on the distribution network with two Wind Turbines connected and the results were analysed in all aspect of the Network. The frequency response of the system as result of disconnecting the generator DG at t = 10 s and the generator connect at t = 30 s as shown in the below simulation results.

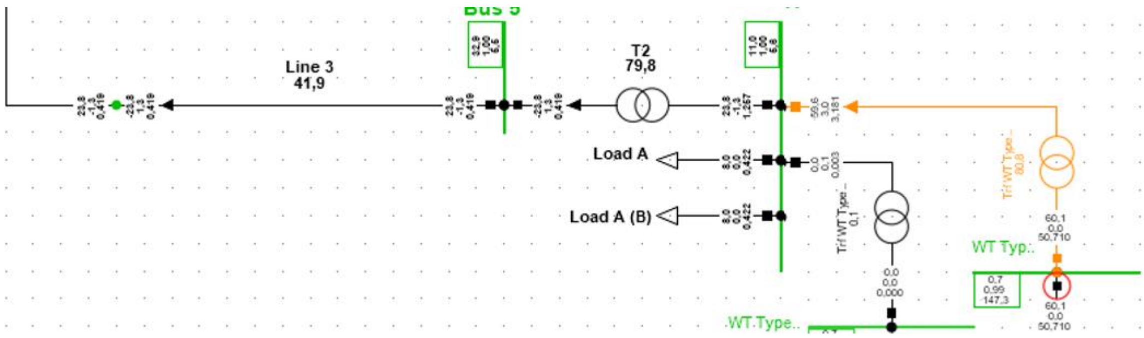

Figure 4. 15: Synchronous Machine as reference

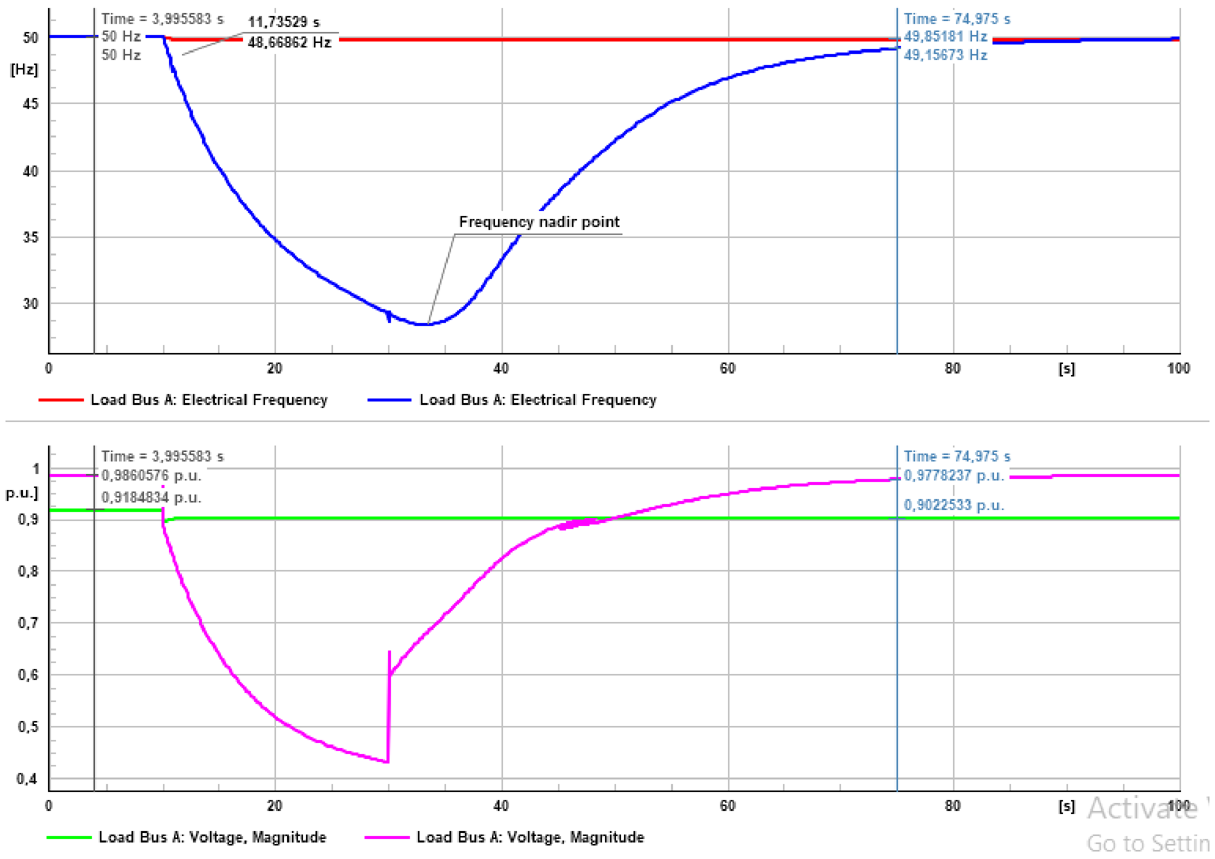

Figure 4. 16: Under frequency test results

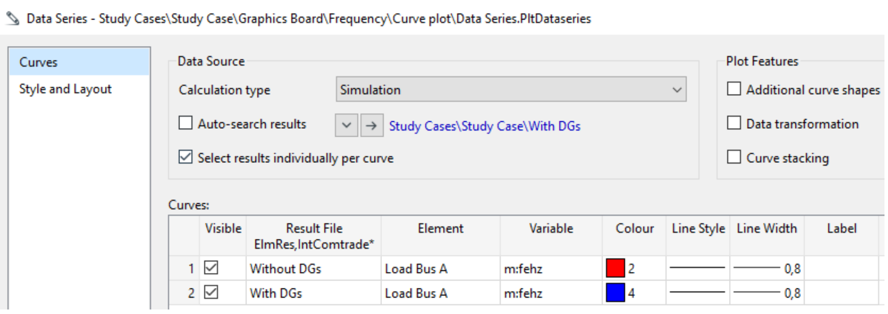

Figure 4. 17: Key elements for waveforms

The figure 4.18 above shows that the governor tries to return the frequency to a normal level after it reached the frequency nadir point and this case synchronous machine is used as a reference instead of using the external grid. When synchronous generators are used in a conventional power system, speed governing is the primary frequency control device.

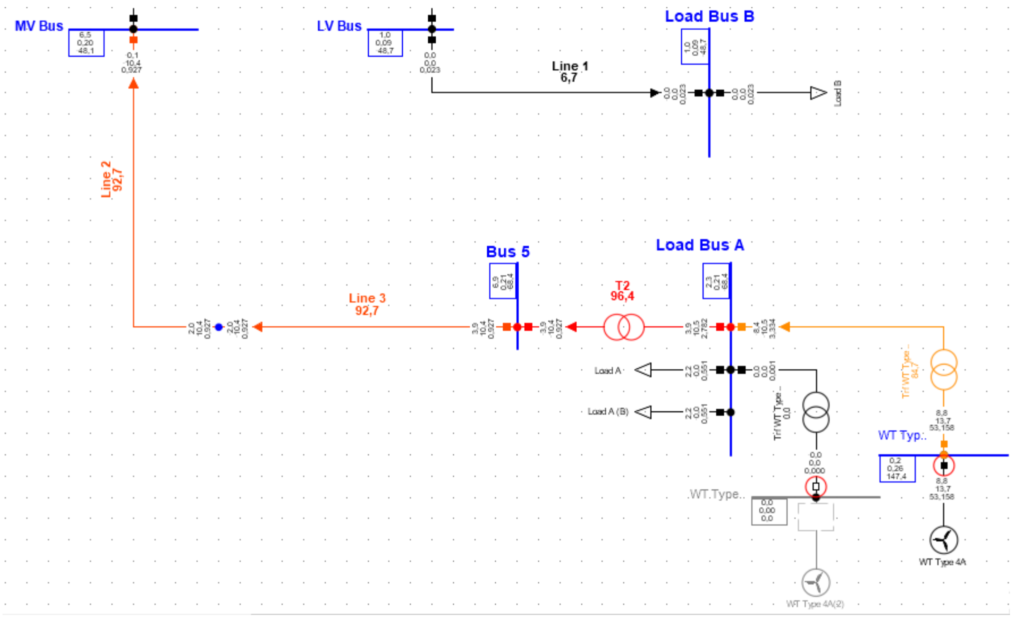

Figure 4. 18: External grid as reference

The increase in load demand, however, has resulted in an increase in costs, when the generator's speed-governing system operates at its adjusted steady-state, it can only maintain a steady frequency, and this level is lower than its nominal value. In the event that the load demand continues to increase, there is the possibility of an electrical system becoming unstable. Power systems may collapse due to frequency instability and blackouts may occur refer to figure 4.20.

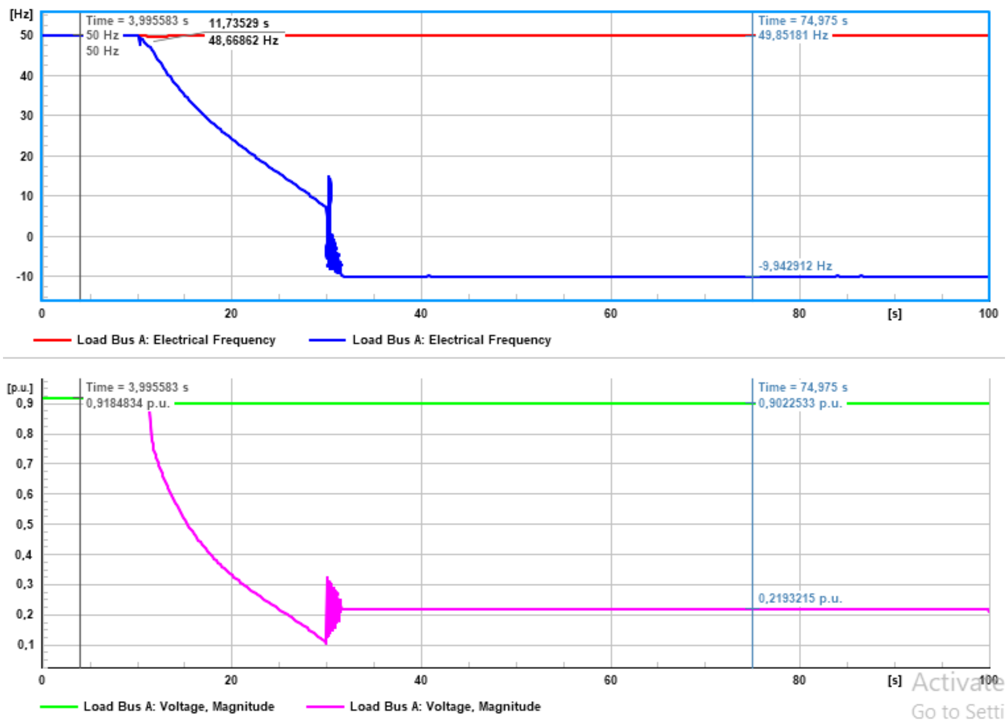

Figure 4. 19: System collapsed as external grid used as reference

Because load demand has increased, low frequency has resulted in grid collapse in the power system; therefore, to regulate frequency within acceptable operating ranges, wind power plants are utilized as active power compensators.

Response of the system with the use of External Grid when under frequency element implemented.

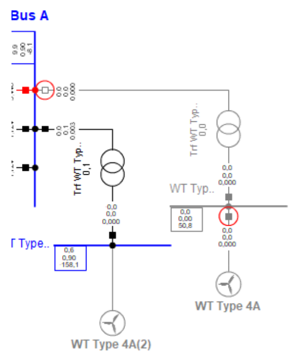

Figure 4. 20a: Under frequency condition when the Generator disconnect at 10 s

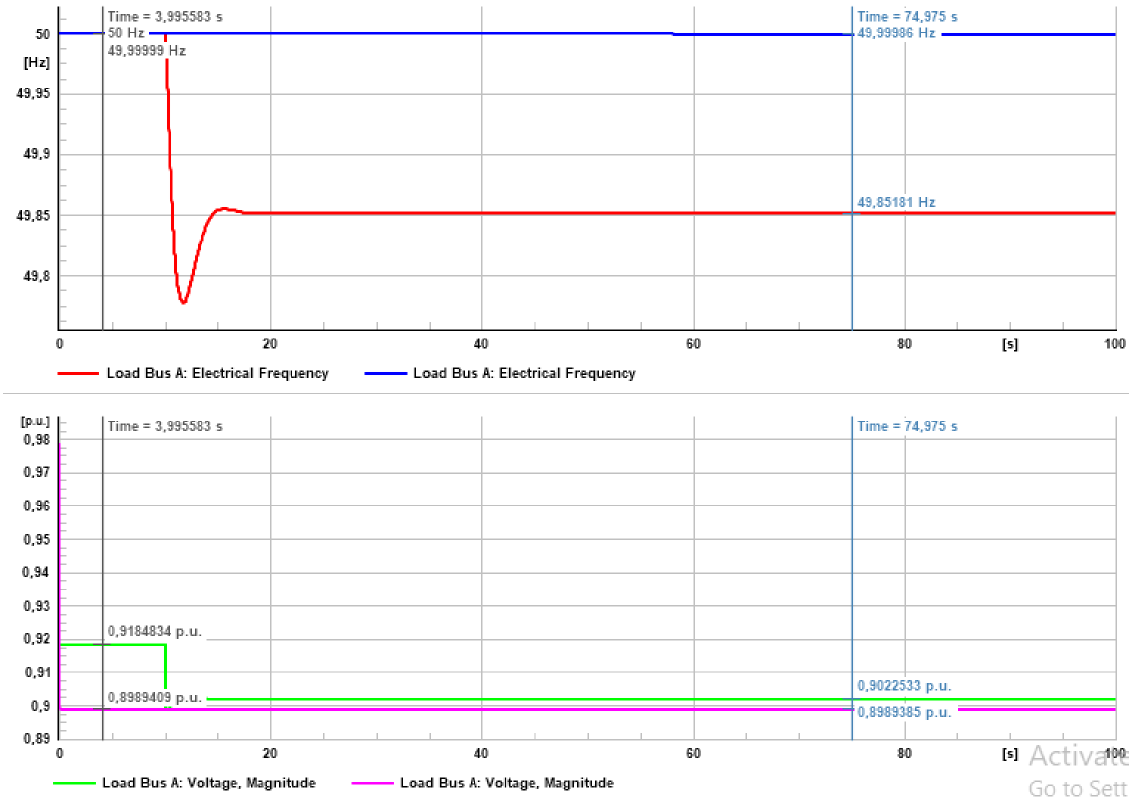

Figure 4. 21b: Response of the system with the use of External Grid

Table 4. 16: Summarised Network Data

Summarised network data							
No. of Substations	0	No of Busbars	8	No of Terminals	0	No of Lines	3
No of 2-w Trfs	1	No of 3-w Trfs	1	No of Syn. Machines	1	No of Asyn. Machines	0
No of Loads	2	No of Shunts/filters	0	No of Wind T	2		
	Real Power [MW]			Reactive Power [Mvar]		Apparent Power [MVA]	
Generation	20			0.00		20	
External Infeed	100			0.05		100	
Inter Grid Flow	0.00			0.00		0.00	
Feeder A	15			0.01		15	
Feeder B	5			0.01		5	

Table 4. 17: The relay tripping time for under frequency protection

Relay tripping time				
Relay	Branch	Terminal	Type	Tripping Times
F81 Frequency Relay	DG	DG Bus	F81 Frequency	0.2 s

4.6.4 Over frequency Protection

An over frequency protection system is suitable for use with generators. During emergencies or abnormal conditions, such as load shedding, source changeovers, and emergency generator starts, the continuous monitoring of frequency allows appropriate action to be taken to safeguard the installation's operation. Monitoring the frequency is part of over frequency protection. In the event of a system frequency-exceeding threshold, the protection activates.

4.6.4.1 Scenario 4: Over-frequency protection testing

4.6.4.2 Over frequency protection testing by open CBGrid to create over frequency conditions

This function is tested in grid-connected operation mode of the distribution network section with Load A set to 8MW, 0.05MVar and load B that is set to 5MW and transformer T2 in Dyn5.

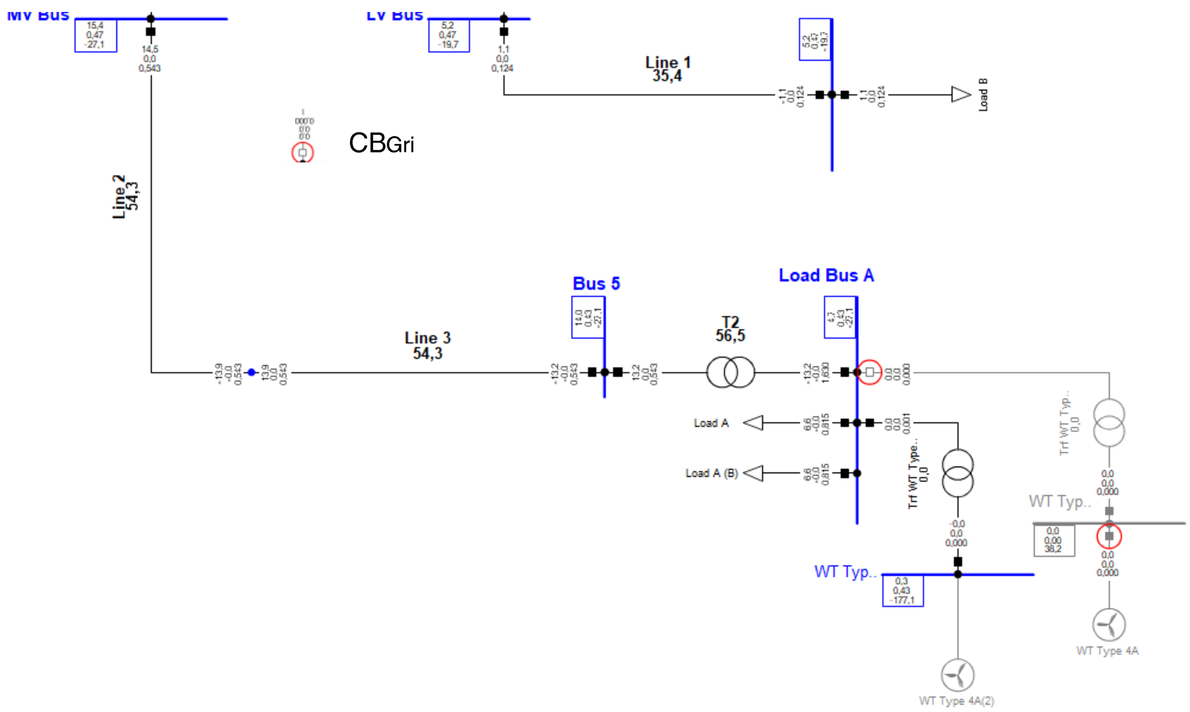

Figure 4. 21: CBGrid opened to create Over-frequency condition

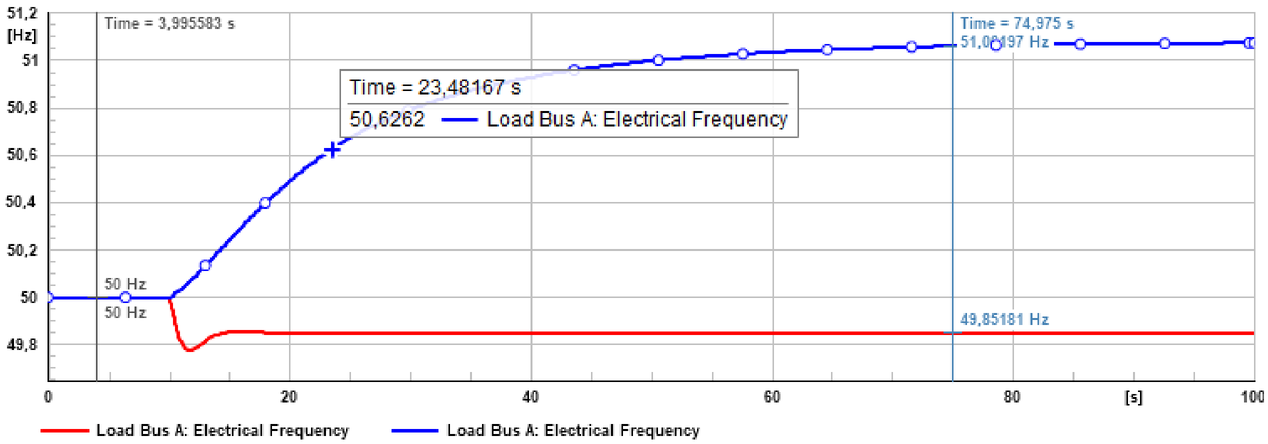

Figure 4. 22: Over frequency condition when the CBGrid tripped

Table 4. 18: Detailed relay tripping time for over-frequency protection

Relay Tripping Time				
Relay	Branch	Terminal	Type	Tripping times
SEL700G Relay	DG	BDG	SEL700G 1A	0.10

4.7 Conclusion

The protection that is utilized to detect islanding has been covered in this chapter. Using the DigSilent software suite, the distribution network was presented, put into practice, and simulated. On the distribution network, the various case scenarios were put into practice, load flow was simulated, and short circuit currents were computed in various fault locations.

The discrimination between the protection-selected devices has been accomplished using a protection relay based on Schweitzer protection devices that implemented time-current characteristics. This chapter examined five hypothetical circumstances. The study's foundation was a simulation of the protection scheme's effectiveness. Detailed results were not clearly stated as to which piece was tripping based on the data obtained on DigSilent.

The lab will host the practical to support the aforementioned findings. The next chapter will consider the same network, However, in this instance a Real-Time Digital Simulator (RTDS) will be employed, and its sole purpose is to produce results that operate in real-time.

CHAPTER FIVE

IMPLEMENTATION OF THE LAB-SCALE TESTING OF THE ISLANDED PROTECTION SCHEME

5.1 Introduction

Testing and validation have always been crucial because power system protection is considered a safety-critical component of all electrical systems. In an electrical system that is usually constructed, speedy operation is important to reduce damage and hazard. reliability and stability have always been placed on the transmission system level protection, where detailed type testing procedures and regulations have been generated over many years of engineering practice. Distribution system protection is similar to transmission system protection, due to the passive nature of the network, cost constraints, and lesser impact on the stability and safety of the overall system. Less difficult has always been created with testing requirements in mind. The validation and protection schemes, including the, are frequently insufficient because different electrical energy sources are used at all distribution levels. The degree of protection now in place and the number of restrictions have already been noted in technical literature. The existing practice it can be addressed with small alterations while others call for the development of new protection techniques.

The islanded protection scheme's laboratory testing is presented in this chapter. Trip time parameters are included in the generator protection SEL700GT relay configuration setting and are detailed in detail. The main protection is provided by the generator protection relay SEL 700GT configuration settings, which contain the following parts: (27) under-voltage and (59) over-voltage elements. The appropriate voltages for testing the islanded protection system have been provided by Omicron CMC 356. The SEL 700GT's hardwired protective mechanisms are tested in a lab setting using pre-set voltage and frequency test module templates provided by the AcSELerator Quickset Software and test universe software of the Omicron device. The voltage protection scheme simulation results from the lab-scale testing of the islanded protection system setup are found in the previous chapter 4.

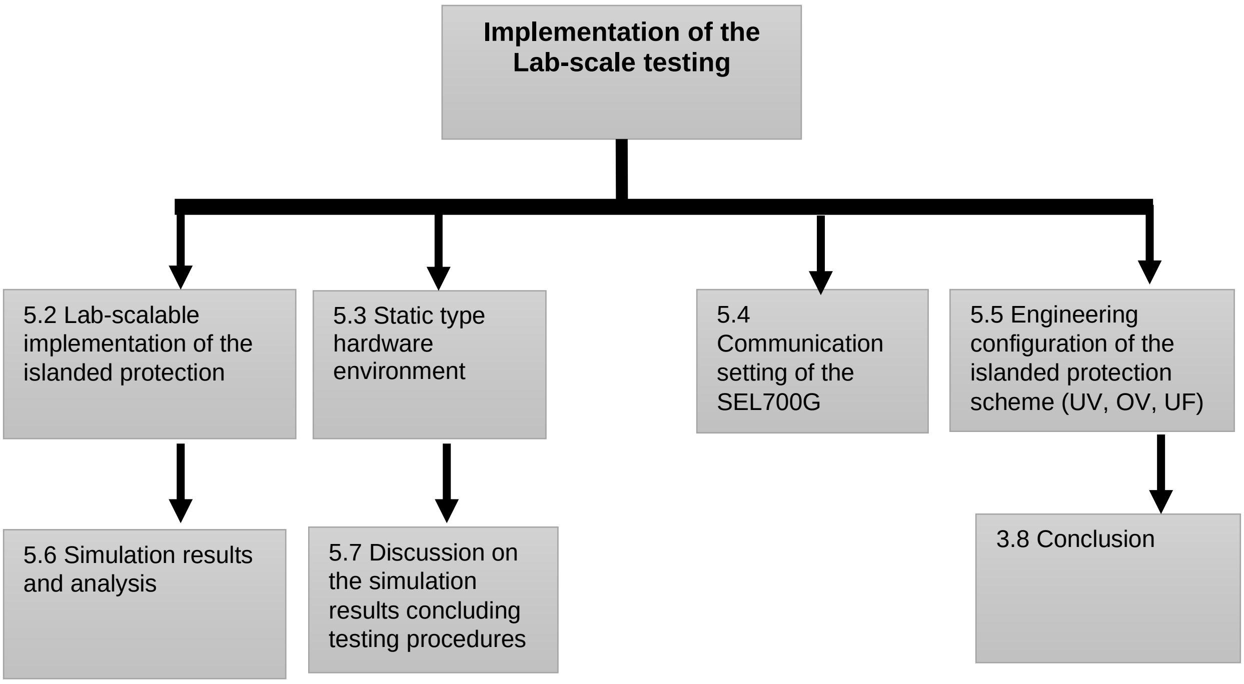

Figure 5. 1: Block diagram structure for chapter five

5.2 Lab-scalable implementation of the islanded protection scheme

section provides the lab-scale testing of the islanded protection scheme set up for the generator protection that includes the following protection elements, voltage, and frequency elements, and is tested using the Omicron test injection device. The islanded protection test setup is shown in Figure 5.1. The SEL700GT relay is configured on the generator side, and the OMICRON test injection device (CMC356) and a personal computer that is loaded with the relay manufacture software configuration and to manage the protection testing using the protection test set (AcSELerator Quickset and Test universe software)

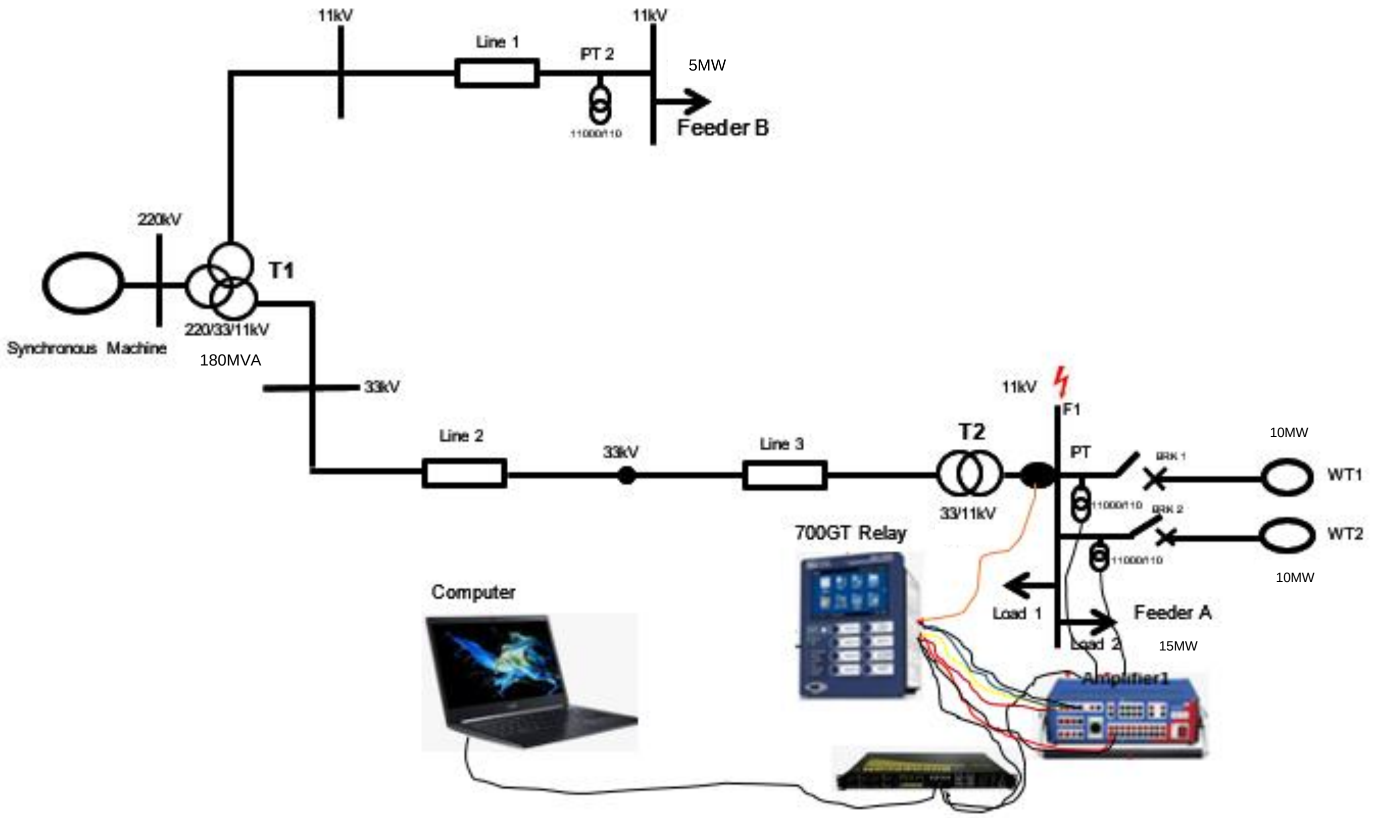

Figure 5. 2: lab-scale testing of the islanded protection scheme set up

Figure 5. 3: Physical layout lab-scale testing of islanding protection scheme set up

5.3 Static type testing hardware environment

The state sequencer technique, also known as the static type test technique, is used to establish limiting values, such as the minimum pick-up hysteresis for a pick-up/drop-off ratio, for instance. AcSELerator Quickset Software directs the amplifier (Omicron CMC) to produce ramps of output voltage, phase, and amplitude, and all of the created ramp responses from the relay are automatically recorded. The PT1 voltage signals are injected into the SEL700GT and The switching device and circuit breakers are linked to the ends of the power transformer, respectively. The binary signal attached to the output port (OUT101) SELogic of the SEL700GT and binary 1 mapped, binary 2 not utilized, indicate the pickup, trip, and closure logic (27PPX1T OR 27PPX2T OR 59PPX1T OR 59PPX2T signal of the circuit breakers. In order to trigger internal events, the SEL700GT IED transmits pickup and trip signals to the test injection device's binary contact, as shown in Figure 5.3.

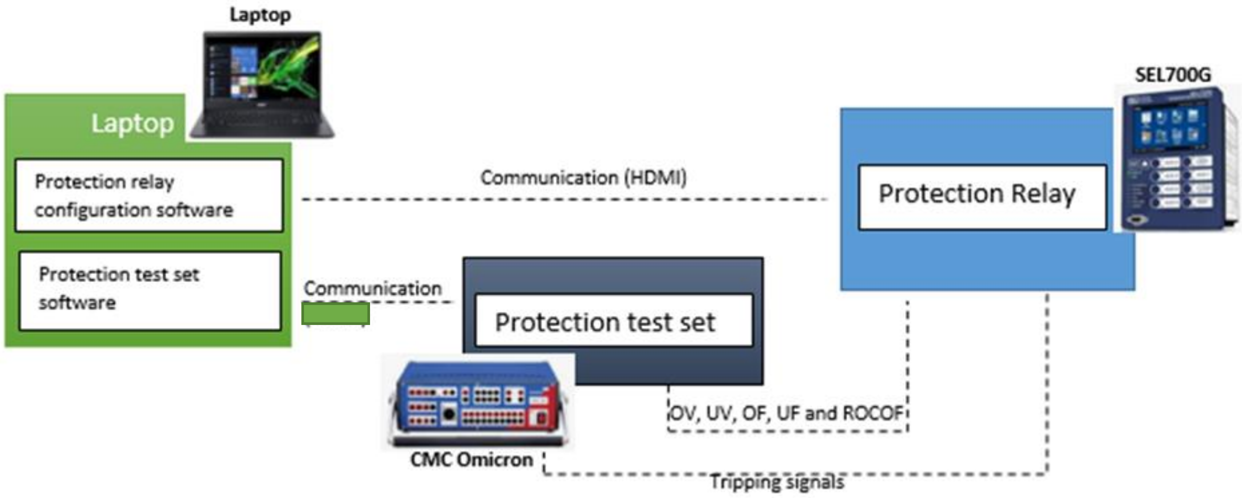

Figure 5. 4: Static type testing hardware environment

The protection test set is shown in Figure 5.3. above generates under-voltage, over-voltage, under-frequency, and over-frequency tests and records the tripping signals received by the SEL 700GT protection relay. This relay is fully IEC61850 commendation as it supports IEC61850 standard operating modes such as Test, Blocked, Test/Blocked, On, and Off for case of commissioning. Therefore, the virtualization of system parameters and synchronization of a generator to the system with built-in Auto Synchronizer applications on the touchscreen display, simply means there is no need for GOOSE messages to be used which are already covered with these new features in the SEL700GT relay.

5.4 Communication setting of the SEL-700GT IED

AcSELerator Quickset Software is a windows-based program supplied by Schweitzer Engineering Laboratories to link with SEL relays through a transmission link. This program is designed in such a way that you are able to create relays settings and send, and retrieve them from any SEL real connection to a computer via network, modem, or serial connection, but in order to be able to communicate with the relay, it is recommended to always first check the Part number of the relay you connecting to. Part number of the relay used in this study for the SEL700GT relay (Part#0700GT1HBH6X7581A671)

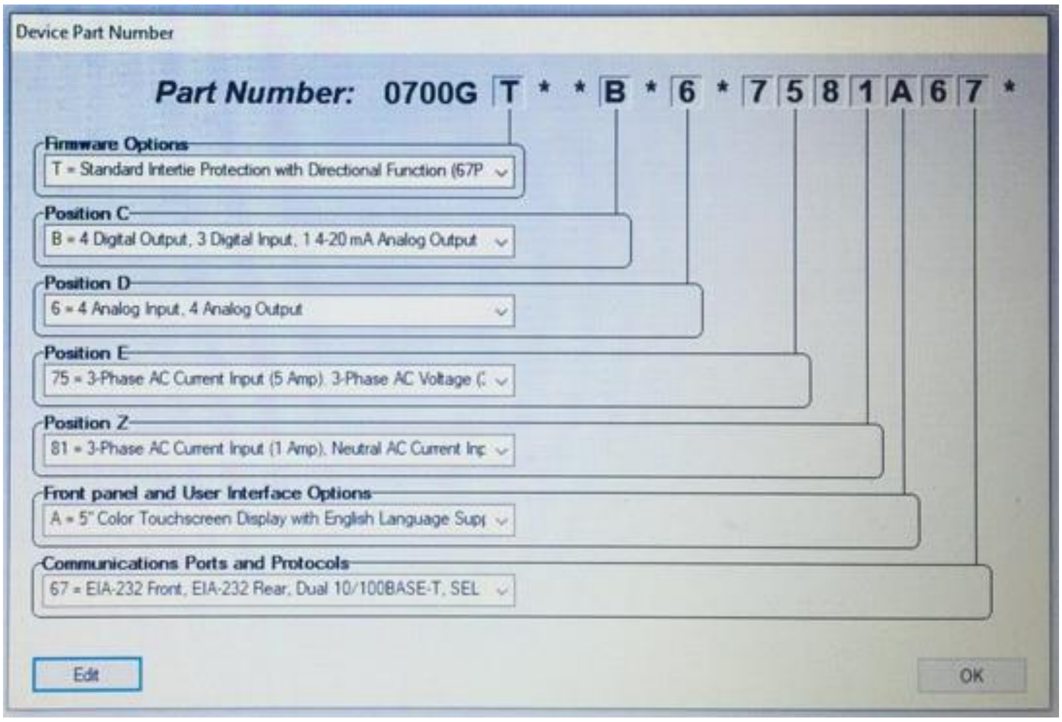

Figure 5. 5: SEL700GT generator protection relay Part Number

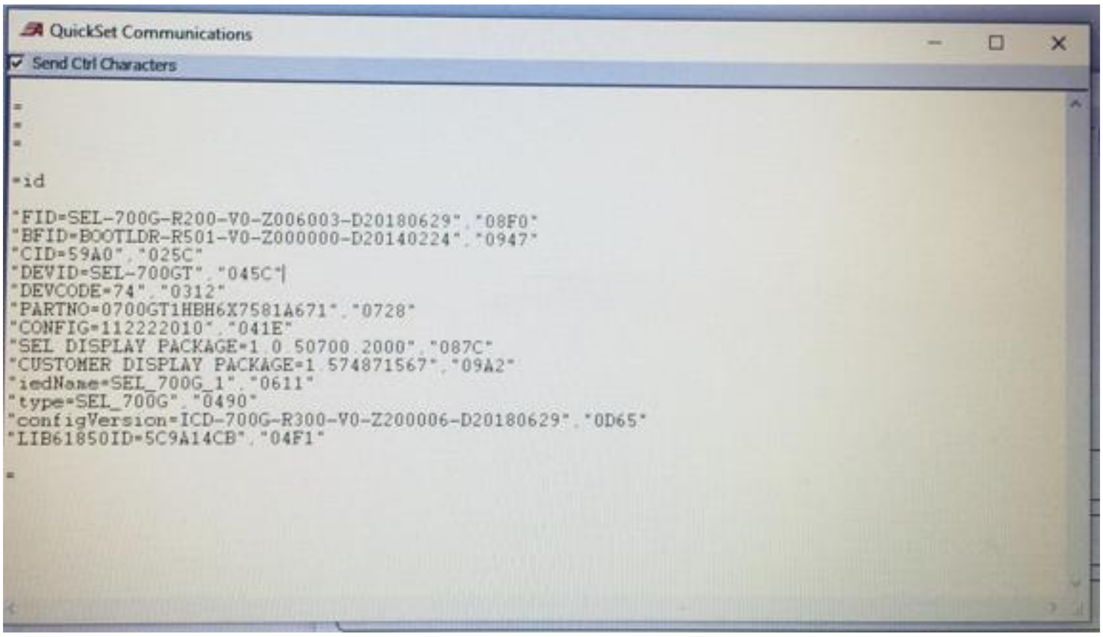

Figure 5. 6: SEL700GT generator protection relay response communication

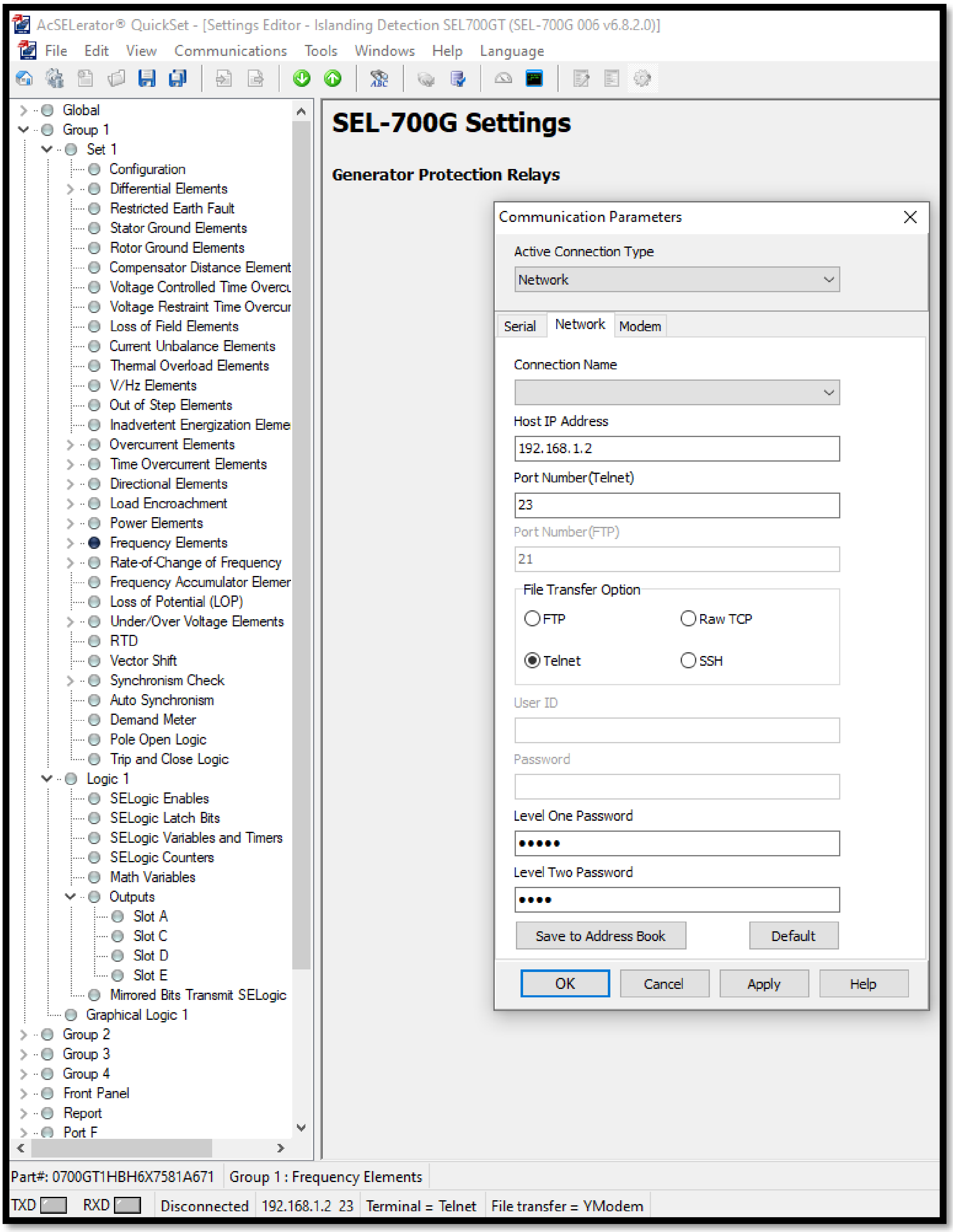

Figure 5. 7: SEL700GT communication parameter settings

AcSELerator Quickset, when used for the analysis of substation events logged by the relay, enables all test findings to be recovered via the Human Machine Interface (HMI). When configuring a computer communication port, the IP address used for the IED's IP address domain should match that used for the port.

5.5 Engineering configuration of the islanded protection scheme (UV, OV, UF, and ROCOF)

5.5.1 CMC Omicron test universe configuration device setting to test UV, OV, UF, and OF protection functions

Test Universe is the most powerful software tool for the settings-based testing protection relays like the SEL700GT relay, more flexibility in testing with sampled values and modules are graphically display relay characteristics, and easily check settings as well as the mode of operation. The Control Centre test document is the key to even greater flexibility and adaptability in testing.

The tests required to test islanded protection are carried out using the state sequencer test module. The standard relay settings are presented, including the device type, manufacturer, nominal values, relay ID, and substation information. The RIO function device offers the Object settings and Hardware configuration for voltage/Frequency element configuration setting, and some of them are connected to the RIO.

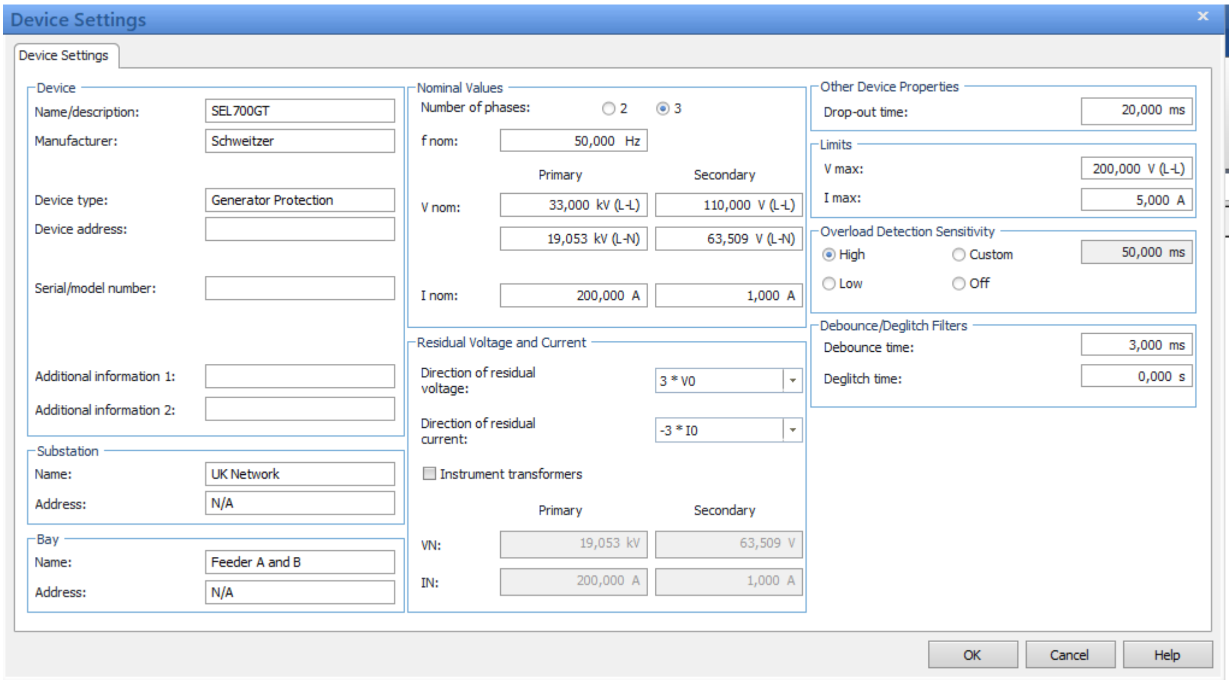

Figure 5. 8: Test Universe settings for the SEL 700GT device

5.5.2 Hardware Configuration parameters

To define the test-specific hardware settings, a configuration module named Hardware Configuration is used. The three-phase voltage signals of the SEL700GT is mapped to the channel A of the CMC 356 test injection device. In this particular study, it is only Voltage Outputs that are configured for testing voltage and frequency elements, there is no injection on the Current Outputs as shown in Figure 5.8. below.

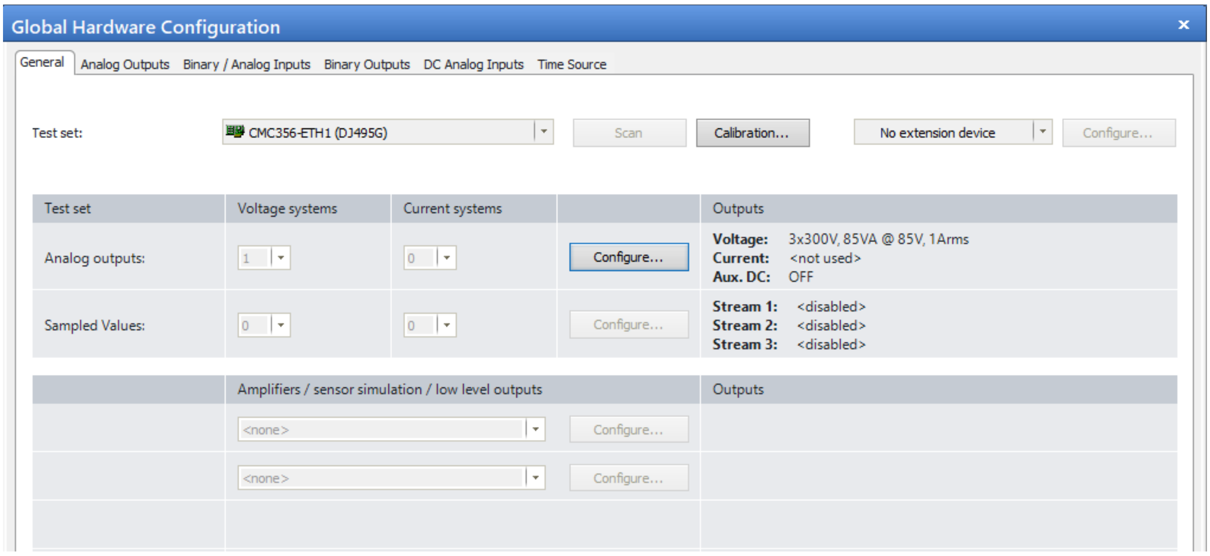

Figure 5. 9: Output configuration settings of the CMC 356 device Analog Outputs configured setting for voltage and frequency elements

On the Analog Outputs, binary inputs, binary outputs are activated in the local hardware configuration and voltage is defined as the usage of the analog outputs as shown in Figure 5.9. The three-phase voltages of the relay are configured to the analog 1 to 3 of the CMC356 test set. On the Binary Outputs tab, the usage has been specified on the CMC test set's binary outputs. In this study all the available binary outputs are displayed according to the test hardware definition at the General tab.

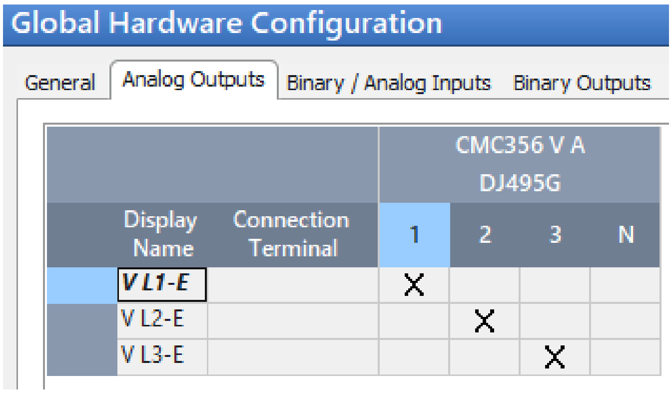

Figure 5. 10: Analog output configuration setting on the CMC356 test set

5.5.3 SEL-700GT Generator protection configuration setting using AcSELerator Quickset software

Figure 5.10 displays the generator protection relay's default global setting. This details all data formats, fault states, transformer ratios derived using the system's primary voltage, a nominal system frequency set to 50Hz, and specified nominal machine voltage.

The CT ratio values for the phase and neutral components are not included in Table 5.1 because they are not configured to be used in the global hardware setup. On the high voltage side of the transformer, the PTRS Synchronizing Voltage PT Ratio and PTRX X Side PT Ratio are linked and estimated to be set at 100V. *PTRS* = *PTRX* =

$$\frac{V_{primary}}{VT_{primary}} = \frac{11000}{110} = 100V \qquad (5.1)$$

Where:

$V_{primary}$ – Primary Voltage of the study network

$VT_{primary}$ – Primary Voltage ratio of the Potential Transformer

In order to report the primary quantities, the relay measures the voltage signals. The relay determines the phase and neutral PT ratios by using the primary/secondary ratio, which is configured to be 1V.

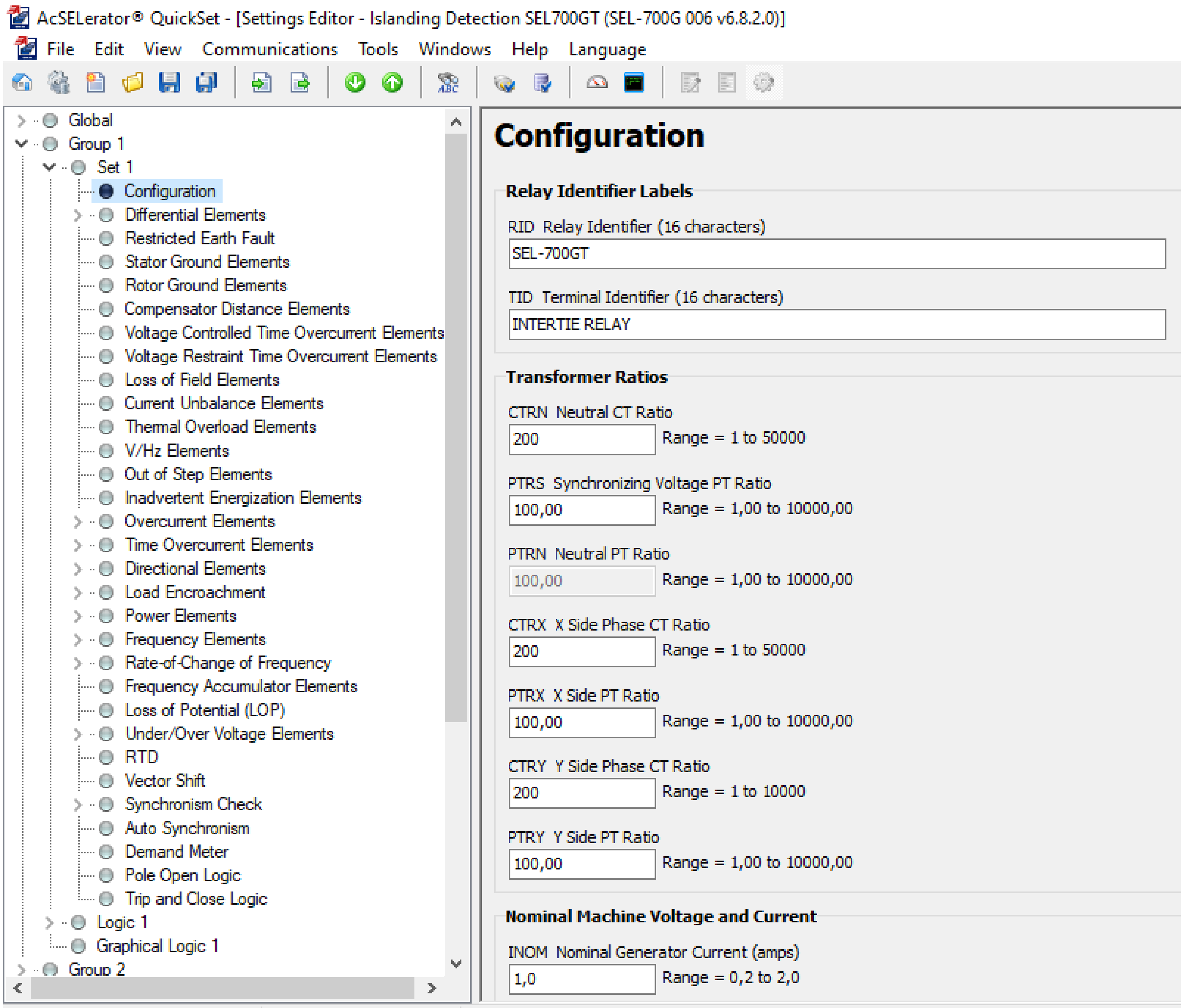

Figure 5. 11: SEL700GT Group 1 Set1 Configuration setting

Table 5. 1: Potential Transformer configuration setting of the SEL700GT

Abbreviation	Description	Value
PTRS	Synchronizing Voltage Ratio	100
PTRX	Phase (VAX, VBX, VCX) PT Ratio	100

Table 5.2 provides the Under/Over Voltage Elements which are configured on the X Side Phase Under-voltage and Phase Over-voltage of SEL 700GT relay and Y Side not in use. In order to determine the setting values for the SEL700GT relay, the Under/Over Voltage are computed using the settings from Table 5.2 above. Below are the calculations on how the voltage values obtained.

Under-Voltage Stage 1

27PX1P $= V_{nominal} \times UV_{setting}$ (5.2)

Where:

$V_{nominal}$ is the nominal voltage

$UV_{setting}$ is the under-voltage setting

27PX1P $= V_{nominal} \times UV_{setting}$

= 63.51 × 0.87

= 55.25 V

Under-Voltage Stage 2

27PX2P $= V_{nominal} \times UV_{setting}$ (5.3)

Where:

$V_{nominal}$ is the nominal voltage

$UV_{setting}$ is the under-voltage setting

27PX2P $= V_{nominal} \times UV_{setting}$

= 63.51 × 0.80

= 50.808 V

Over-Voltage Stage 1

59PX1P $= V_{nominal} \times UV_{setting}$ (5.4)

Where:

$V_{nominal}$ is the nominal voltage

$UV_{setting}$ is the under-voltage setting

$59PX1P = V_{nominal} \times UV_{setting}$

$= 63.51 \times 1.10$

$= 69.861$ V

Over-Voltage Stage 2

$$59PX2P = V_{nominal} \times UV_{setting} \quad (5.5)$$

Where:

$V_{nominal}$ is the nominal voltage

$UV_{setting}$ is the under-voltage setting

$59PX2P = V_{nominal} \times UV_{setting}$

$= 63.51 \times 1.04$

$= 66.05$ V

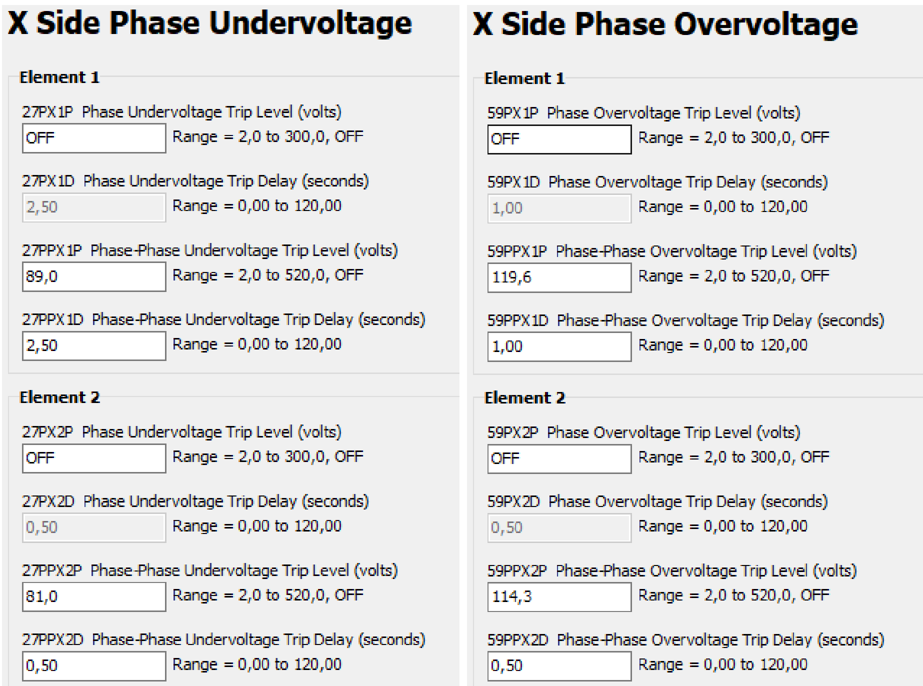

Figure 5. 12: Voltage Elements Configuration setting for SEL700GT

Table 5.3: Provides the Trip and Close Logic configuration setting for SEL700GT relay, all the above configuration settings for voltage elements and the frequency elements are all mapped to the output 101. The relay logic it allows the conditions that cause a trip and unlatch the trip and mapped to the output contact of the relay as the tripping logic is designated to control the switching action of the circuit breakers.

Table 5. 2: Trip and Closed Logic configuration setting for SEL700GT

Abbreviation Relay Word Bit	Description of the relay word bit	Value
27PPX1T	Level1 phase under voltage element trip	51.44 V
27PPX2T	Level2 phase under voltage element trip	46.77 V
59PPX1T	Level1 phase over voltage element trip	69.05 V
59PPX2T	Level2 phase over voltage element trip	65.99 V

Figure 5.12. Demonstrates the logic diagram for X-side frequency elements as configured on the physical SEL-700GT relay. The logic shown below permits the events that trigger trips and unlatch trips that are routed to the relay's output contact. When there is an imbalance between the load and the active power generated, the frequency changes in power systems.

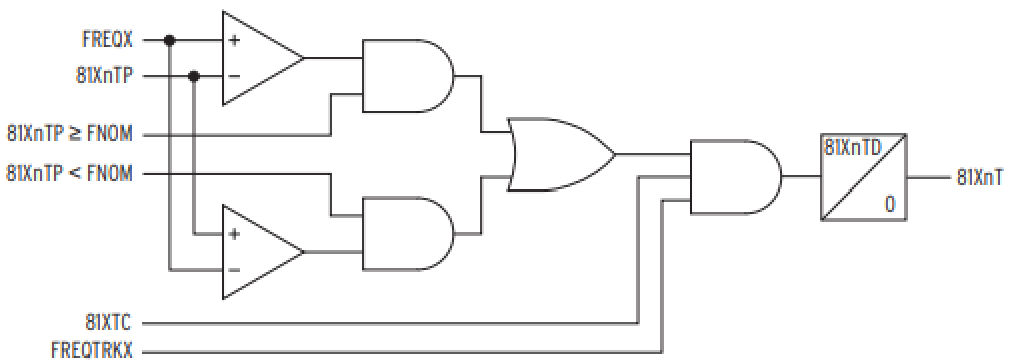

Figure 5. 13: X-Side Over- and Underfrequency Element Logic (SEL-700G Instruction manual, 2015)

n = Frequency Elements 1-6

FREQX = Measured Frequency

81XnTP = Frequency Pickup Setting

FNOM = Nominal Frequency Setting

81XnTD = Over and Underfrequency Element Pickup Time Delay

81XnT = Definite-Time Delay Over and Underfrequency Element Relay Word Bit

FREQTRKX = Relay Tracking Frequency FREQX

81XTC = Over and Underfrequency Element Torque Control Bit

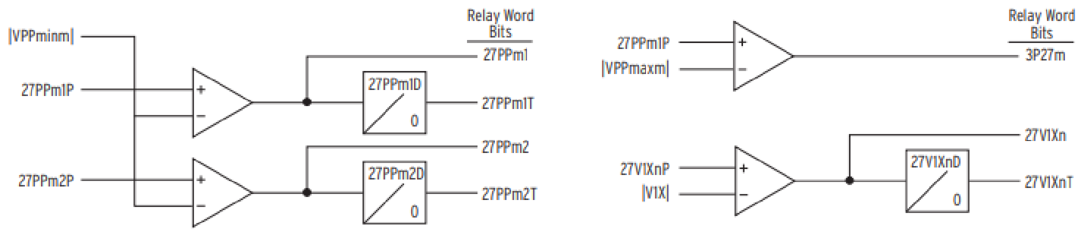

Figure 5. 14: Under voltage Element Logic (SEL-700G Instruction manual, 2015)

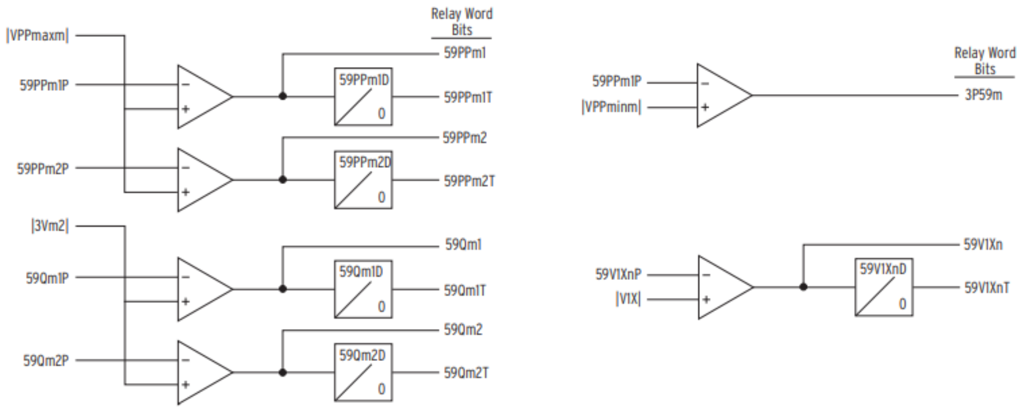

Figure 5. 15: Over voltage Element Logic (SEL-700G Instruction manual, 2015)

5.5.4 Test injection configuration for the islanded protection scheme

This section provides the testing injection configuration procedure for the islanded protection scheme using CMC Omicron Test Universe. Testing file created in order to test and proves the islanded protection which divided into two protection scheme testing voltage elements and frequency elements. The method used for testing these elements was known until State Sequencer Module introduced.

State Sequencer is discovered as a very flexible test module for determining operating times such as the actual time that relay operate, deviation time calculated automatically and logical timing sequences. The advantage about using State Sequencer in this study, it is because more states can be added within a single test, and state is defined by the output conditions such as voltage, binary outputs and a condition for the transition to the next state. Besides the direct input of the individual voltages and frequencies, the integrated fault calculator allows the automatic calculations of the test quantities.

5.5.5 Test injection configuration for Under-voltage stage 1

The State Sequencer Module has been designed to provide automated tool for testing, a complete sequence of state can be defined and measurements can be assessed automatically, the state sequencer interface has been structured the same way as other modules, the table view summarises all defined states. During these test challenges were encountered and the tests were failing because on the Trigger State Termination, under binary input(s) and /or timeout. The time assessments failing because only one box ticked which is “Timeout” instead of ticking “Use binary trigger condition as specified below”. Figure 5.15a. shows the test injection configuration for under-voltage stage 1 and assessment passed.

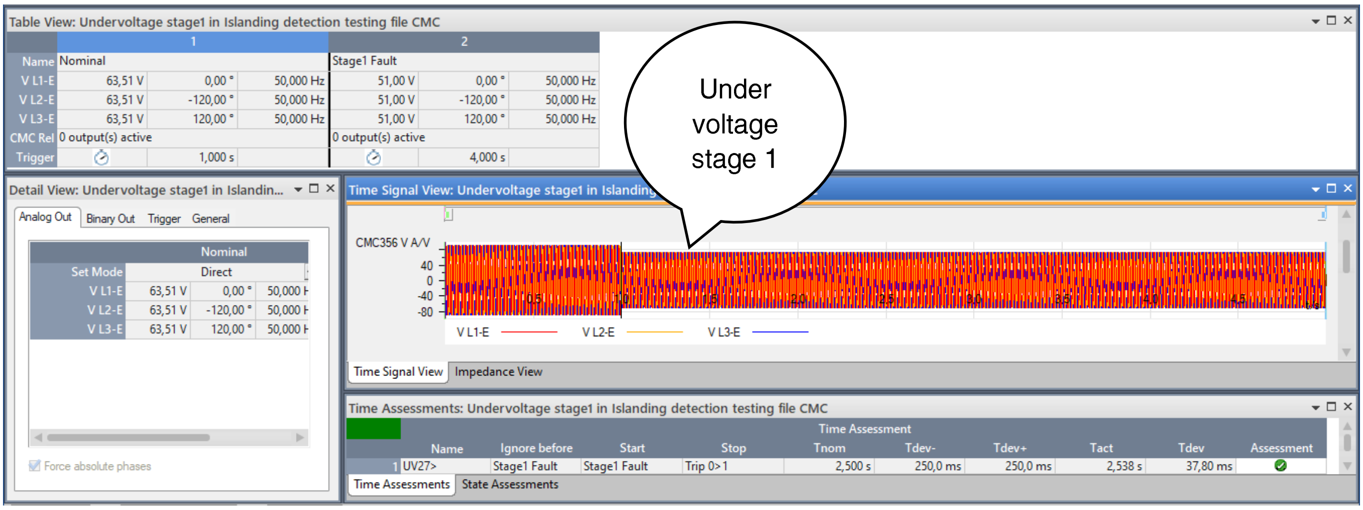

Figure 5. 16a: Test injection configuration for Under-voltage stage 1

5.5.6 Test injection configuration for Under-voltage stage 2

The testing results for stage 2 were all failing at the deviation of 10%, the adjustments were made on deviation of 10% to be adjusted and allows deviation of 20%. The second thing that made test results to be failing was the timeout, under detail view: Trigger and state termination only timeout was selected instead of selecting both timeout and binary input(s) and /or timeout, the input display name state trip was changed from X to 1. After all these changes were made, the test results all passed.

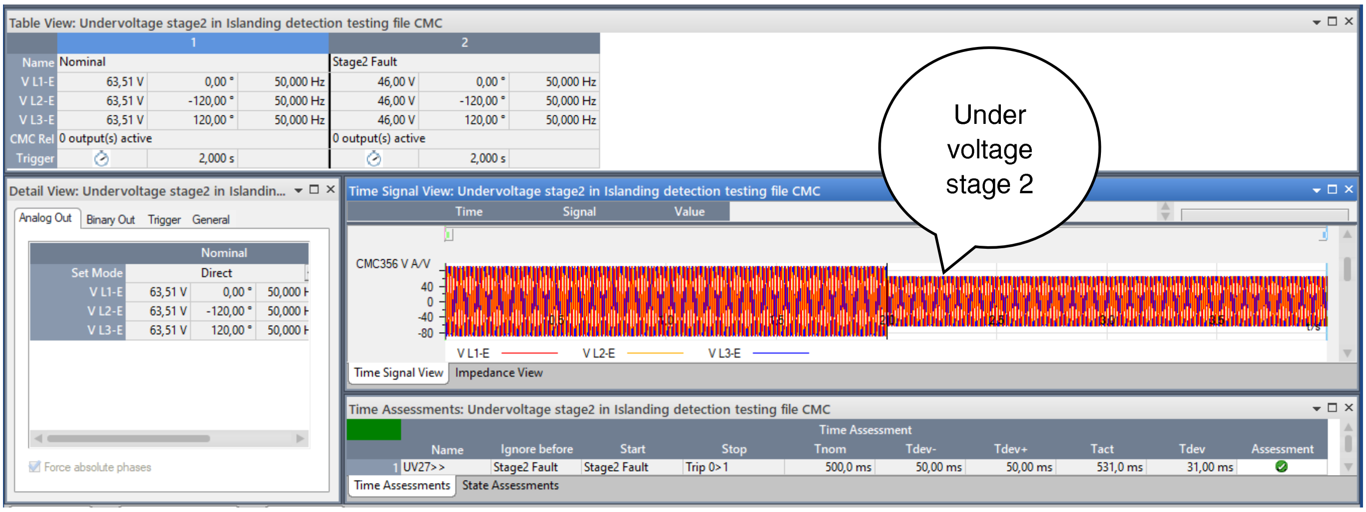

Figure 5. 17b: Test injection configuration for Under-voltage stage 2

5.5.7 Test injection configuration for Over-voltage stage 1

During the testing of over-voltage stage 1, the nominal time for tripping the relay was 500 milliseconds + 10% deviation which gives enough time for the relay to operate, but the actual tripping time was 533.8 milliseconds, causing late relay tripping with a deference of 20.8 milliseconds. The voltage was measured between three phase distribution network. Time Signal View showing the transition from nominal state to stage 2 fault and difference can be seen on the waveforms.

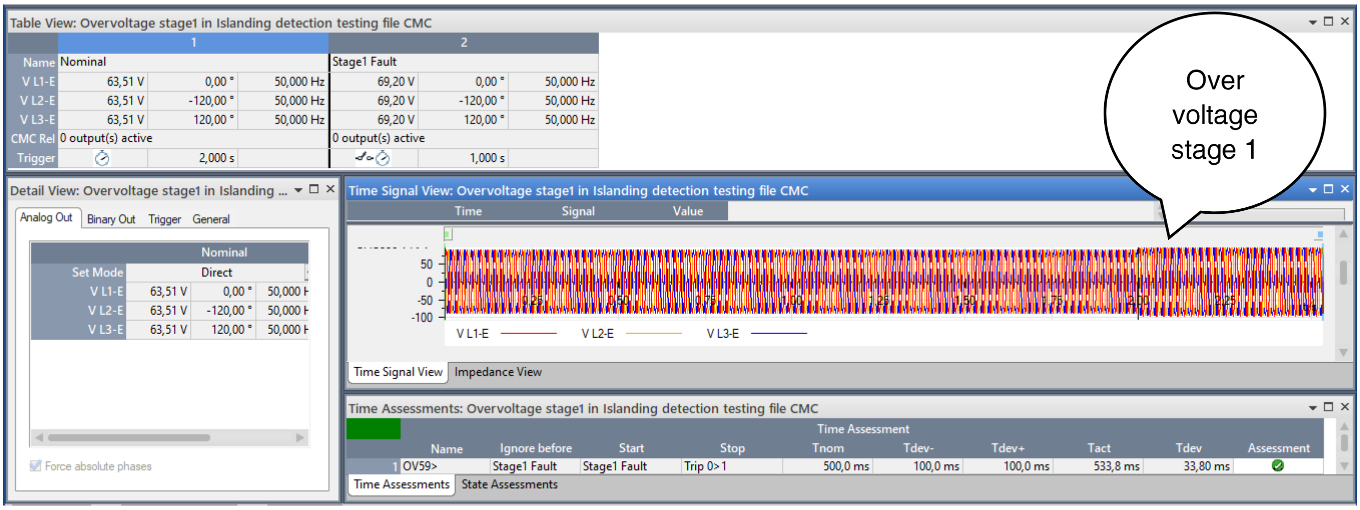

Figure 5. 18a: Test injection configuration for Over-voltage stage 1

5.5.8 Test injection configuration for Over-voltage stage 2

The operating time for the relay was set to Tnom (Nominal time) =1.00 s and 10% deviation which then relay operates at Tact (Actual time) =1.033 s and comparing the two operating times there is no much difference. The nominal voltage is 63.51 V and stage 2 fault is 65.99 V.

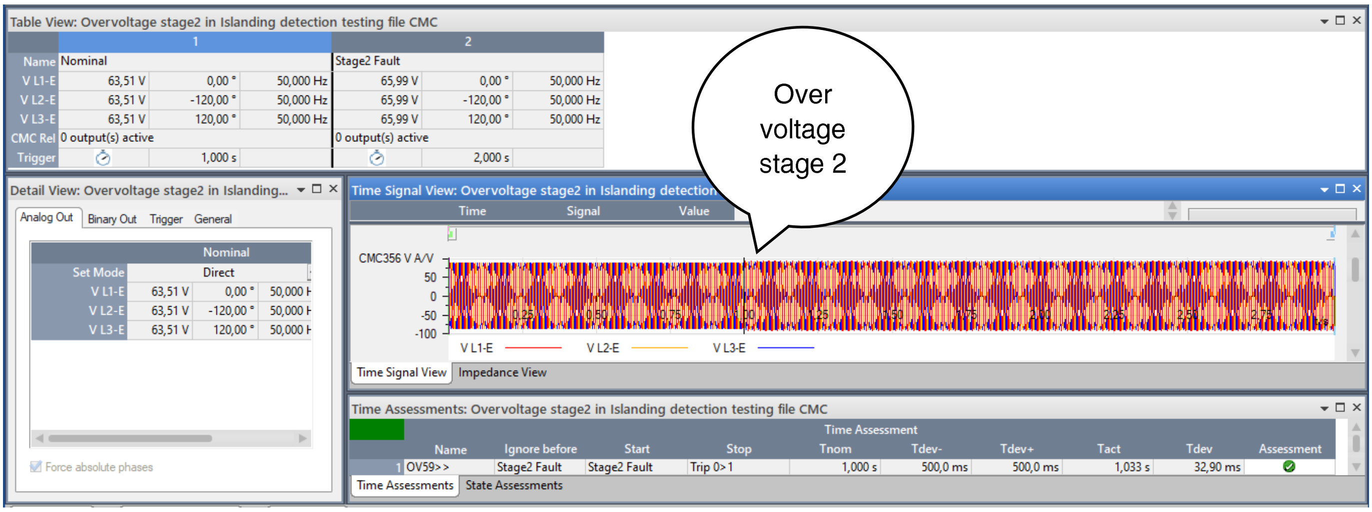

Figure 5. 19b: Test injection configuration for Over-voltage stage 2

5.5.9 Overview of the test injection configuration

The overview below in Figure 5.19 demonstrate all the different protection tests for the Islanded detection. During the test different functions were examined, activated one by one to make sure that the configured relay settings are tripping according to the recommended times. After all functions were activated one by one, simultaneous test for all elements introduced by pressing the start/Continue All, and all the protection elements passed. The test report is composed and generated according to the settings in the selected test report form.

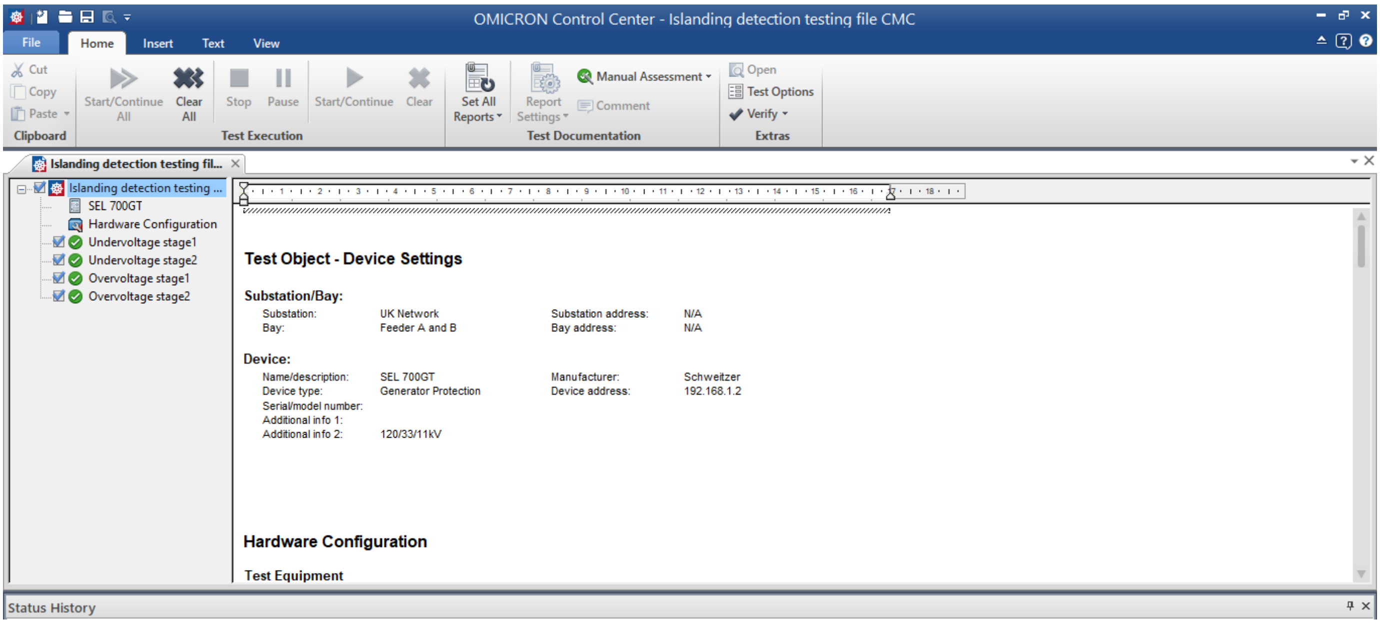

Figure 5. 20: Overview of the test injection configuration

5.6 Simulation results and analyses

In this study case, the SEL700GT generator protection relay's real-world tripping time is being evaluated for the Islanded protection scheme, under-voltage protection testing, and over-voltage protection testing. This section focuses exclusively on the simulation results for the Islanded protection strategy that were recorded and examined using the AcSELerator Analytic tool.

5.6.1 Case study 1: Under-voltage protection

In this case study the method that is used to test these elements it is different form the method that is used in DigSilent simulation test as represented in the below paragraphs.

The test performed is Under-voltage protection. This function is tested in the islanded mode of the distribution network section with feeder A set on LoadBus A and transformer T2 in YNyn. The performance test has been done to test protection sensitivity by applying a phase A to ground fault at fault location LoadBus A and given a time duration of 10 second. The 1000-Ohm fault resistance is initially set and gradually reduced in steps of 100 Ohm.

5.6.2 Under-voltage stage 1 Results

The below results shows the behaviour of 700GT relay during under voltage test for stage 1 whereby the report obstructed from SynchroWAVe Event report and the operating time of the relay is approximately to 235 ms once the under voltage condition implemented.

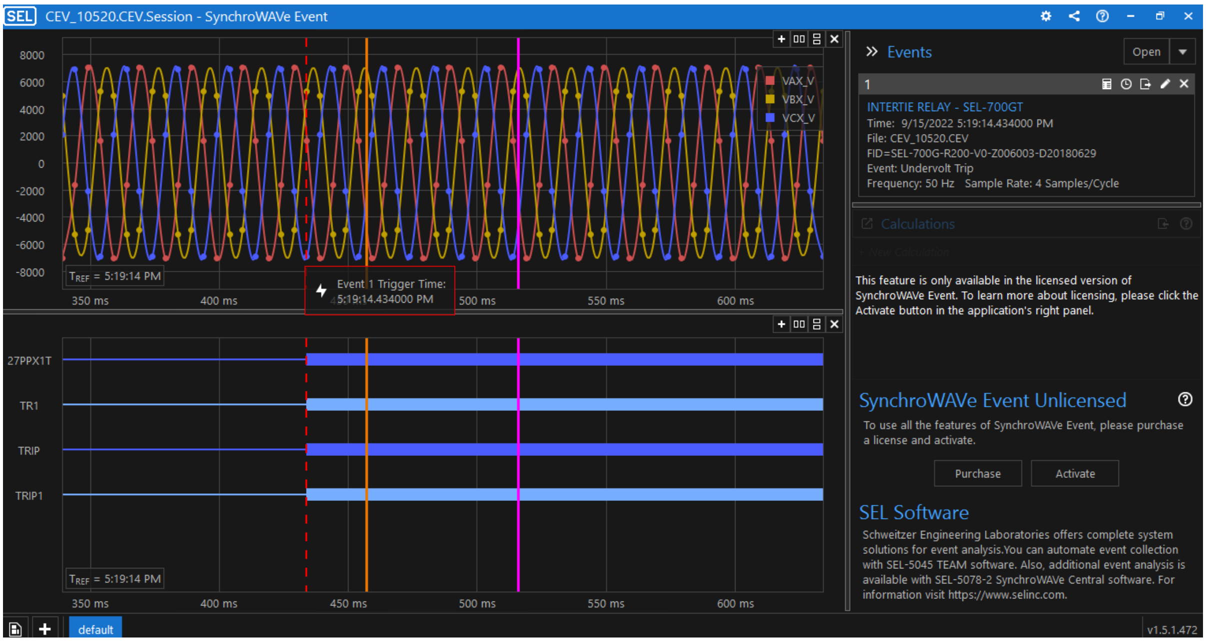

Figure 5. 21a: SynchroWAVe Event test results for Under-voltage stage 1

5.6.3 Under-voltage stage 2 Results

The SynchroWAVe Event test results for Under-voltage stage 2 compared to under voltage stage 1 there is no much difference, the same procedure that was used to test stage 1 is the same procedure used to test stage 2 and the only different is the relay tripping times. The relay operated at 40 ms and the only side that is configured on 700GT relay is the X side and Y side is not in production.

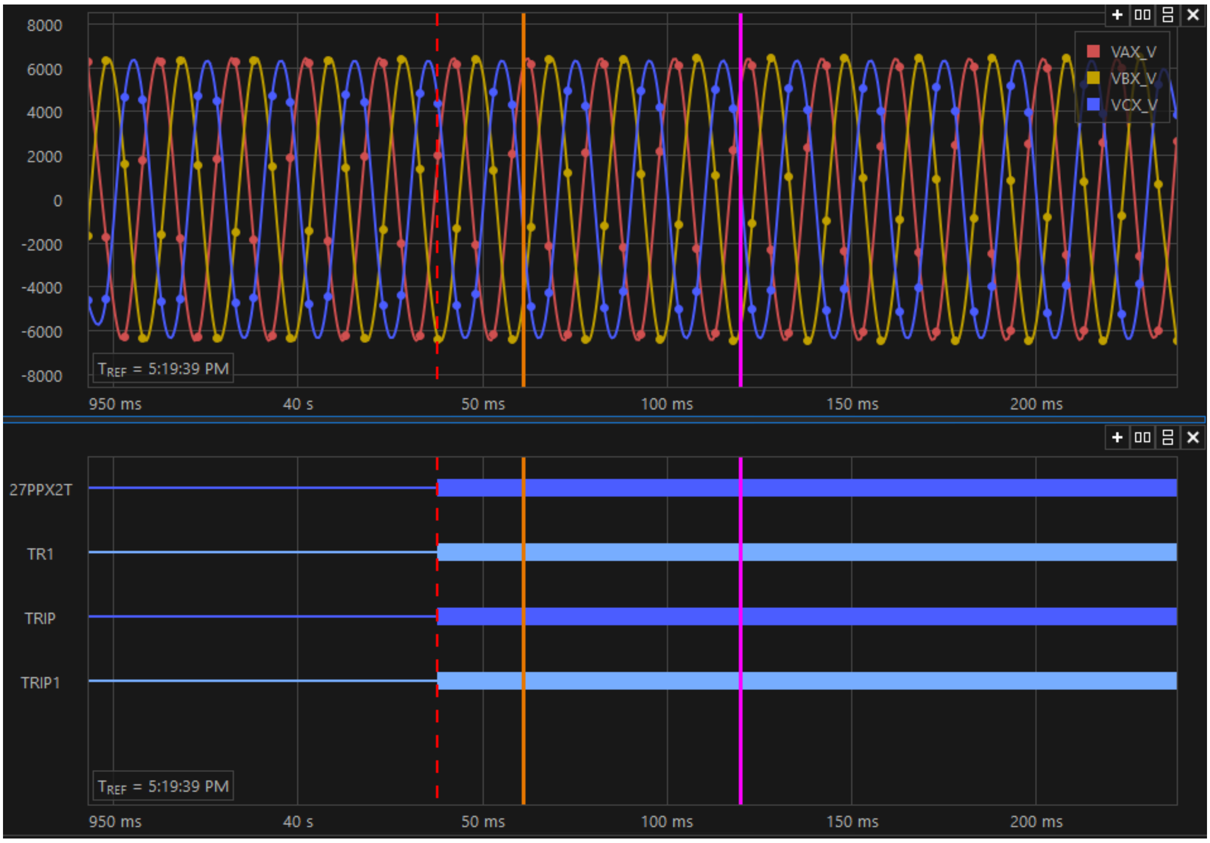

Figure 5. 22b: SynchroWAVe Event test results for Under-voltage stage 2

5.6.4 Case study 2: Overvoltage protection

The overvoltage protection function is tested by on the distribution network section with Feeder A whereby load reduction implemented by disconnecting load 2 to create overvoltage condition.

The test performed for the above mentioned voltage protection elements and test done in lab-scale testing by configuring the relay settings and CMC Omicron configuration settings, since on the hardware configuration output only voltage outputs used and injected.

5.6.5 Over-voltage stage 1 Results

The over voltage on distribution network is very curious part because that where the loads are connected too, and therefore the equipment needs to be protected. The analysis on this wave form represented in figure 5.22a shows the relay tripping time, after over voltage condition implemented the relay tripped and it never reset again.

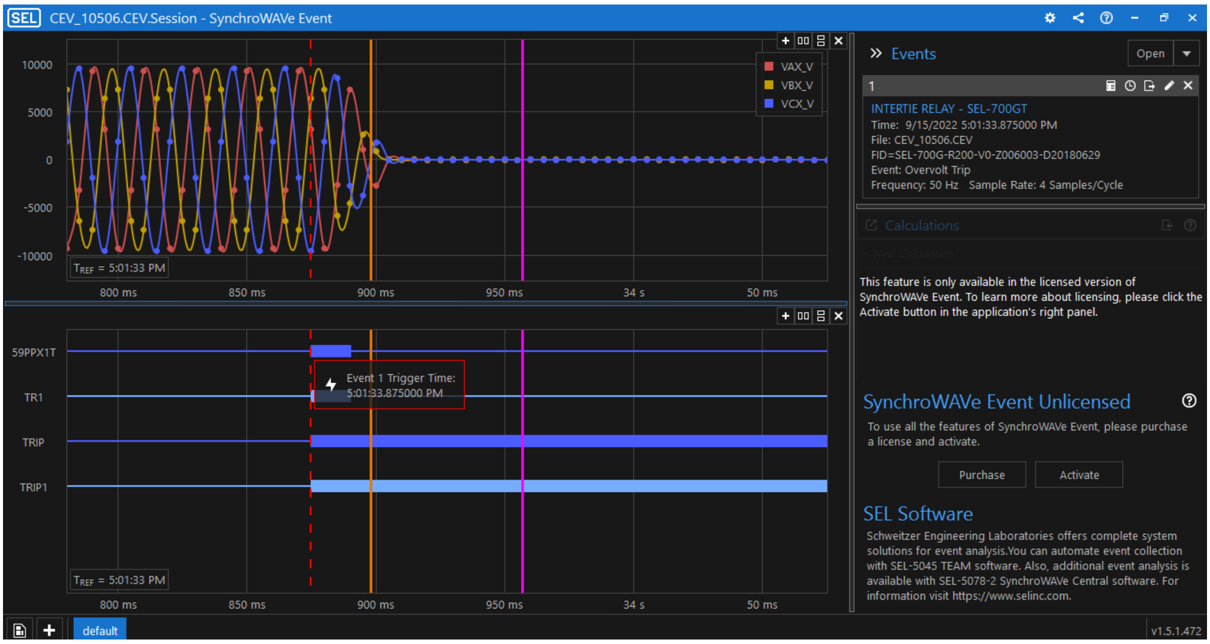

Figure 5. 23a: SynchroWAVe Event test results for Overvoltage stage 1

5.6.6 Over-voltage stage 2 Results

The same procedure has been used to test Over voltage stage 2 and after the relay operated it was able to reset again unlike on stage 1, the system tries to regain the stability.

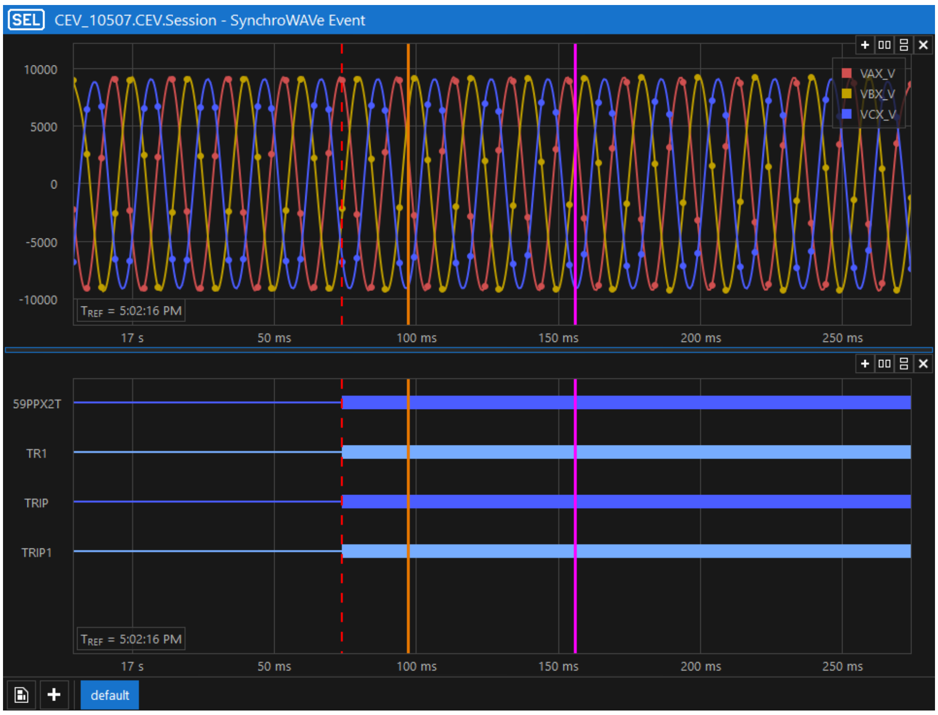

Figure 5. 24b: SynchroWAVe Event test results for Overvoltage stage 2

5.7 Discussion on the simulation results concluding testing procedures

There is a difference from the results obtained on DigSilent simulation in comparison with the results obtained from lab-scale testing of the islanded protection scheme. The reason for this is that the DigSilent results are calculated from the software perspective relay that has no moving contact or injection ports and no signals that are being transmitted through hardwire unlike the lab-scale testing. With the lab-scale test, the SEL700GT generator protection relay has moving contacts inside that have a time delay to them from the manufacture. The time delay caused by the time it takes the feedback signal to travel through physical hardwire, and the time taken by the Omicron test set to process that signal and asses the test is very accurate. The waveforms from DigSilent compared to the waveforms from Lab-scale testing SynchroWAVe Event report represents slightly different compare to DigSilent.

Table 5. 3: Comparison of the DigSilent simulation results with Lab-scale testing

Type of Events	**DigSilent simulation results tripping times**	**Lab-scale testing results tripping times**
Undervoltage 27Stage 1	0.4 s	530.1 ms
Undervoltage 27 stage 2	0.4 s	2.538 s
Overvoltage 59 stage 1	1 s	1.032 s
Overvoltage 59 stage 2	1 s	532.1 Ms

5.8 Conclusion

All of the configuration options for the components of the islanded protection scheme were supplied in this chapter. The AcSELerator Quickset setups, CMC Omicron configuration settings, and a full description of the object settings are all given. The comparison on SEL700GT protection relay trip times performance was tested and compared with the DigSilent simulation results and the tripping times are different between the two performed simulations. Particular focus was placed on ever improving the protection technologies, in terms of testing practices emphasis was made on the importance of static testing as dynamic testing is to be completed in the following chapter 6 that can be delivered through laboratory-based platforms such as real-time simulators, integrated substation automation infrastructure and flexible testing micro grids. This not only informs the shaping of new islanded protection testing and network integration practices by end users but also enables the process of de-risking new islanded protection technologies. This experimental work highlights the better standardisation solutions in the near future.

CHAPTER SIX

IMPLEMENTATION OF ISLANDING DETECTION ALGORITHM FOR DISTRIBUTED GENERATOR INTEGRATED POWER SYSTEMS USING THE REAL-TIME DIGITAL SIMULATOR (RTDS)

6.1 Introduction

RTDS Technologies introduced a fully digital real-time power system simulator in 1989. The RTDS simulator is still used across the world to simulate real-time power systems. The simulator is used to do tests on protection and control systems. The RTDS simulation uses specialized hardware and software solutions to do real-time electromagnetic transient simulations.

RSCAD is a user-friendly interface that engineers and designers utilize to establish a comfortable working environment. The software, in addition to communicating with the RTDS hardware, allows users to plan, conduct, and analyze simulations. It is intended to allow users to complete all of the tasks required to prepare, execute, and analyze simulations. RTDS has tested and commissioned electrical equipment at power utilities and research universities. The advantage of employing RTDS in power systems is that it offers a safe environment in which people can manage and test schemes. RSCAD FX is the most recent and powerful version of our proprietary simulation program, with a modern design and novel functionality. RSCAD FX is the industry's next step as the next generation of real-time digital simulation software. This technique enables in-depth analysis and system-level testing, which are extremely advantageous and, in certain cases, vital to the current power system. The RTDS Simulator may be used to test microgrid control systems, distribution automation equipment, intelligent switchgear, IEC 61850 substation automation, synchronphasor-based protection systems, power electronics control systems, inverter characterisation, and cybersecurity.

An islanding situation occurs when a distributed generator (DG) operates in place of external electricity to power a location. It is common to hear someone claim that their inverter is protected from islanding, Islanding detection is often based on voltage and frequency detection, and it can detect grid outages. Consequently, it can prevent the grid from receiving power back from the generators and protect utility workers.

Literature reviews have outlined the difficulties associated with islanded DG. It is imperative that the protection system detects islands quickly and reliably in order to prevent island operations. The protection of distributed generation has been extensively studied in literature. Problems and issues are presented in a number of publications, but solutions are rare. There are many islanding algorithms that have been done before on the previous papers and here is the list of the existing methods used to detect Islanding; An IEC 61850 GOOSE fast LS system is based on messaging, where the final LS decisions are made in real-time by a fast load-shedding controller. Communication-based islanding detection systems and Remote islanding detection operating principles are used recently. Microprocessor based islanding protection algorithm, Implementation of an Ethernet communication network in a ring that links substations at a large industrial facility in a closed communication loop. Anti-Islanding algorithm, Passive Islanding detection algorithm, ESPRIT base robust anti-islanding algorithm, Power convert based distributed generators using frequency domain analysis, and hybrid methodology that combines efficient methods of communication and passive methods.(Patra et al., 2017) In all methods I have, I identified that they did not use a communication-based method for detecting islanding, I, therefore, proposing to develop a new method of Islanding detection and initiation algorithm for DG integrated power systems, and configuration of GOOSE messaging based on IEC61850-7-420. Communication-based methods have proven to be best for Islanding, compared to the passive and active methods, because all circuit breakers are observed by the control system. A communication-based on IEC 61850 protocols has a huge advantage compared to the other methods used for islanding detection. This algorithm is used to significantly reduce the wiring of copper control, resulting in lower costs, wiring errors, including construction time and commissioning time.

Network data from a typical 220/33/11kV network is utilized in this case study to perform dynamic type testing of distribution generator interface with protection relays. RSCAD FX is used in the initial phase to model the 11kV network under study. The model for which the relay is configured includes a synchronous machine, as well as upstream network sources, transformers, lines, circuit breakers, and loads.This chapter covers the implementation of islanding detection algorithm for distributed generator integrated power systems where the RTDS GTNET Configuration for Islanding detection scheme using OV and UV elements has introduced and the protection is based on Schweitzer protection device that implements voltage protection schemes using the RSCAD. This chapter investigate two case studies which are Under voltage and Over voltage protection schemes and the configuration of IED with AcSELerator QuickSet software implemented. The same parameters for both case studies are used to configure the protection device SEL700GT with the aim of achieving the new algorithm using UV and OV protection functions for Islanded detection.

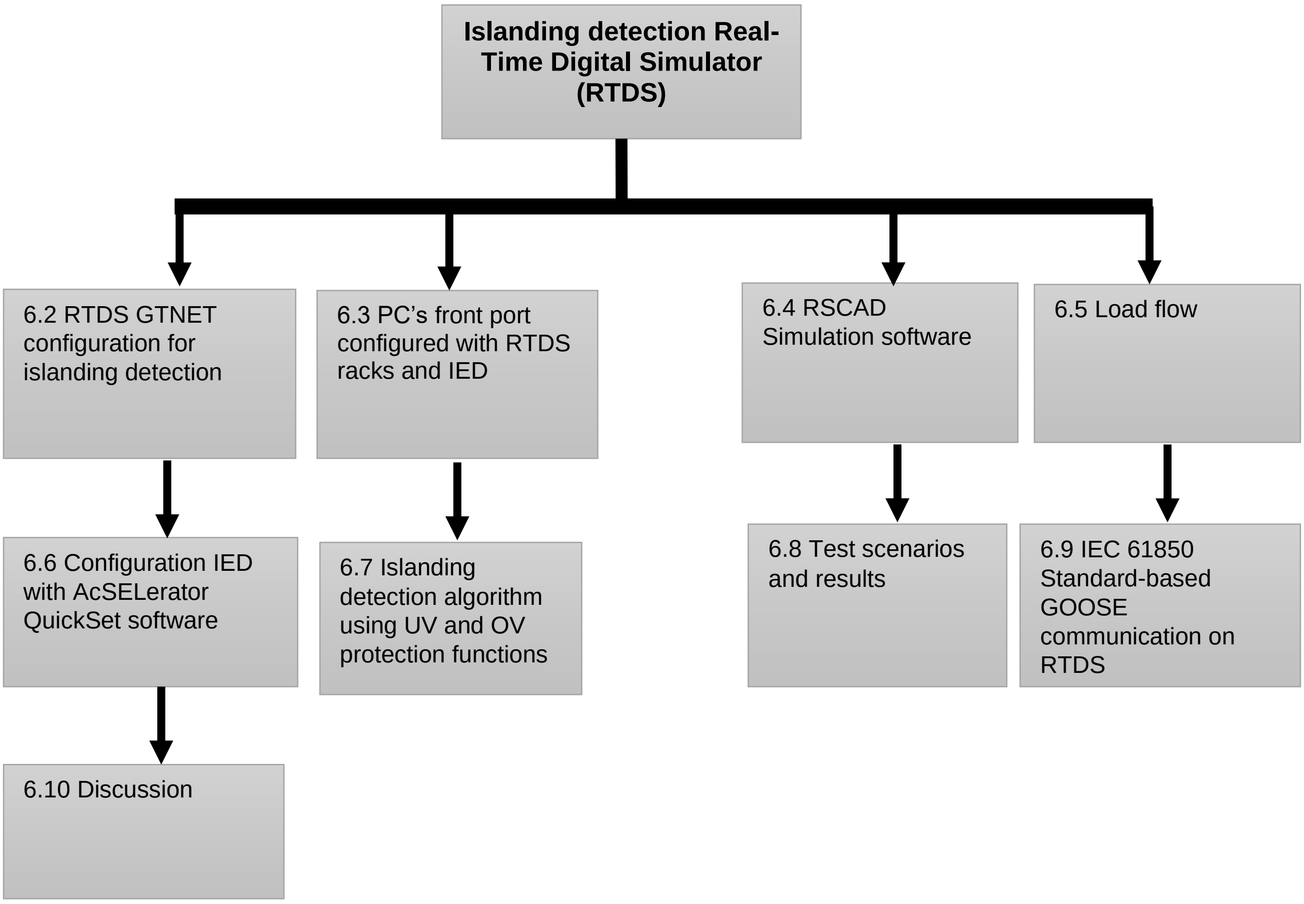

Figure 6. 1: Block diagram structure for chapter six

6.2 RTDS GTNET Configuration for Islanding detection scheme using OV and UV elements

The RSCAD configuration files provide all information on the hardware setup of RTDS. IP addresses, GTAO, GTDO, and GTDI cards, as well as IP addresses of other rack ports, are all recorded here. When the hardware configuration file is wrongly setup, RTDS will not simulate any conditions. Users can change the configuration file using the RSCAD program. Figure 6.1 shows a snapshot of the configuration file editor. It also indicates that Rack 1 is connected to GTAI, GTAO, GTDI, GTNETx2, and the various setup values of other racks.

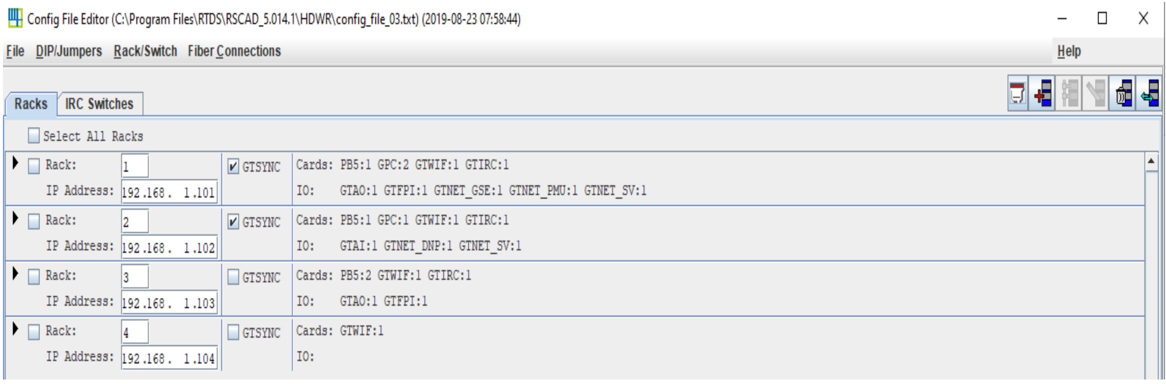

Figure 6. 2: Configuration of the GT cards on RSCAD

A Gigabit Transceiver Analogue Output (GTAO) function block and a Gigabit Transceiver Front Panel Interface (GTFPI) function block are both necessary to accomplish draft module in RSCAD, as illustrated in Figure 6.2.

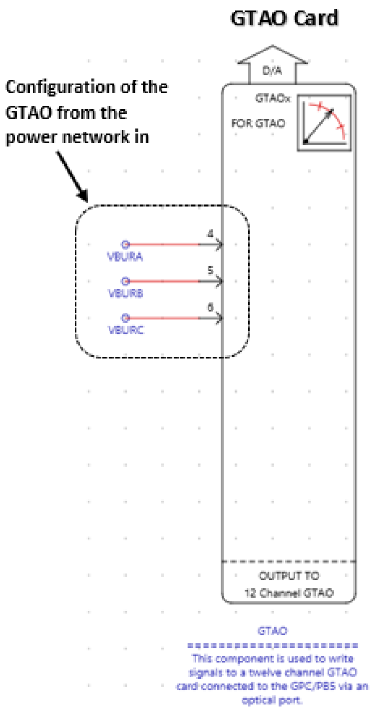

Figure 6. 3: GTAO card under draft module

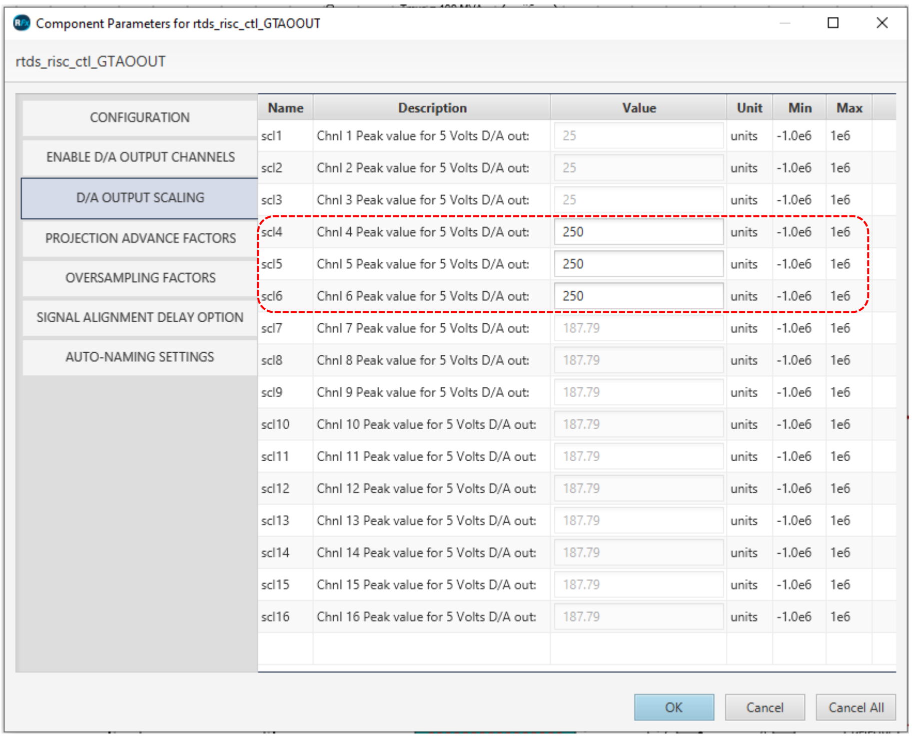

Figure 6. 4: GTAO component set to 250

The analog outputs of the simulation were configured using RSCAD real-time simulation so that voltage signals could be transmitted to hardware OMICRON CMS and 356 amplifiers. The amplified voltage signals are then received by SEL 700GT IEDs via analog inputs and sent to amplifiers. In addition to the runtime module, the scaling calculation was required for the external SEL700GT IEDs. This GTAO component has 12 channels that receive signals from CTs and VTs and then transport those signals to the D/A output scaling. In this project, 4 to 6 channels are set up to deliver secondary VT signals as relay input.

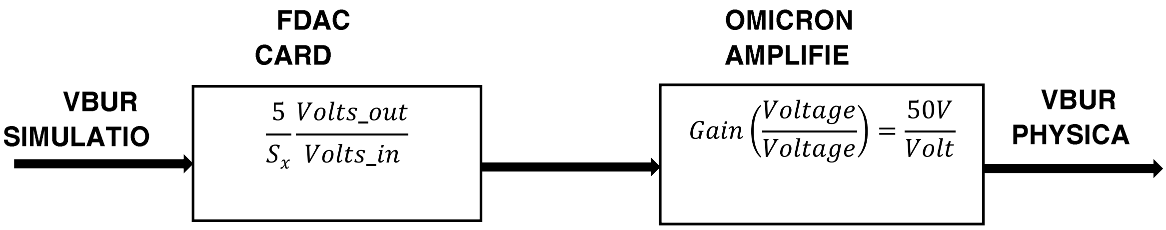

Figure 6. 5: The output scaling diagram for voltage signals

On the input side of the D/A output scaling diagram, it shows simulated signals created by VTs deployed at all loaded bus nodes in the network. These signals are routed to the Front Digital to Analog Converter card, where the gain setting is controlled and the

GTAO card generates new levels. VBUR signals are then transferred to the OMICRON amplifier, where they are subjected to yet another mathematical computation to generate a new signal. The GTAO component configuration in the draft module for the D/A output using the scaling factor of 250 gain i.e (5 X 50 = 250 gain) as shown in Figure 6.4 above.

$$\frac{5}{S_x}\left(\frac{Volts}{Amps}\right) x\ 50\left(\frac{Volts}{Amps}\right) = 1$$

To accomplish the aforementioned goals. In this scenario, the GAO component for 4 to 6 channels was fixed gain of 250. The GTAO component on Rack1 was setup in accordance with the draft module's specifications.

6.3 The PC's front port is configured to interact with the RTDS racks and IED.

The RTDS, Omicron amplifier CMS156, PC are connected via TCP/IP protocol.

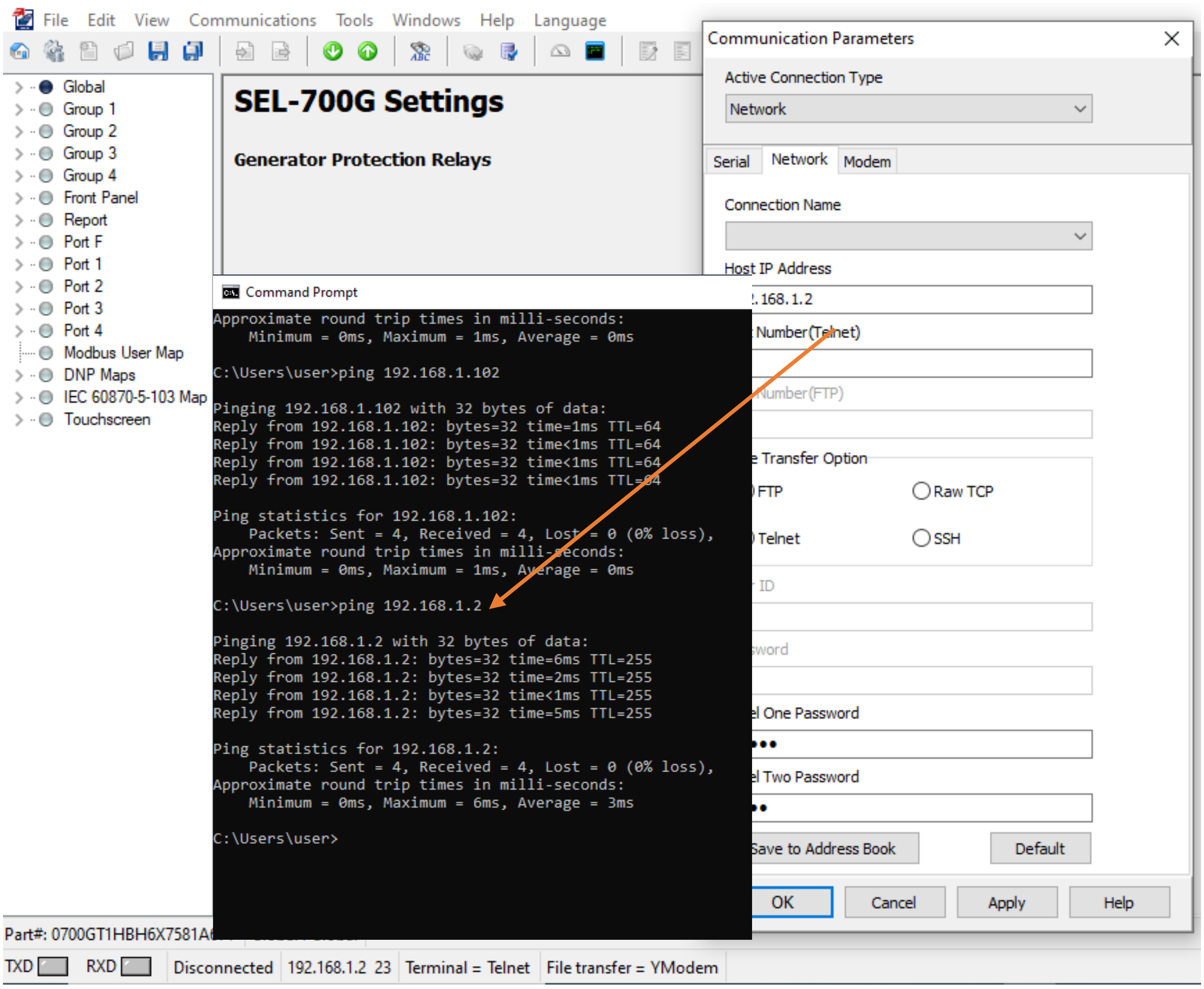

Figure 6. 6: RTDS and PC ping command results for SEL700GT and RTDS racks.

PC IP addresses and Subnet masks must be specified, and IP addresses must not be identical to IED IP addresses. Following selection, the ping command was used to test connectivity between the PC, Racks, and IED.

6.4 RSCAD Simulation software

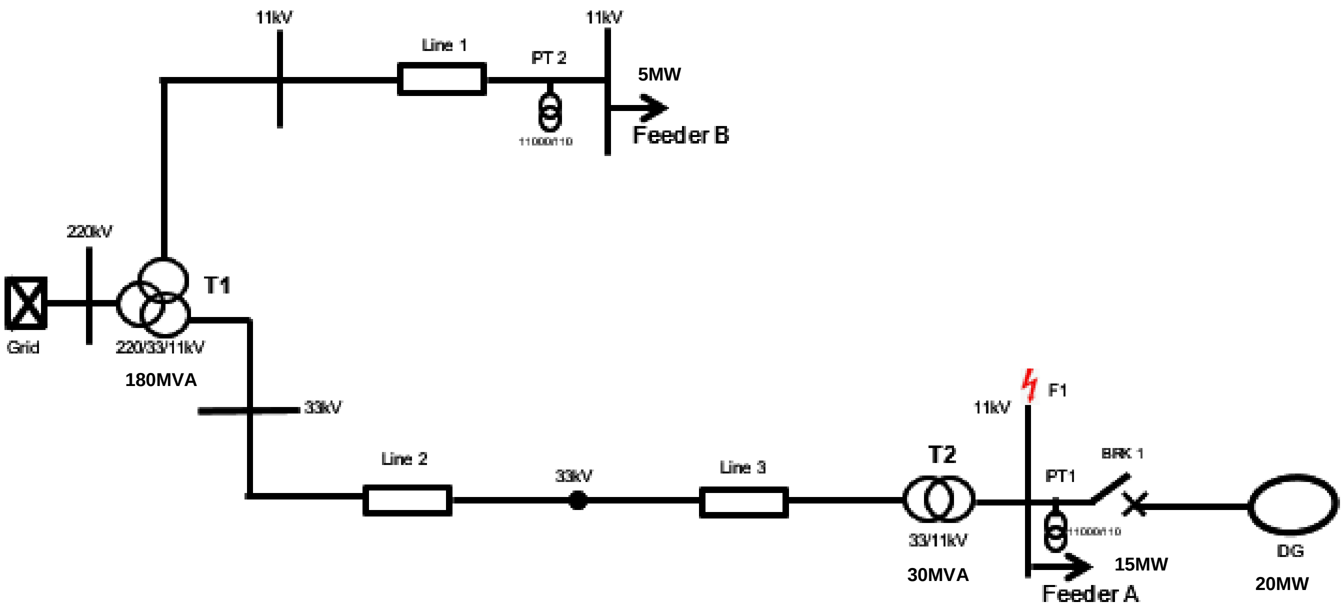

Figure 6. 7: Power system single line diagram

The selected distribution network from United Kingdom has been modelled and simulated with the following parameters as presented in chapter four. The utility operating is maintaining the balance between used power and generated power in the island grid, meaning an energy storage system can be used. The synchronous generator is typically connected to feeder A (Load A), the synchronous generator is highly capable of sustaining an island

Table 6. 1: Instrument transformers data

Instrument transformers data			
Main Data for PT1	Name	Description	Value
	F	Frequency	50 Hz
	csa	Cross-sectional Area	10.0e-3
	PLen	Path Length	1.88
PT1 INPUT SIGNAL NAMES	VA	A Phase Voltage Signal	N16
	VB	B Phase Voltage Signal	N17
	VC	C Phase Voltage Signal	N18
Transformer Data	Rp	Primary Side Resistance	11.33 ohms
	Lp	Primary Side Inductance	6.0 H
	Np	Primary Side Turns	11000
	Rs	Secondary Side Resistance	0.55e-3

	Ls	Secondary Side Inductance	0.29e-3
	Ns	Secondary Side Turns	110
Main Data for PT2	Name	Description	Value
	F	Frequency	50 Hz
	csa	Cross-sectional Area	10.0e-3
	PLen	Path Length	1.88
PT2 INPUT SIGNAL NAMES	VA	A Phase Voltage Signal	N7
	VB	B Phase Voltage Signal	N8
	VC	C Phase Voltage Signal	N9
Transformer Data	Rp	Primary Side Resistance	11.33 ohms
	Lp	Primary Side Inductance	6.0 H
	Np	Primary Side Turns	11000
	Rs	Secondary Side Resistance	0.55e-3
	Ls	Secondary Side Inductance	0.29e-3
	Ns	Secondary Side Turns	110

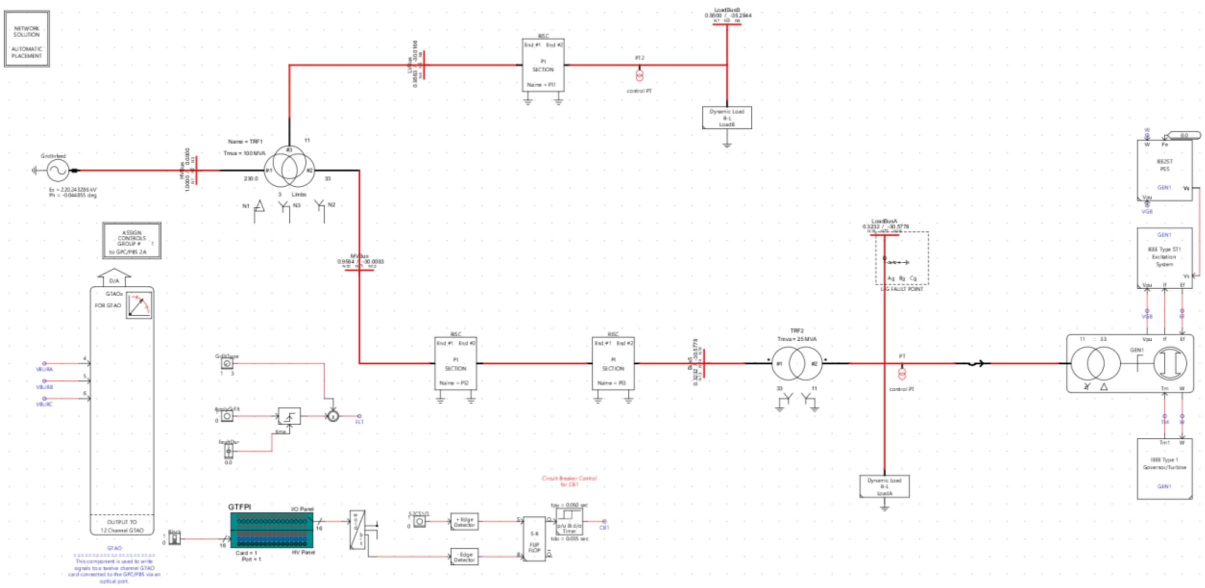

Figure 6. 8: The network diagram used in this study is shown above

By changing fault locations and connecting to island operating modes, several test scenarios are simulated. The power system network modelled in RSCAD/RTDS is operated using a runtime graphical user interface.

6.4.1 The GTFPI control logic technique for circuit breakers.

Whenever the relay is operating, there are outputs on the relay which are connected to the front panel of the relay, whenever the relay trip, the output of the relay is integer, it will change from word bit to relay word bit, and that bit will send to the flip-flop when relay trips, that means is 1, CB initial closed.

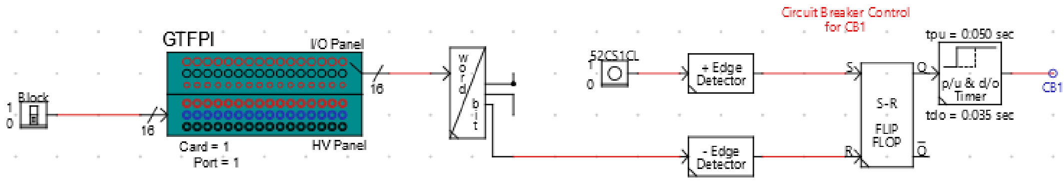

Figure 6. 9: GTFPI control logic technique for circuit breakers

6.4.2 Description about fault control logic.

It is necessary to apply faults on the distribution feeders in order to verify the fault level in the system at various branches. A circuit breaker must be able to be controlled during operation to control the type, location, and closure of faults. A fault logic diagram is shown in figure 6.9 which enables fault application and fault change at runtime. In comparison to switching between the runtime and draft interfaces in order to alter faults on the system, the logic provides a more efficient way to test. With a push button, a fault can be activated, and a dial switch allows selection and alteration between the different combinations of line-to-ground faults.

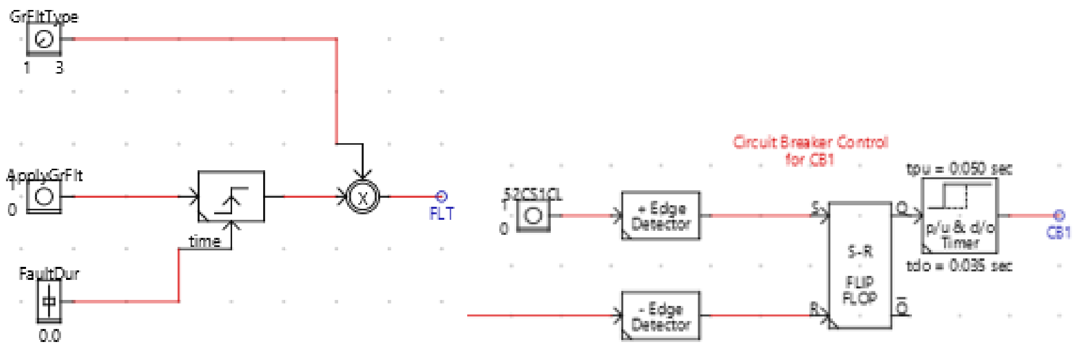

Figure 6. 10: Fault control logic.

A fault on any one of the three phases of the system will negatively affect all three phases of the distribution lines. During simulation, the circuit breaker model is opened and closed using a single logic input. By using an SR flipflop component, the circuit breaker responds to separate operation commands. As shown in Figure 6.9, when the relay issues a trip command to the breaker logic, it triggers the logic to open. During operation, a 'close' button on the circuit breaker is pressed to close the circuit breaker after receiving the signal to open.

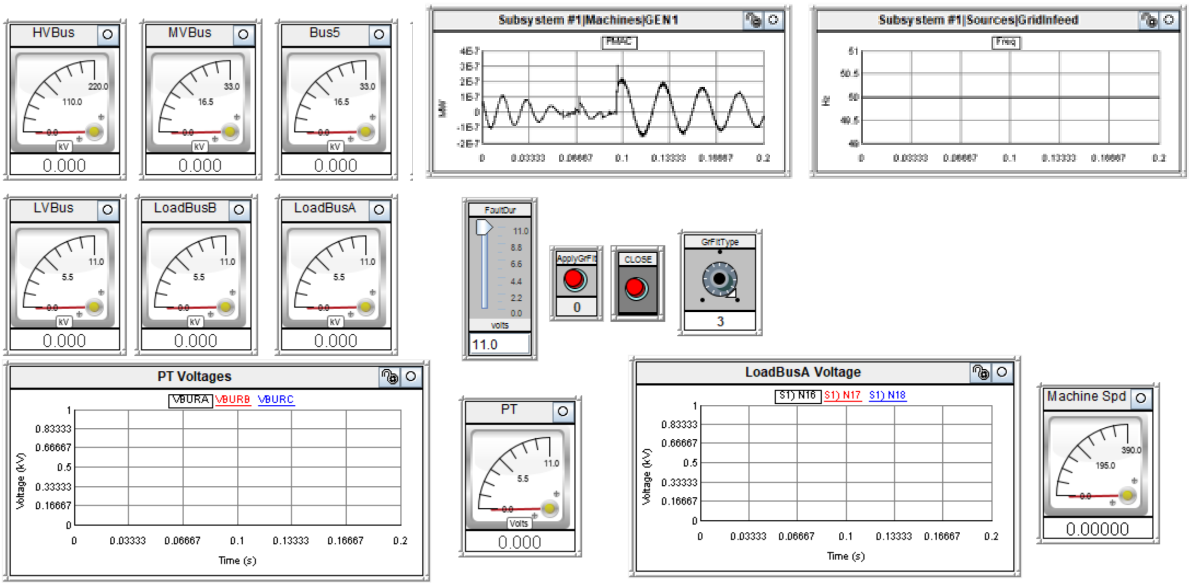

Figure 6. 11: RTDS Runtime environment for the power system model

6.5 Load flow

The network is successfully compiled by RSCADFX, but there are certain issues that arise after compilation, such as the circuit breaker that connects the generator to the network isolating it during loadflow. During the troubleshooting phase, a circuit breaker configuration was corrected.

Table 6. 2: Load flow simulation

Grid	P Q Pt	Real power Reactive power Specified Initial Real power	20 MW 0.01 MVAR 20MW
HV Bus	Vd Ad	Voltage Result (From load flow) Angle Result (From load flow)	1.0000 p.u 0.000 deg
MV Bus	Vd Ad	Voltage Result (From load flow) Angle Result (From load flow)	0.956420 p.u -30.00 deg
LV Bus	Vd Ad	Voltage Result (From load flow) Angle Result (From load flow)	0.956320 p.u -30.016630 deg
Bus 5	Vd Ad	Voltage Result (From load flow) Angle Result (From load flow)	0.311220 p.u -45.185970 deg
Load Bus A	Vd Ad	Voltage Result (From load flow) Angle Result (From load flow)	0.311220 p.u -45.185970 deg
Load Bus B	Vd Ad	Voltage Result (From load flow) Angle Result (From load flow)	0.850010 p.u -35.284460 deg
T 1	Tmva	Transformer MVA	180 MVA
T 2	Tmva	Transformer rating (3 Phase)	20 MVA
DG	Vmagn Vangl P0 Q0	Load Flow: Voltage Magn Load Flow: Voltage Phase A Load Flow: Real Power Load Flow: Reactive Power	1.0 p.u. 0.0 Degress 20 MW 0.05 MVAr

	Pt Qt	Specified P at Machine Terminal Specified Q at Machine Terminal	20 MW 0 MVAr

Based on simulations of the modelled distribution system, the section concisely presents findings and Load flow results. The system is run on RSCAD after all parameter settings for the model equipment have been made. A load flow system calculation is shown in Table 3, along with bus voltages and line voltages.

6.5.1 Case study A: DG circuit breaker open state

As shown in figure6.11. below, this is the same network used in DigSilent simulation of the DG circuit breaker when it is open during loadflow. The results of the simulation, which can be monitored on Runtime, indicate that when this circuit breaker is opened, no voltage should be applied to the grid-connected system, because the external circuit breaker is closed. On the other hand, this DG circuit breaker closes only when the grid-connected system is in island mode.

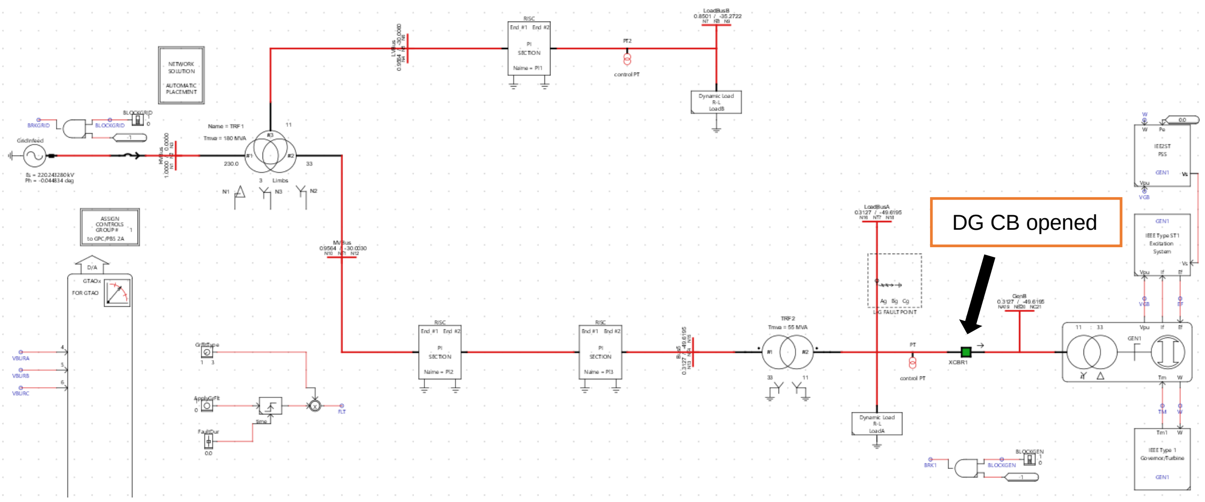

Figure 6. 12: Grid-connected islanded mode

The figure 6.12. below represent the runtime results when the grid-connected system circuit breaker is closed, as there are only voltage readings captured on runtime, and a glance at the HV bus meter clearly demonstrates that the grid-connected system is providing power to the loads.

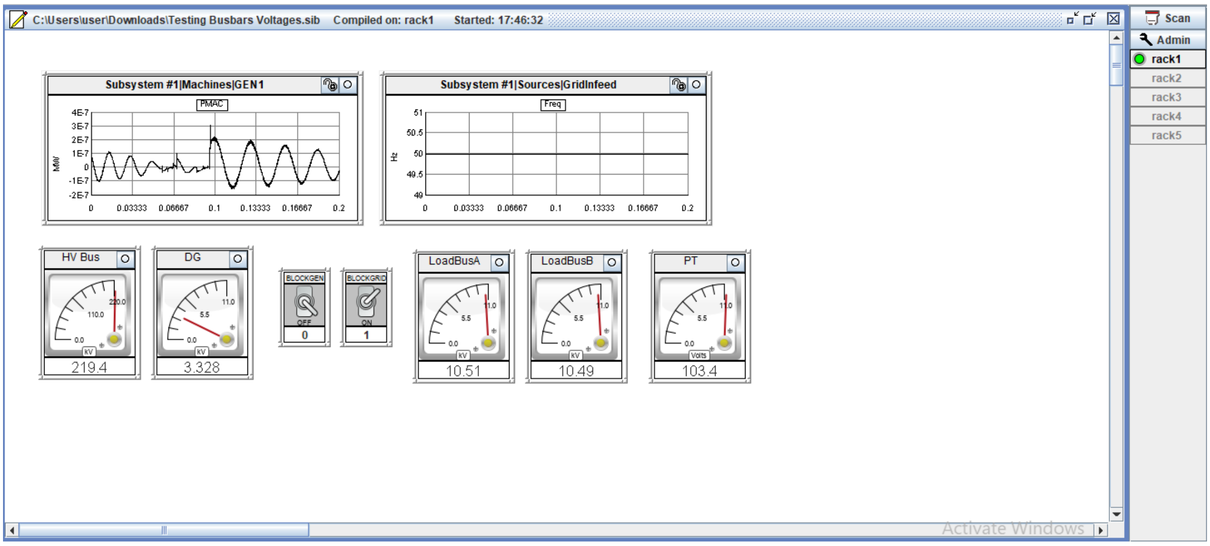

Figure 6. 13: DG circuit breaker open

6.5.2 Case study B: Grid circuit breaker open state

This figure 6.13. below shows the network when it is on Microgrid connected system supplying to the loads while Grid circuit breaker is on open state. The aim of this case study is to emphasis the islanded mode operation on both Grid-connected islanded mode and Microgrid connected islanded mode operation. The protection of islanding detection is done separately and results are found in chapter four, chapter five and chapter six.

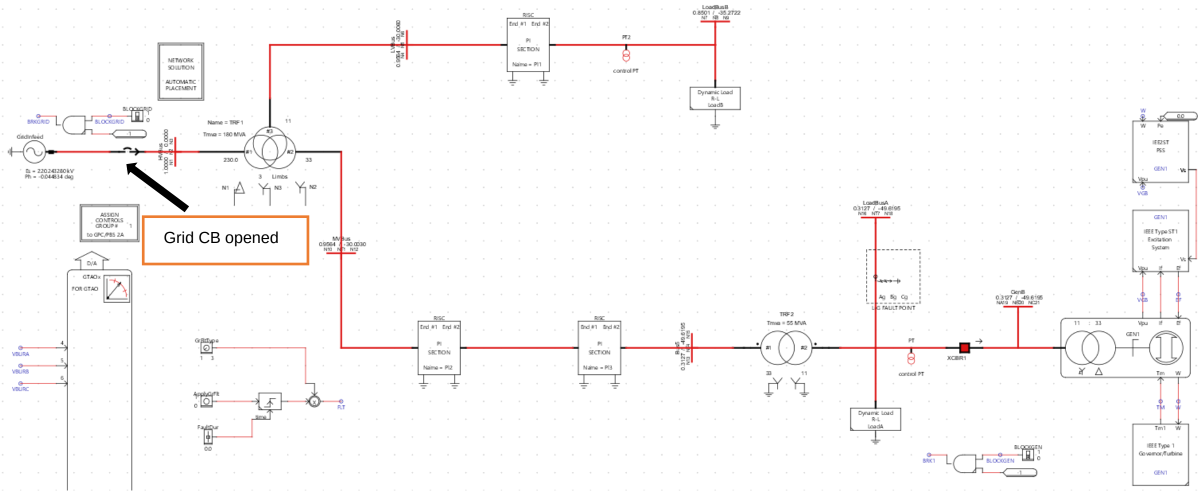

Figure 6. 14: Grid circuit breaker open state

This figure 6.14. below represent the runtime simulation results whereby Grid cirucit breaker is on open state. The results indicate that the Microgrid conneted system is supplying voltage to the loads, as shown by meter DG which is pushing 10.51kV and the meter readings on the

HV bus are close to zero because the Grid circuit breaker is open, and, hence, no voltage should be delivered by the Grid-connected.

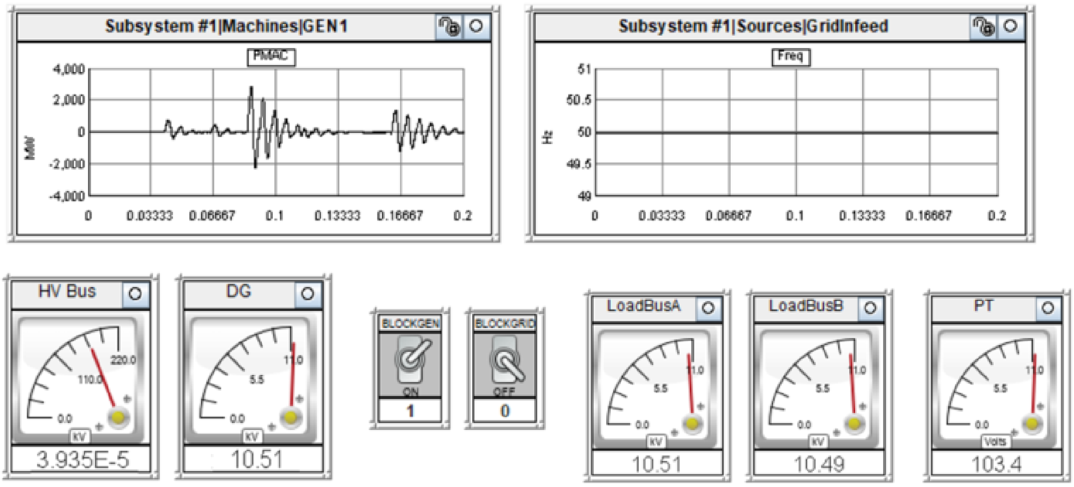

Figure 6. 15: Grid circuit breaker on open state

6.5.3 The Voltage protection scheme

Small distributed generation (DG) systems can be effectively protected against loss of grid (LOG) by relaying under and over voltage. In accordance with .(Chowdhury et al., 2008) DGs' control systems can compensate for the changes in loading caused by LOG, keeping voltage more or less stable. However, they may fail to operate if the load changes caused by LOG can fail to be compensated by the DGs' control systems. If the output voltage falls below a preset level, overvoltage protection shuts down the supply or clamps the output. The term under/overvoltage Protection refers to circuits that protect downstream components from damage caused by overvoltage.

6.5.3.1 Implementation of voltage protection schemes using the RSCAD

The protective relay is being prepared for testing at this process is to set the multiple levels for overvoltage and undervoltage protection functionalities. The relay and the RTDS are connected in a closed loop. The test setup utilized for the case study is depicted in the Figure 6.12 below.

A description of the procedures involved in configuring and programming the RSCAD/RTDS simulation settings to parameters configuration. Variables were measured on the RTDS and communicated to the external physical SEL 700GT device via the RTDS GTNET card communication in this experiment.

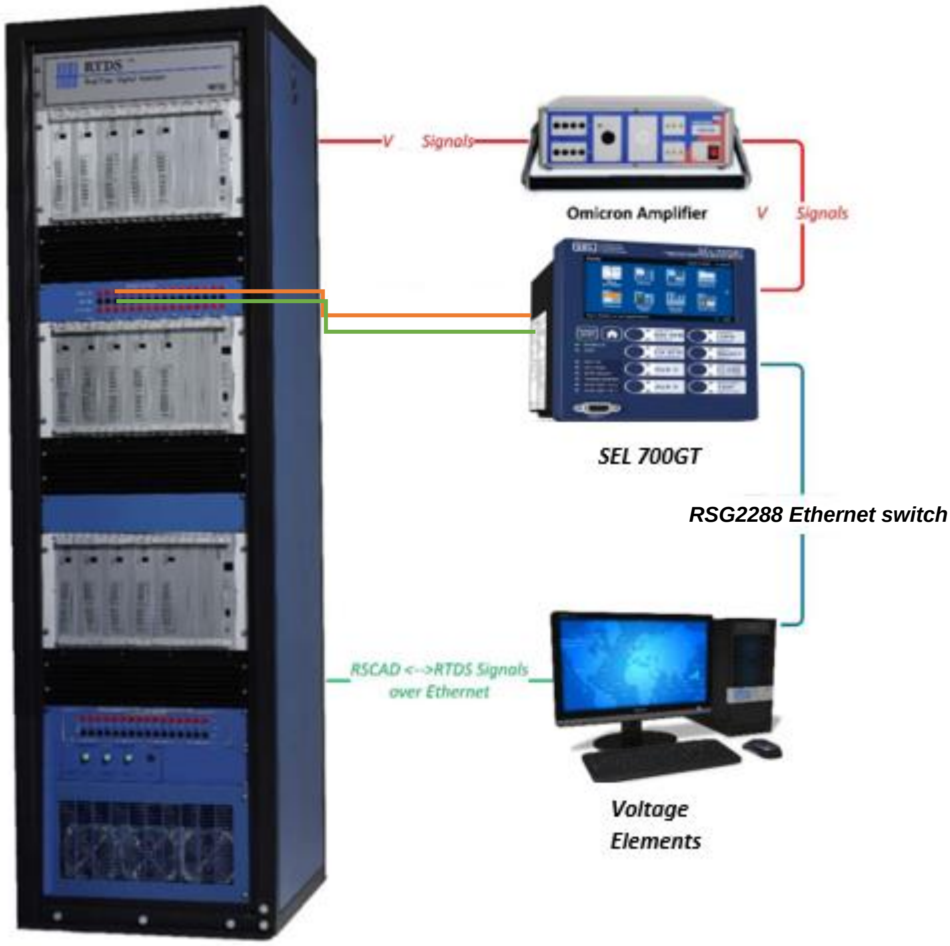

Figure 6. 16: Hardware-in-the-Loop structure

Calibration was required to guarantee that the values measured by the physical IEDs matched those measured by the RTDS simulator. When the variables are received by the external physical device, the programmed logic takes over and makes a decision, which is then sent to RSCAD. All of the preceding procedures are carried out using real-time simulation. The RTDS rack has an I/O channel in the front that was used for connecting digital singals from relay output to emulate the circuit breaker operation.

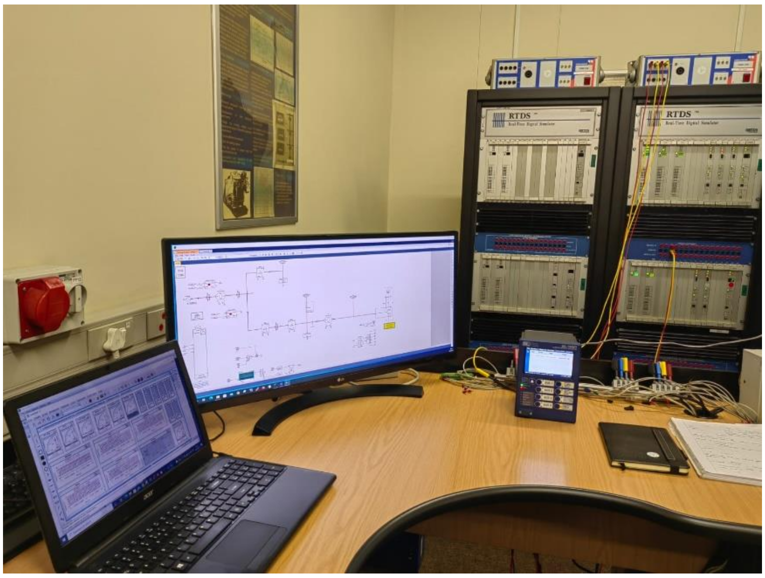

Figure 6. 17: RTDS Lab-scale physical connection

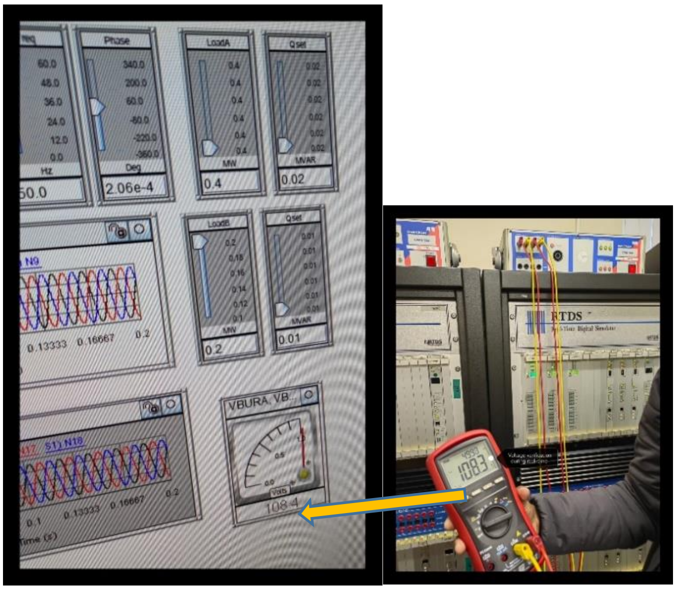

Figure 6. 18: Voltage verification on the PT connected next to the LoadbusA

6.6 Configuring IED with AcSELerator QuickSet software.

The SEL700GT device is configured using the AcSELerator QuickSet software. The AcSELerator QuickSet software application presents a set of two windows after inputting the device's component number, as seen in figure 6. The capabilities of the SEL700GT device are displayed on the right side window, while the description and settings necessary to setup the SEL700GT are presented on the left side window. In this actual implementation, just the configuration of group 1 is used. The Global, Front Panel, Reports, and Ports are some of the most often utilized objects. General elements such as phase rotation and rated frequency are given in the Global function. Because the electricity system under consideration operates at 50Hz, the phase rotation was set to ABC.

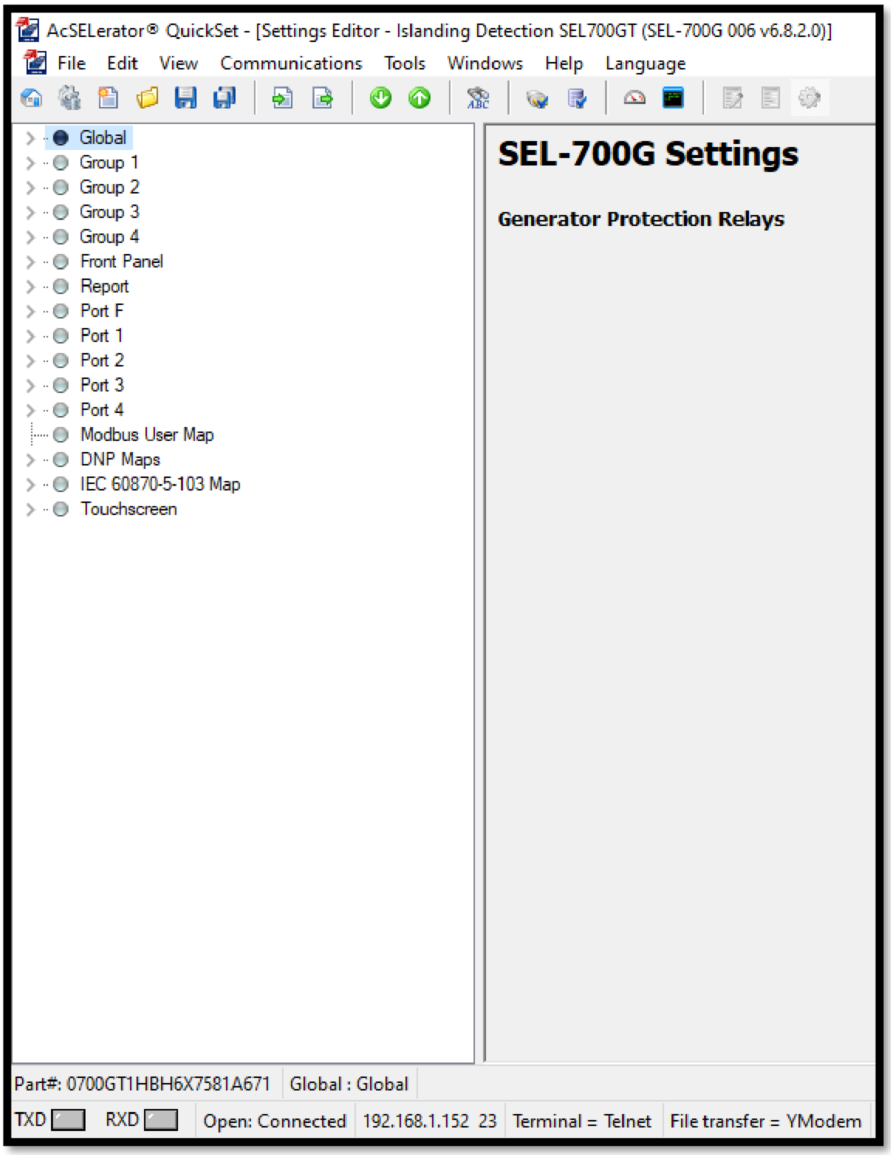

Figure 6. 19: AcSELerator QuickSet configuration window

Group 1 has been chosen, as illustrated in Figure 6.16. Under the Group 1 item, the SEL700GT device may be programmed to perform a variety of functions. The Under/Over Voltage is configured in this project. Four configuration slots are required: PT Ratio (PTR), Line Voltage, Normal Line-to-Line, and Transformation Connection (DELTA Y). All other spaces were left default.

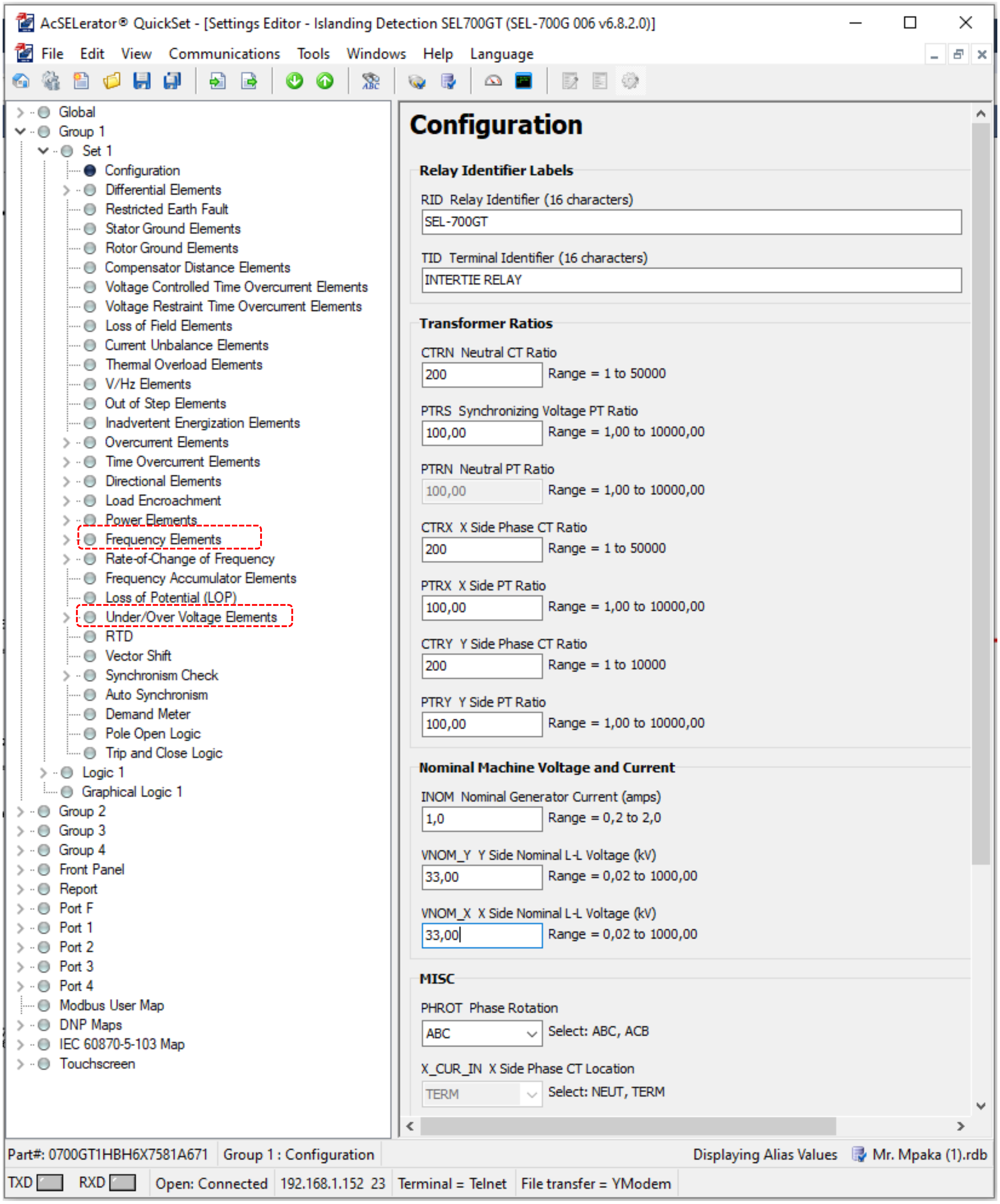

Figure 6. 20: Configure the SEL700GT's frequency and under/overvoltage elements.

Table 6. 3: Protection settings

Protection Settings		
Protection Element **Undervoltage**	Phase-Phase Under voltage Trip Level (volts) Stage 1	Phase-Phase Under voltage Trip Delay (seconds) Stage 1
27PPX1P	89.0 volts	
27PPX1D		2.50 seconds
27PPX2P	81.0 volts	
27PPX2D		0.50 seconds

Protection Element **Overvoltage**	Phase-Phase Over voltage Trip Level (volts) Stage 1	Phase-Phase Over voltage Trip Delay (seconds) Stage 1
59PPX1P	119.6 volts	
59PPX1D		1 seconds
59PPX2P	114.3 volts	
59PPX2D		0.50 seconds
PTRX	PTRX X Side PT Ration	100.00
VNOM	VNOM_X X Side Nominal L-L Voltage (kV)	33.00
OUT101 (SELogic)	27PPX1T, 27PPX2T	59PPX1T, 59PPX2T

After completing the procedures listed below, configure the Logic 1 setting in Slot A of Figure 6.17. After the SEL700GT has been set using the calculation method, the trip signals must be delivered back to the RTDS rack through the FrontPanel Interface Card (GTFPI). In this scenario, a (Pickup or START) signal was applied to each of the under/overvoltage 27PPX1P, 27PPX2P, 59PPX1P, and 59PPX2P components, initiating their timers. RTDS replicates a power system in which circuit breakers trip when a timer expires. When the timer runs out, signals are delivered to GTFPI through OUT101 (SELogic).

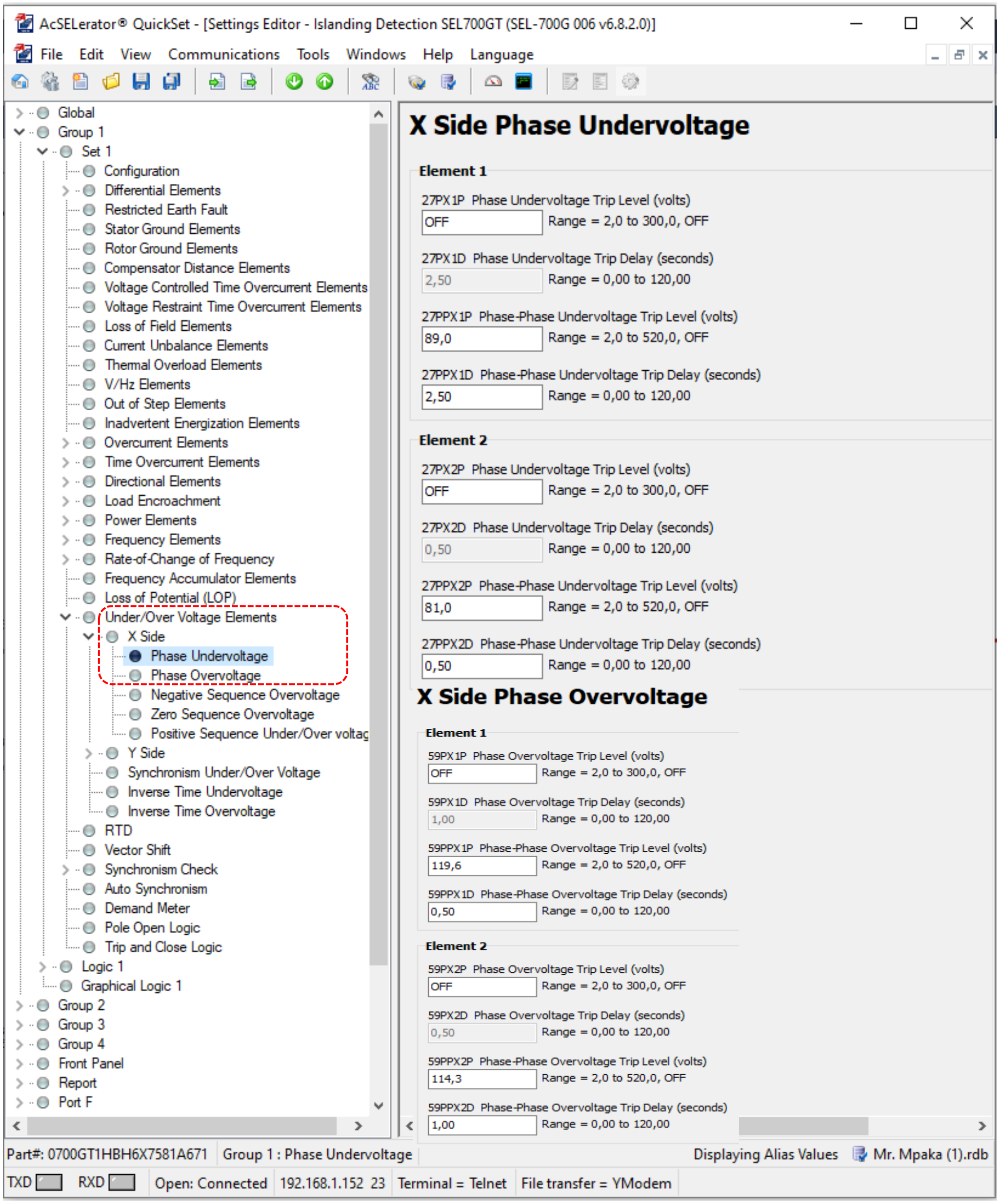

Figure 6. 21: Voltage Elements on the X Side of the SEL 700GT

Figure 6.18 shows the Target LEDs configuration for the Front Panel and SEL700GT operation indication to determine when the device is active. It also aids in determining which protective features were triggered during the malfunction or when the disturbance applied to the simulated power system.

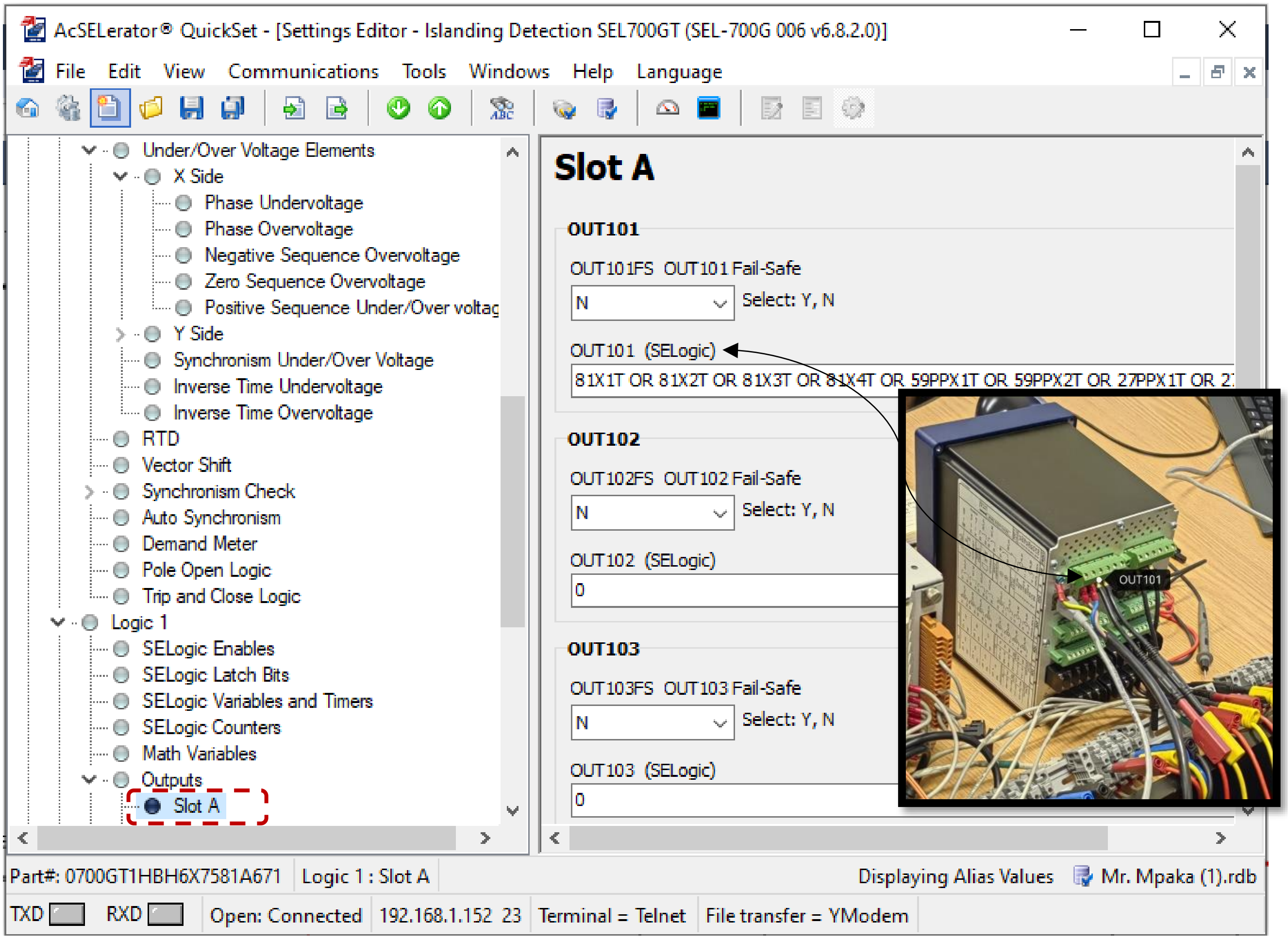

Figure 6. 22: Logic 1 Slot A Voltage elements and Frequency elements

The configuration of the protective elements that are mapped to OUT101 (SELogic) and also mapped to Trip and Close Logic identical relay wordbit is shown in the screenshot above. Under/Over-Voltage Protective and Under/Over-Frequency Protection are the primary protection components being evaluated in this project.

6.7 UV and OV protection functions

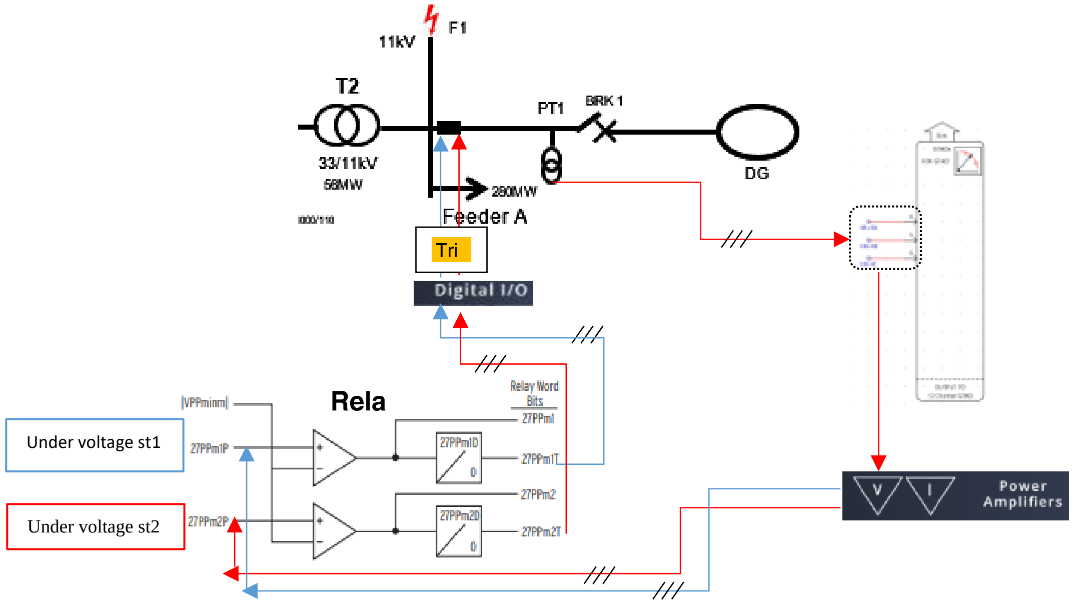

Figure 6. 23: UV protection functions

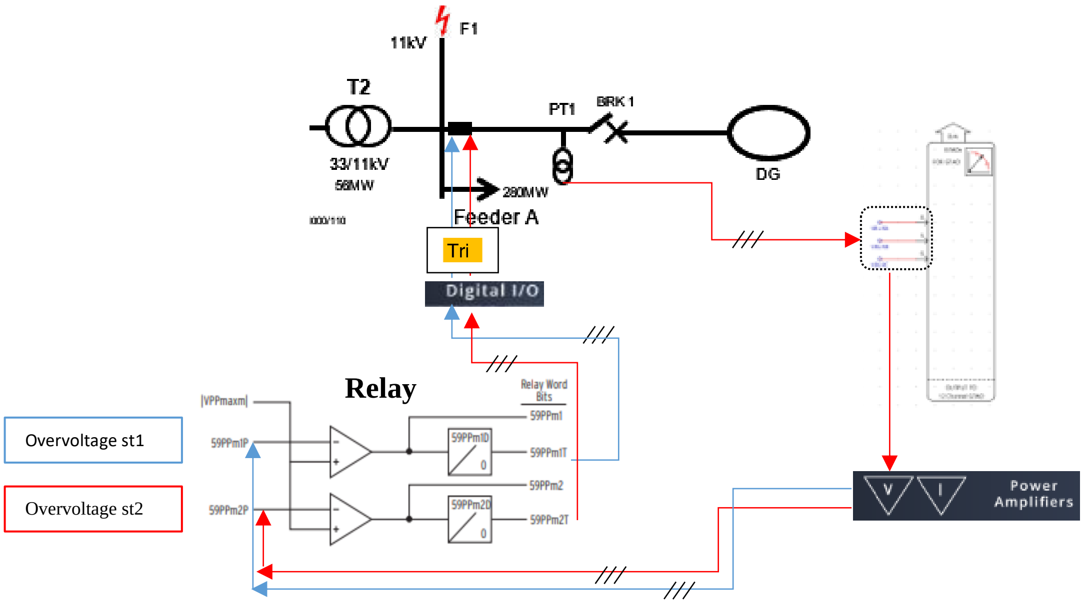

Figure 6. 24: OV protection functions

6.8 Test scenarios and results

A four-stage test scenario involves investigating undervoltage protection for stage 1 & stage 2 as well as overvoltage protection for stage 1 & stage 2. By using protective relay, the backup relay circuit breaker should be closed before the relay closest to the fault can remove the fault from the system. In the form of voltage protection schemes, relays of interest are coordinated on the generation side and low voltage side of the system.

6.8.1 The following test scenario is investigated:

I. Under voltage protection for stage 1 and stage 2

II. Over voltage protection for stage 1 and stage 2

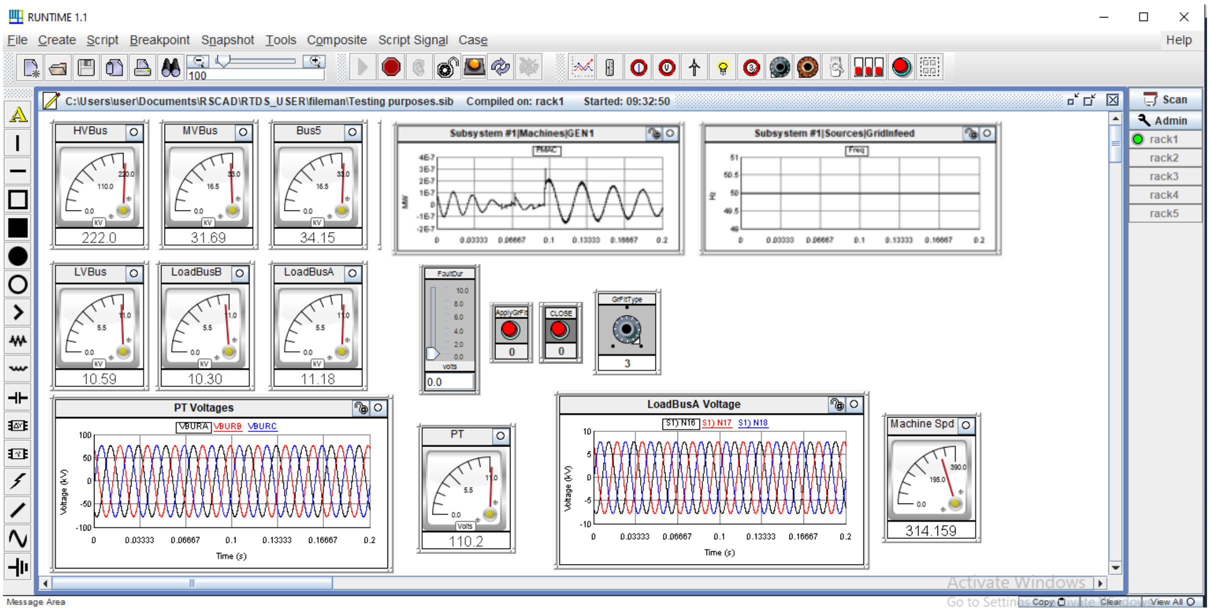

Figure 6. 25: Runtime displaying Node voltages and logic controllers

(a) An under voltage test in island mode employing faults (phase A to ground)

The Undervoltage feature is tested by Applying a short circuit in the network specifically on Load Bus A. The protection responsiveness is illustrated by how the voltage protection relay responds to this fault. The system is connected to a 15MW, 0.05MVAr load A and a 5MW, 0.01MVAr load B.

6.8.2 Under Voltage testing Stage1

RTDS simulates the under voltage stage 1 by introducing a single phase to ground on Load Bus A with runtime controllers (ApplyGrFlt push button, GrFltType Dial switch, Close push button), and the main focus is on the PT meter, which represents the UV stage 1. The reason why PT meter is chosen is because of the PT ratio which is referred as a reference point.

The nominal voltage is 63.50 V and if you divide line-line voltage 11kV by square root 3 you get 63.50 V, meaning the readings on the PT meter is 89.63 V you divide by square root 3 that equals to 51.75 V which is below 63.50 V that is why it is represented as Under voltage stage 1.

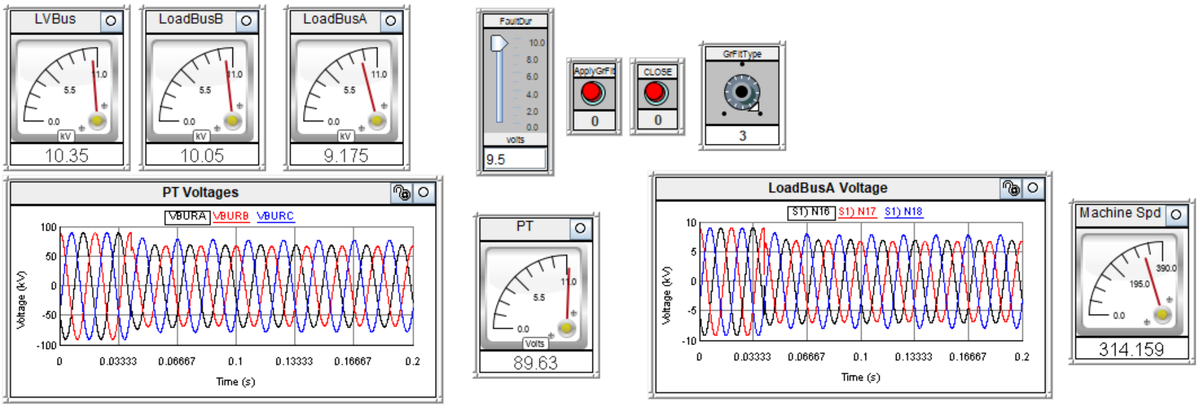

Figure 6. 26a: Runtime Under Voltage results for stage1

Below is the event report obstructed from the relay after the test was completed. The event report illustrates the voltage waveforms and waveforms are level and the relay tripped at 630 ms, as it was set to operate at 500 ms, however, because the slider was set to 9.5, the delay took a bit to complete.

Figure 6. 27b: Event report results for under voltage stage 1

The Human-Machine Interface (HMI) in Figure 6.24, is an easy way to visualize data and generate custom diagrams for controlling the system. From this point of view, it shows the changes in the relay state during testing, as well as the output contact. Device voltage is reading 5292,80 V which is the same reading shown on the multimeter display that presents under voltage stage 1.

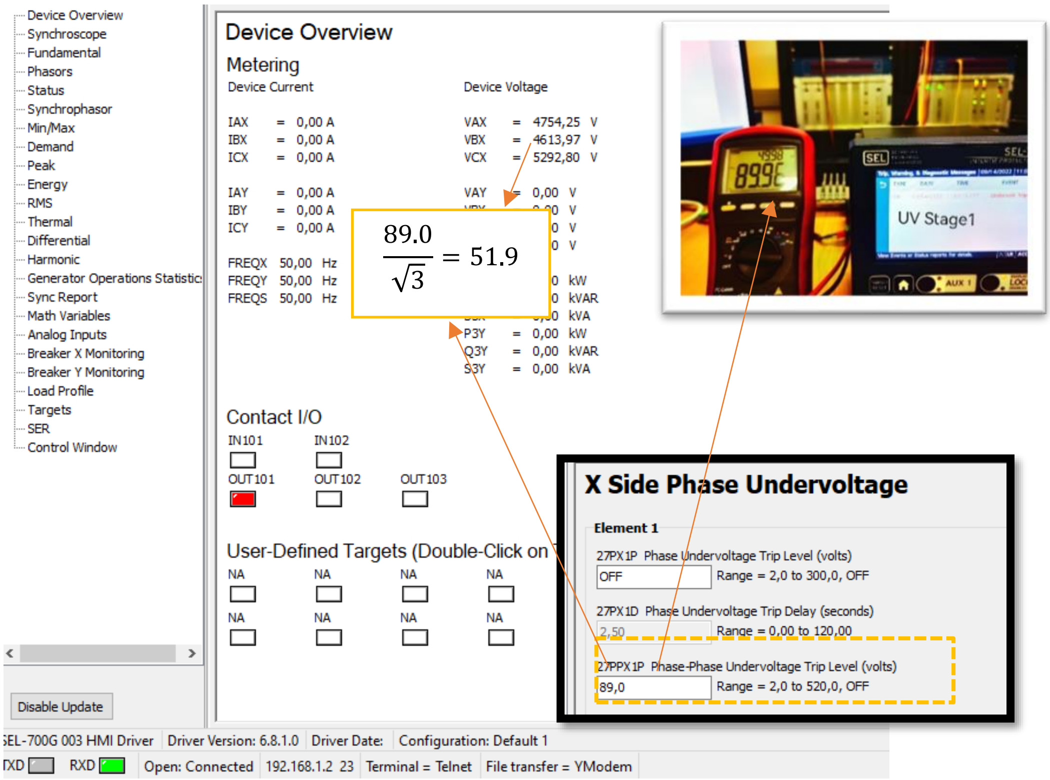

Figure 6. 28c: UV findings for stage 1 are displayed on the HMI display by monitoring relaying output port OUT101

6.8.3 Under Voltage testing Stage2

RTDS simulates the under voltage stage 2 by introducing a single phase to ground on Load Bus A with runtime controllers (ApplyGrFlt push button, GrFltType Dial switch, Close push button), and the main focus is on the PT meter, which represents the UV stage 2. It is the same procedure that has been implemented for testing stage 1 but now the only thing has changed is the dial time or tripping time for the relay which is set to operate at 2.5 seconds for Under voltage 27PPX2P = 81.0 V as displayed on the PT meter.

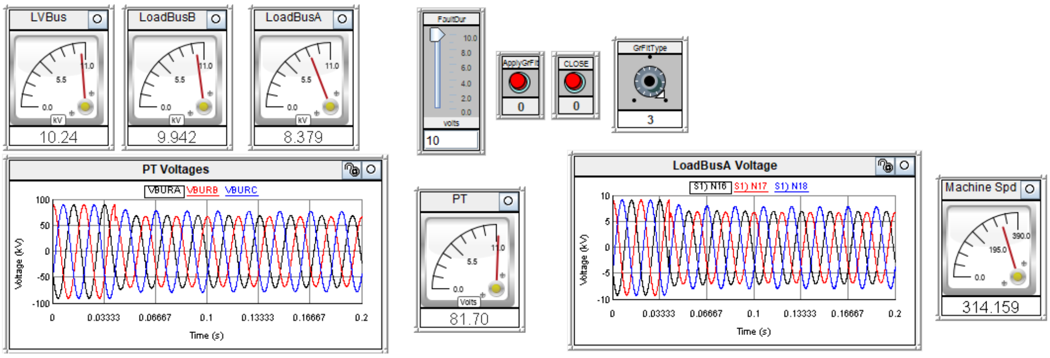

Figure 6. 29a: Runtime Under Voltage results for stage2

The event report illustrates the voltage waveforms and waveforms are level and the relay tripped at 950 ms. Although it was set to operate at 2.5 seconds, the slider was at 10, and comparing the relay tripping times for under voltage stages 1 and 2, it delayed as set for stages 2 and 3.

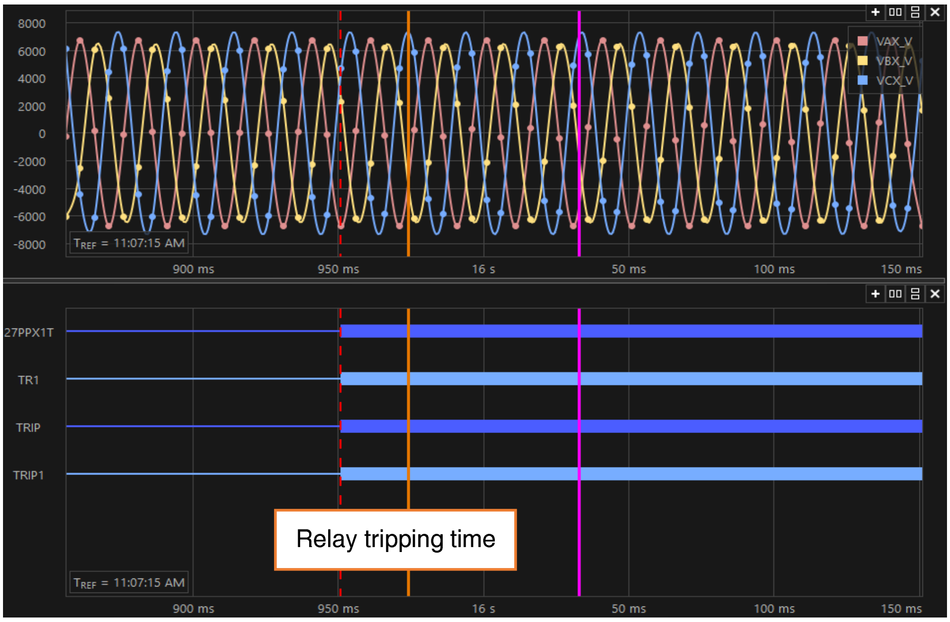

Figure 6. 30b: Event report results under voltage stage 2

The Human-Machine Interface (HMI) in Figure 6.11 Device voltage is reading 4620.02 V on VBX phase, and the setting on the relay is 81.0 V, therefore this 81.0 V is divided by square root 3 = 46.7 V, which is the same reading shown on the HMI that presents under voltage stage 2

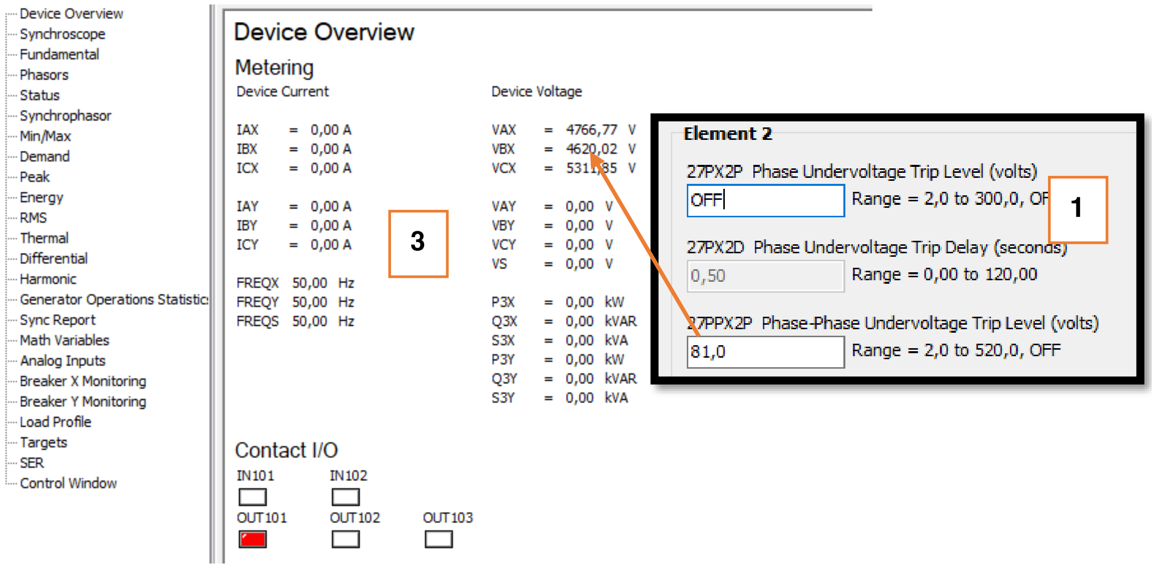

Figure 6. 31c: Under voltage findings for stage 2 are displayed on the HMI display by monitoring relaying output port OUT101

A 50% reduction in load A in a mode of islanding results in an overvoltage test

6.8.4 Over Voltage testing Stage1

Testing of the overvoltage function is conducted in the islanded operation mode of the network section, with transformer T2 connected to YNyn. The initial load A is set to 15MW, 0.05MVAr load A connected to the system, and there is a 5MW, 0.01MVAr load B. The slider on the runtime can be used to create an overvoltage condition by decreasing load A from 15MW to 5MW manually.

RTDS simulates the over voltage stage 1 protection by introducing a load deduction that is happening at Load Bus A. The load is actually reduced by 50% from the normal load being supplied on Feeder A, and therefore theoretically as the load decreases, the output voltage rises. Over voltage is measured or displayed on the PT meter 119.6 V.

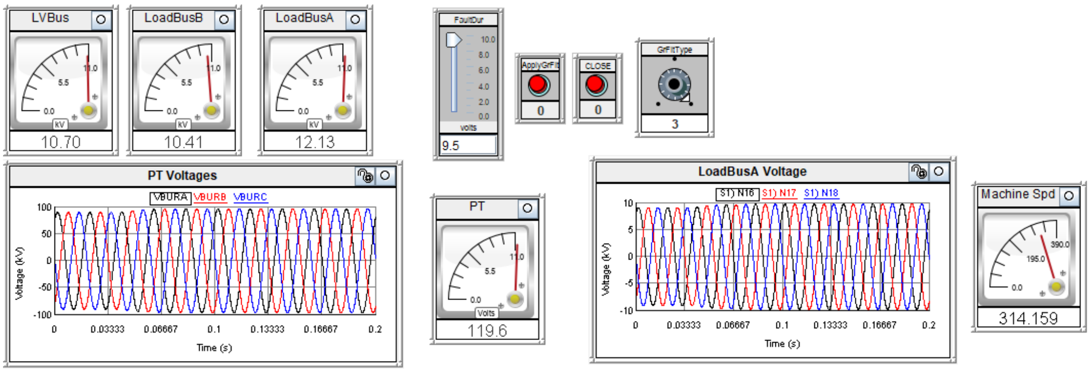

Figure 6. 32a: Runtime Over Voltage results for stage1

The SynchroWAVE Event pulled from the SEL700GT relay which represents the Over voltage stage 1 waveform voltages and the relay operating time once the 50% Load reduction implemented on the distribution network system. The relay tripped at 250 ms and the setting on the relay is 500 ms, at this stage the relay operated faster than it was supposed, that improved the protection when it comes to Over voltage which could lead to damage the appliances.

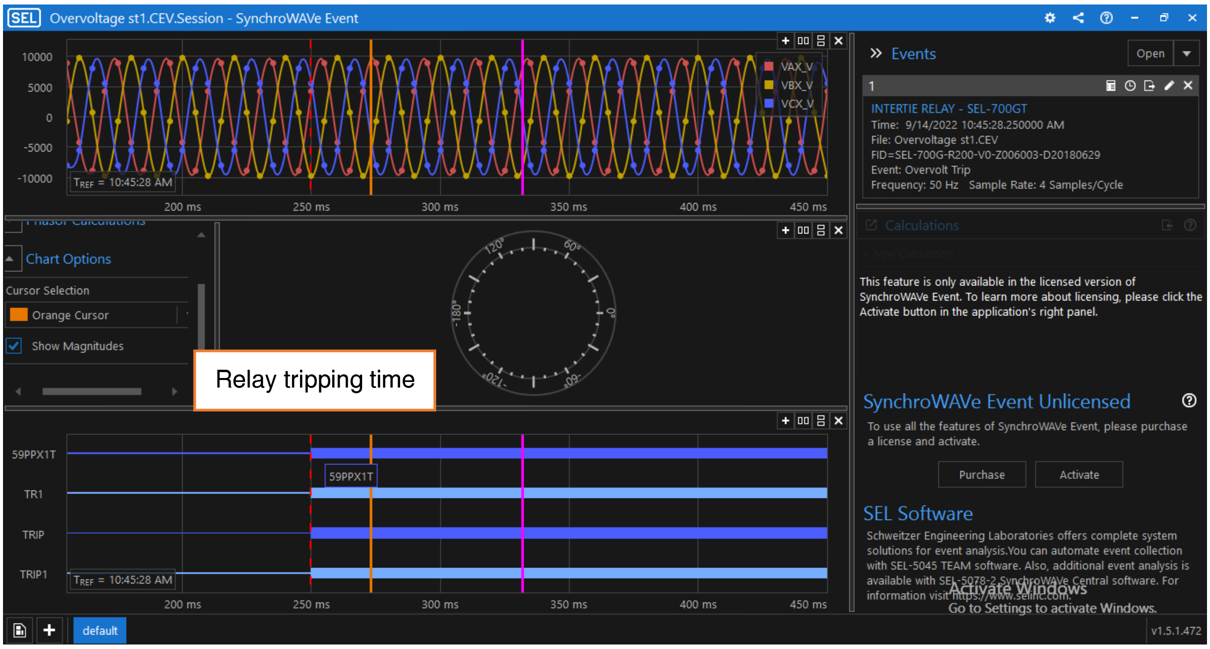

Figure 6. 33b: Event report results over voltage stage 1

The HMI displays the voltage readings on the protection device SEL700GT generator protection relay testing Over voltage stage 1, the readings on the Multimter, HMI and relay setting all corresponds. The contact output shows that the relay operated or tripped during the fault occurrence on the system.

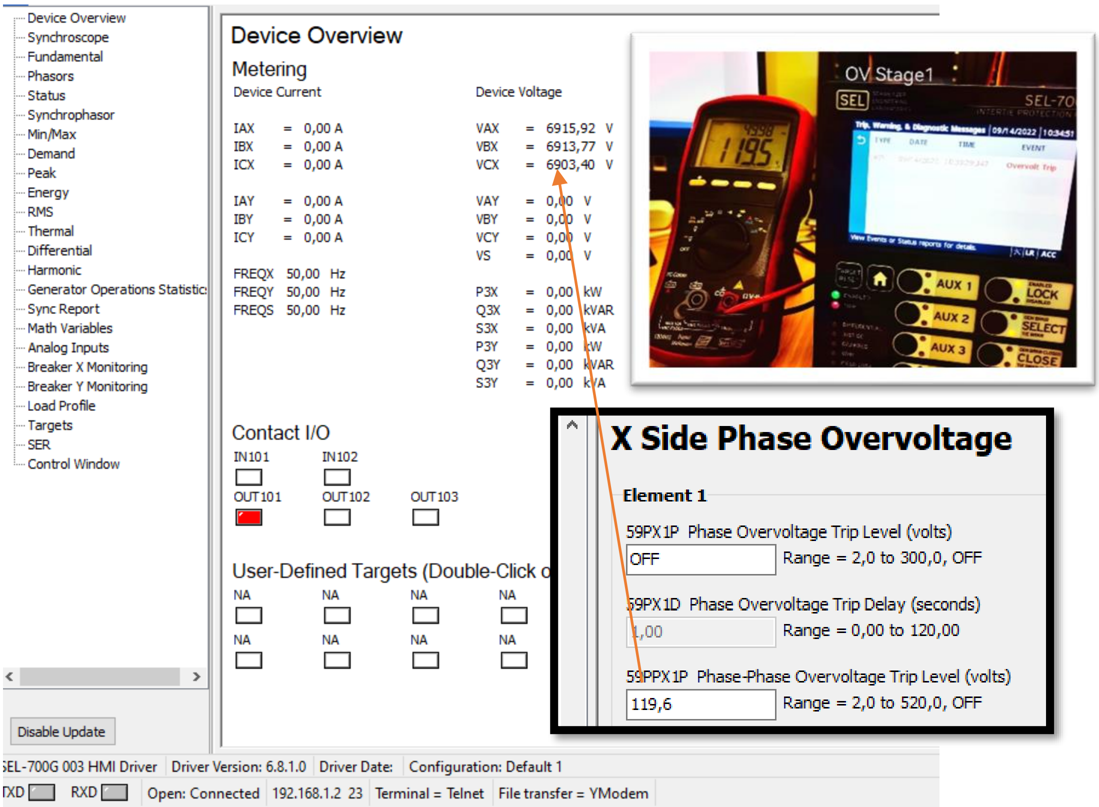

Figure 6. 34c: Over voltage findings for stage 1 are displayed on the HMI display by monitoring relaying output port OUT101

6.9 Over Voltage testing Stage2

RTDS simulates the over voltage stage 2 protection by introducing a load deduction that is happening at Load Bus A. The only thing that has changed for stage 2 is the time dial for the relay to operate, it is still the same implementation of reducing the load by 50% from the normal load being supplied on. Over voltage is measured or displayed on the PT meter 114.3 V.

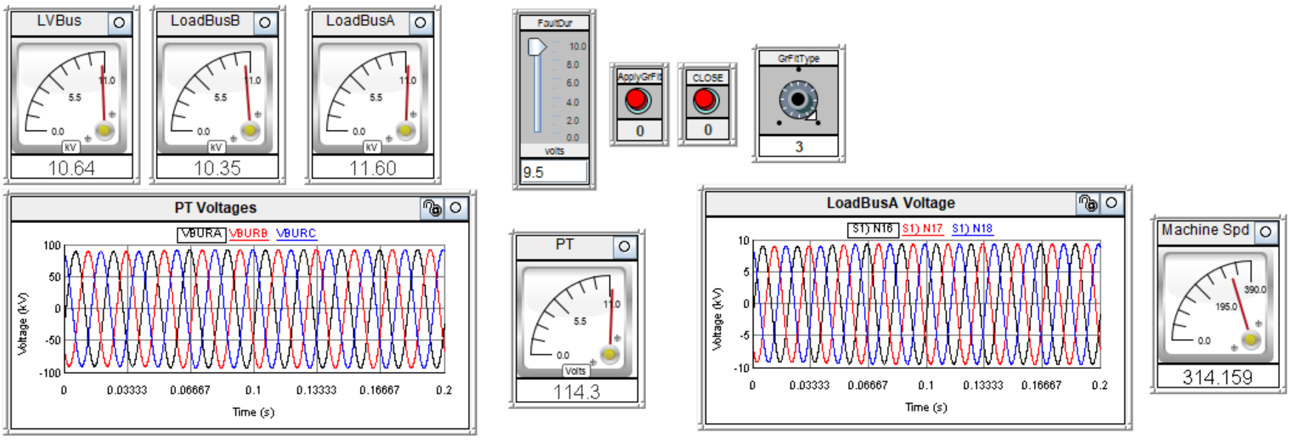

Figure 6. 35a: Runtime Over Voltage results for stage2

The SynchroWAVE Event pulled from the SEL700GT relay which represents the Over voltage stage 2 waveform voltages and the relay operating time once the 50% Load reduction implemented on the distribution network system. The same principle applies as Over voltage stage 1 display and the only difference between the two is the relay operating times.

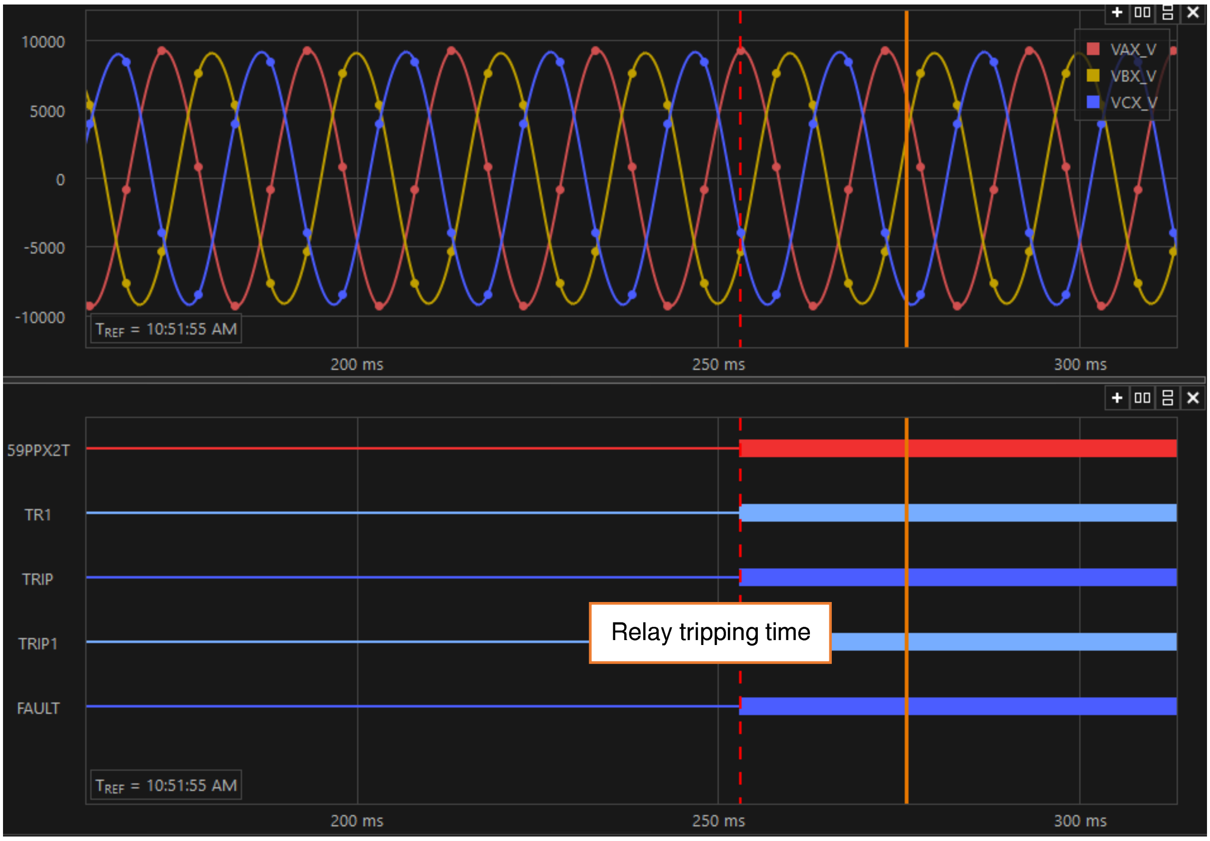

Figure 6. 36b: Event report results over voltage stage 2

The Over voltage findings for stage 2 are displayed on the HMI display by monitoring relaying output port OUT101.

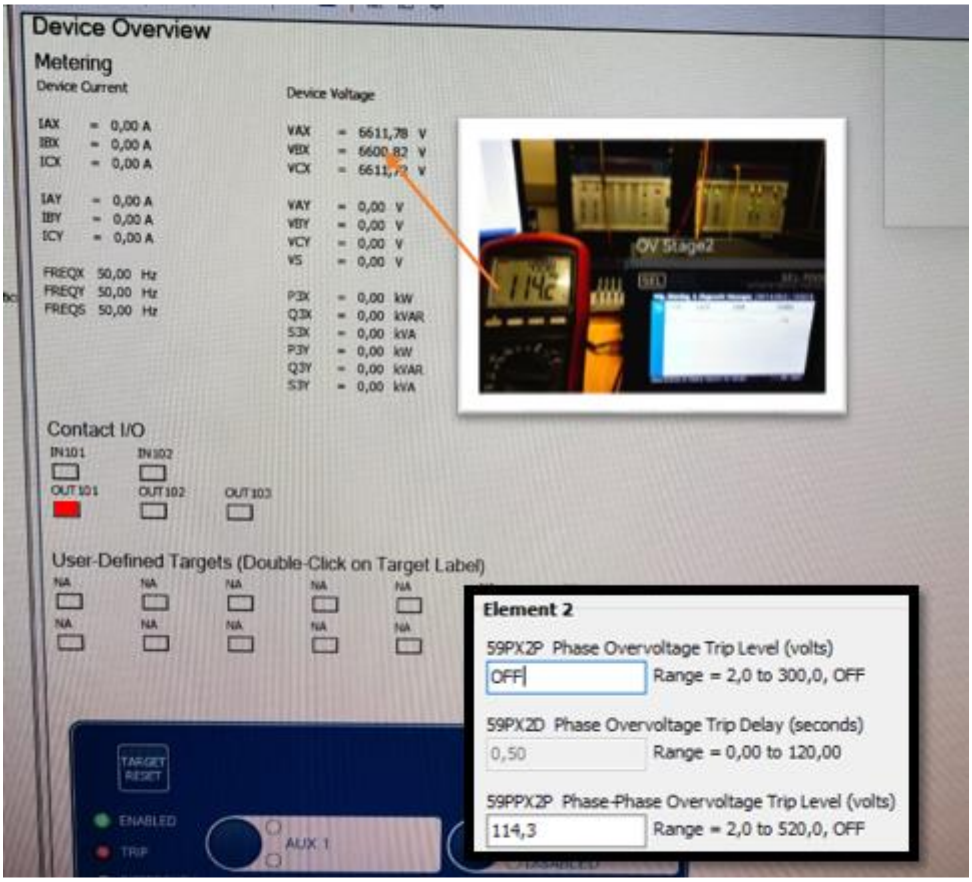

Figure 6. 37c: Relay settings for over voltage stage2

6.10 EC 61850 Standard-based GOOSE Communication on RTDS

A growing number of power systems and power electronics applications are using simulation-based real-time testing (RT) using hardware-in-the-loop (HIL). As part of the HIL testing process, actual power system components like control and protection devices are interacted with simulated and real networks of power systems incorporating different communication protocols. This case study assesses the implementation of the IEC 61850 generic object-oriented substation event (GOOSE) protocol. The lab's local area network (LAN) functions in real-time as an IEC 61850 station bus station of the IEC 16850 standard-based islanding detection algorithm for transmitting Boolean signals between the RT target and actual digital relay.

According to IEC 61850 System Configuration Description Language (SCL), GOOSE communication are configured through a System Configuration Description (SCD) file. IEC 61850 IED Configuration Tool (the SCD Editor) is embedded in RSCAD that generates SCL files within the SCD Editor, and GTNETx2-GSE-v7 IED Capabilities Description (ICD) files are exported for use in other configuration tools to specify GTNETx2-GSE-v7 capabilities.

By utilizing the GTNET hardware, the GTNET-GSE component performs IEC 61850 GSSE or GOOSE communications. Up to 64 binary output points from the simulator are sent in GSSE or GOOSE messages by GTNET-GSE.

GOOSE messages are received via 8 specific Intelligent Electronic Devices (IEDs) external to GTNET-GSE, but only one IED was used in this research. A GOOSE communication requires commissioning (NdsComm) flags for both transmitting and receiving data, as well as the quality bitmap and the header test.

6.10.1 Advantages of Closed Loop (HIL)

- To allow test multiple devices and entire scheme at once
- To allow detailing of the system network and modelling power electronics, and it is very valuable for the engineers to able to test interaction between different systems with real time operation

6.10.2 Distribution network diagram used for IEC 61850

Figure 6.28. below is a representation of the network used for implementing the new algorithm for GOOSE messaging on the RTDS services based on IEC 61850

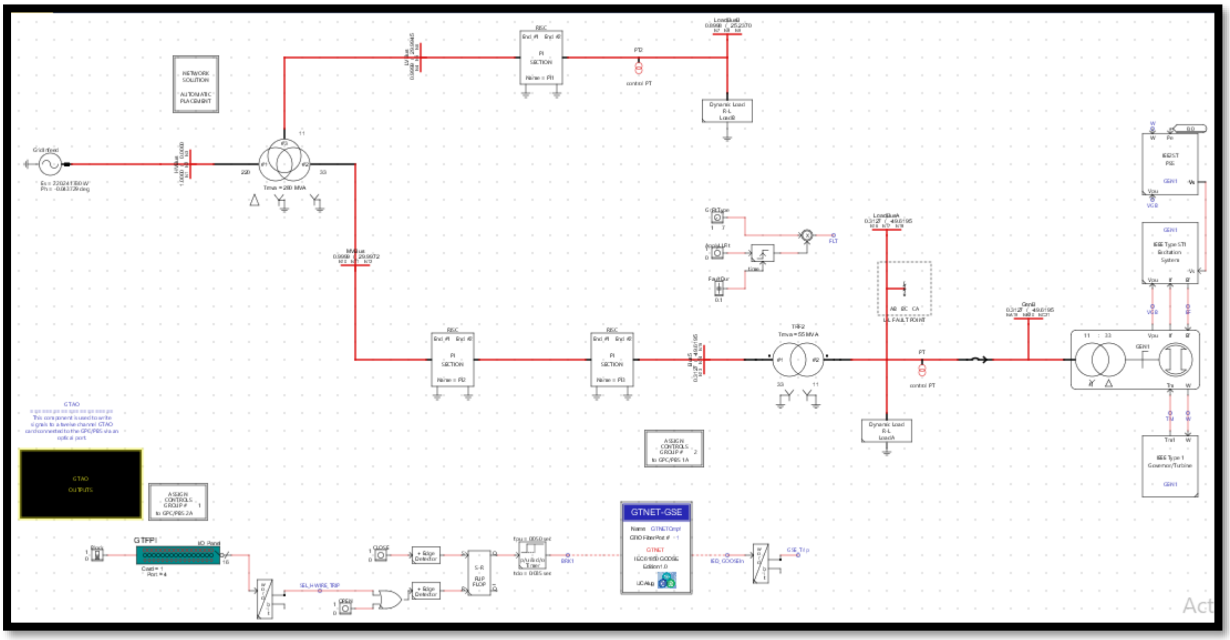

Figure 6. 38: Study network diagram for IEC61850 implementation

6.10.3 Configuration of GTNET-GSE

The received time allowed to live (TATL) check can also be done per GOOSE message, when enabled this option determines if each configured GOOSE input is receiving data from the external IED, providing an on/off status. Each configured GOOSE input can also be checked to see if it is receiving data from the external IED, based on the time allowed to live (TATL) check.

An Ethernet port on the GTNET connects to the GTIO port on the NovaCor for connecting to the RTDS simulator, and to the GTIO port on the Titan for connecting to the external IEDs.

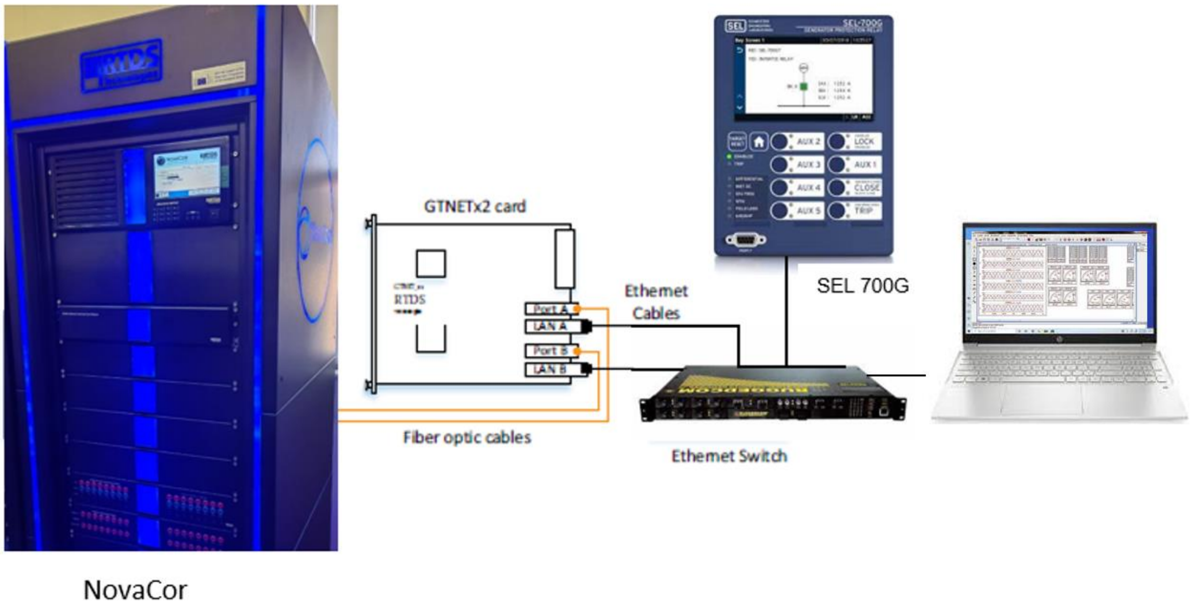

Figure 6. 39: Connection of the GTNETx2-GSE-v7 to external device (IED)

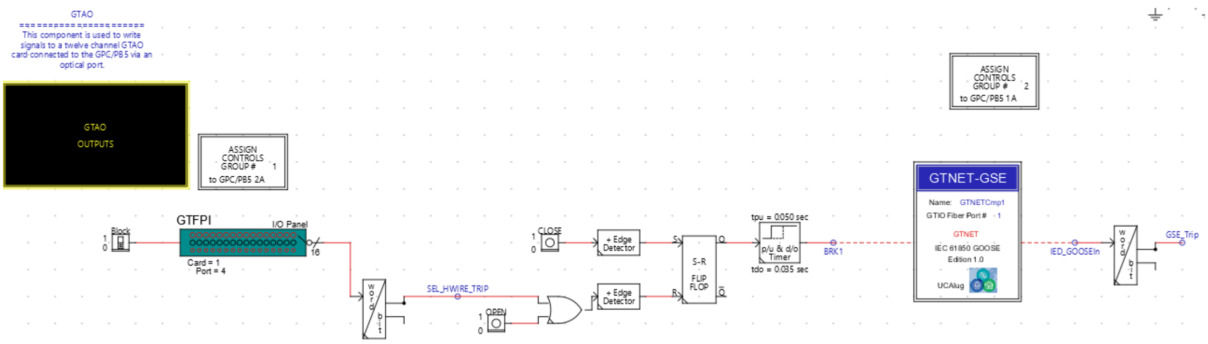

Figure 6. 40: GTNET-GSE layout and controls

This represents how the GTNET-GSE configuration works whereby when a fault happens, a signal is sent to the breaker, which sends a signal back to the GTNET network. However, in this example, the primary focus is on the virtual response. The output 1 is mapped as signal name **BRK1.**

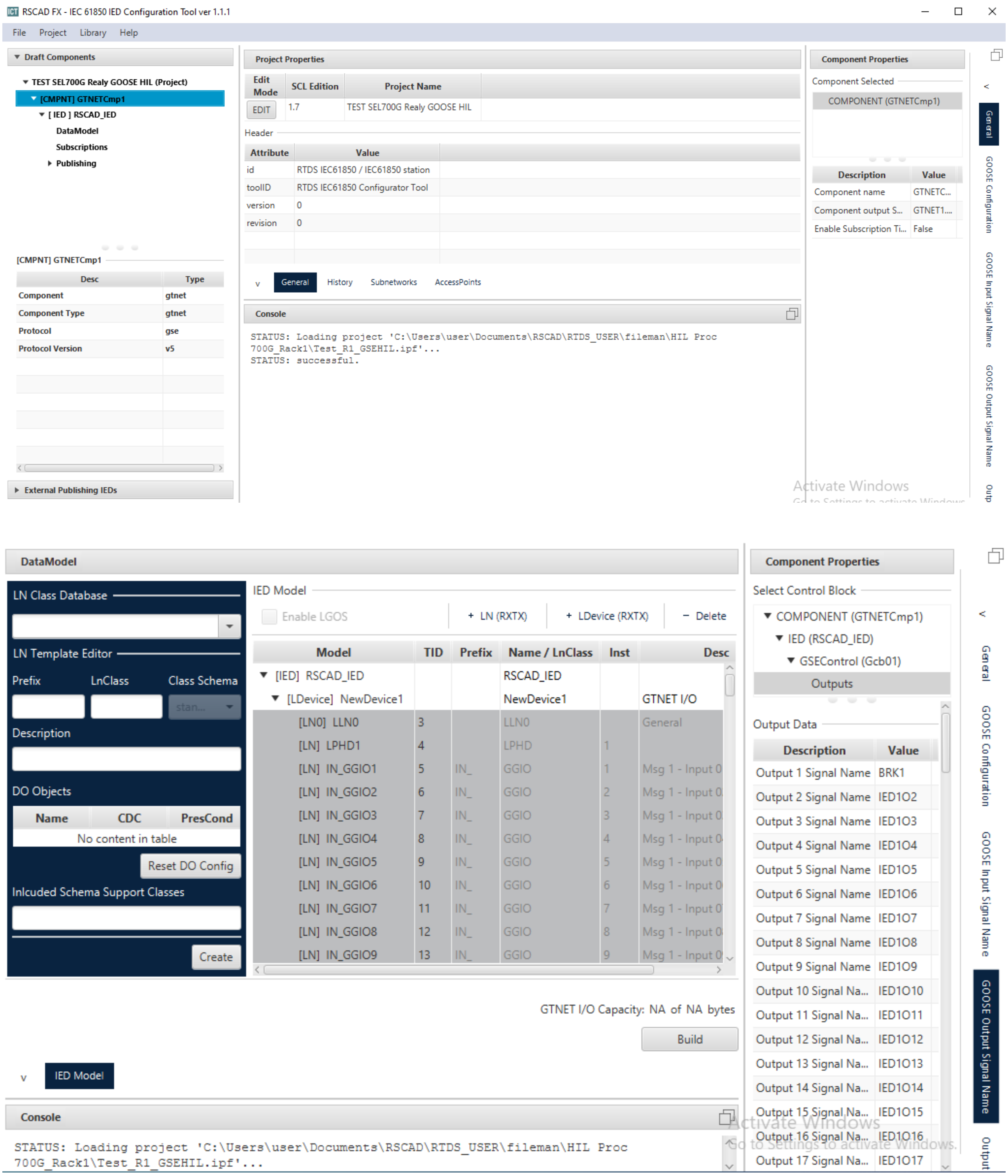

Figure 6. 41: IEC 61850 GOOSE messaging from the RTDS simulator using the new ICT tool in RSCAD-FX

6.10.4 Implementing reverse harmonic blocking with GOOSE configuration as specified in IEC 61850

SEL devices can be set up for IEC 61850 GOOSE communication with AcSELerator devices using AcSELerator Architect. You can create and amend datasets, generate general GOOSE messages for substation events, set up IED description files, and create files in Substation Configuration Language using AcSELerator Architect.

The primary components of the configuration tool for AcSELerator Architect are shown in Figure 6.32.

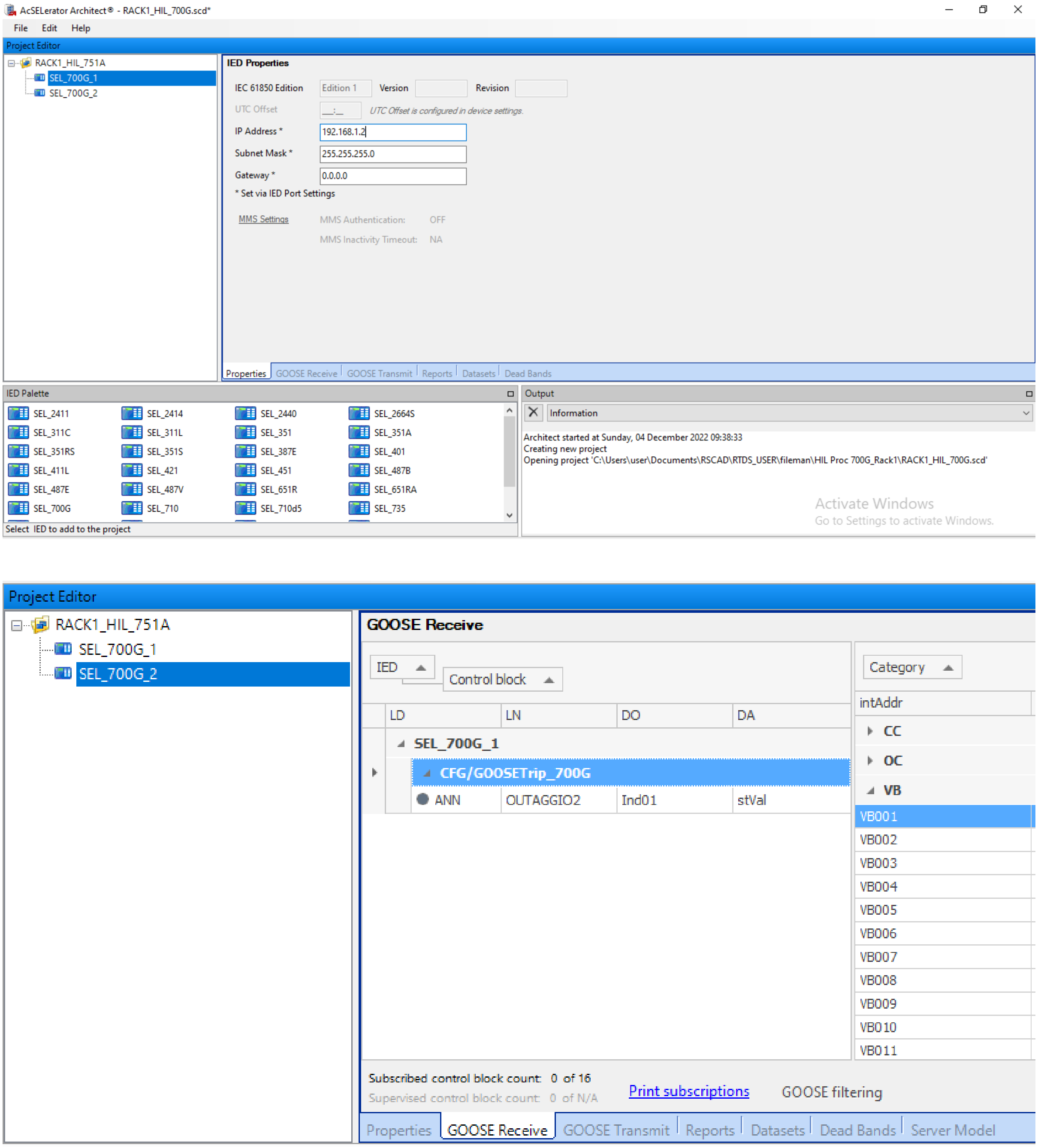

Figure 6. 42: GOOSE configuration on AcSELerator Architect

The IED Palette contains a list of SEL devices that adhere to IEC 61850. The IED configuration window opens after a device has been successfully added to the project editor. The IED palette displays after dragging a device into the project editor.

When the IED configuration files are ready, you can send them to the IEDs by selecting "Send CID" from the context menu when you right-click the IED in the project editor. An access control window will show up when the CID file has been uploaded to the IED, as seen in figure 6.39 below.

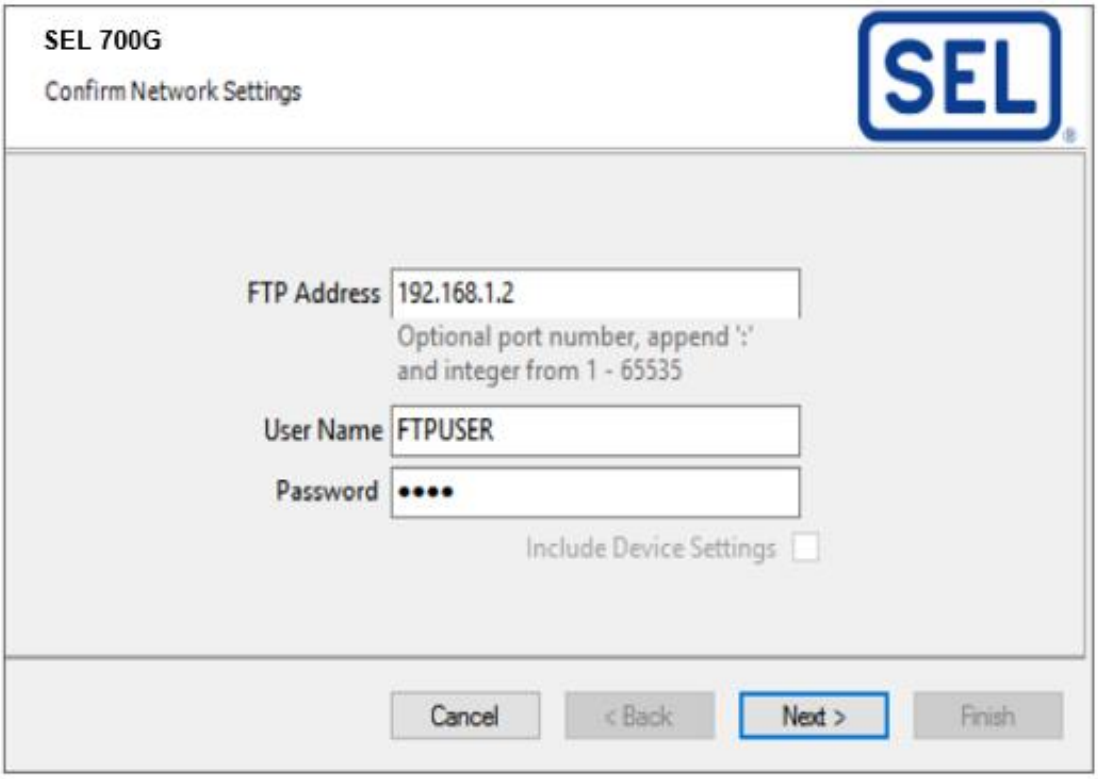

Figure 6. 43: SEL 700G Access control window

6.10.5 Simulation results on IEC 61850 GOOSE Messaging

In this section, we describe and demonstrate the implementation of a three phase short circuit in the lab on the outgoing feeder A where IED_A is installed with timing settings for voltage protection testing.

Figure 6.40 illustrates circuit breaker response and voltage as well as trip signals and GOOSE messaging during a fault. However, no fault occurred in this case and CB control was invoked to open circuit breaker BRK1.

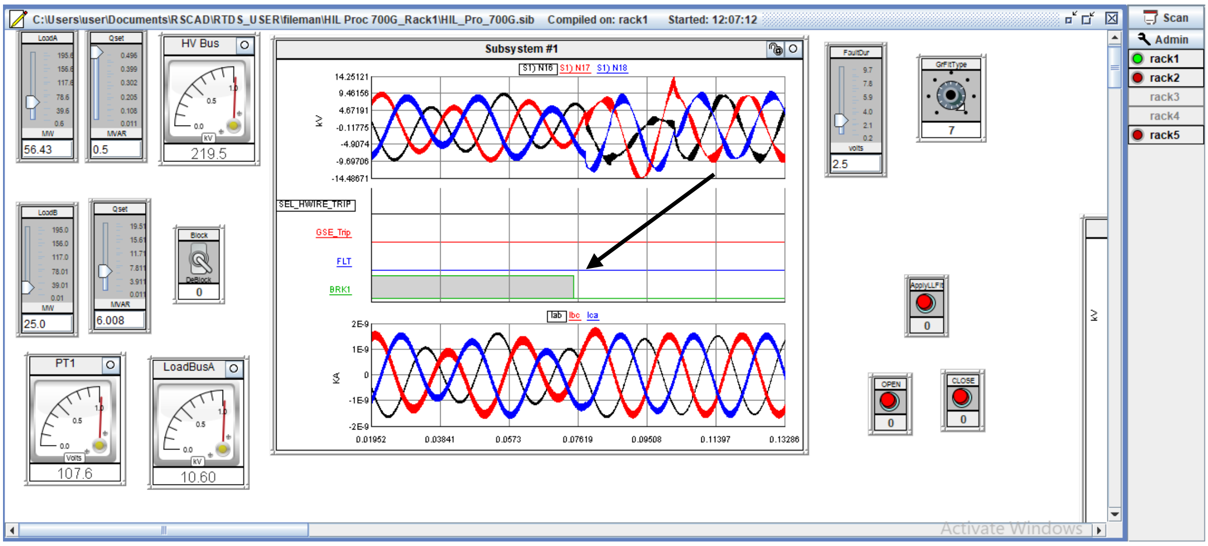

Figure 6. 44: Circuit breaker BRK1 shows open state

Figure 6.36. Displays the status of the circuit breaker when it is in the closed state

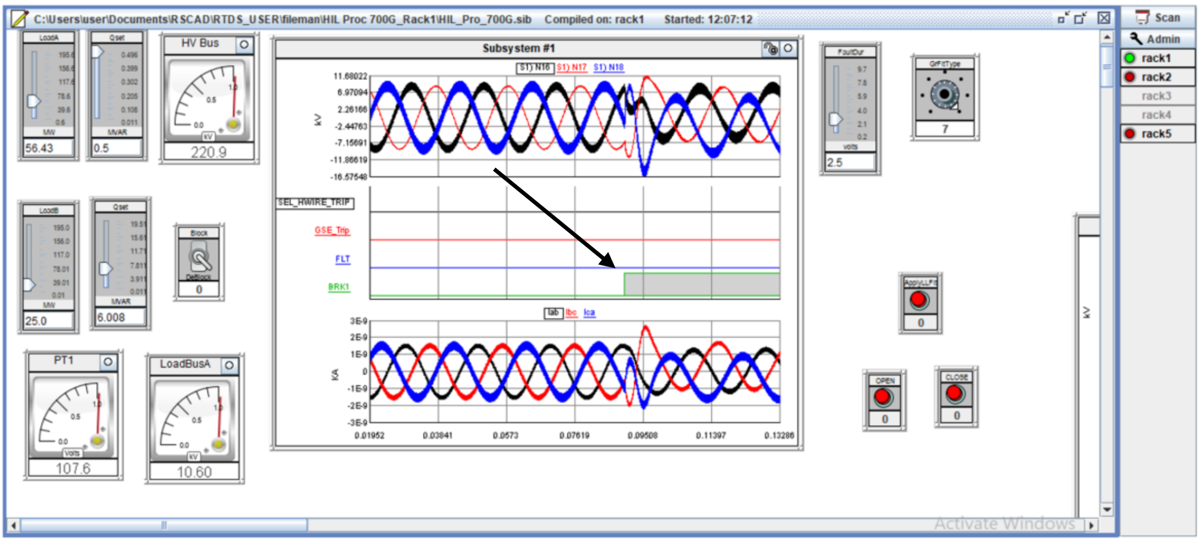

Figure 6. 45: Circuit breaker BRK1 shows closed state

The purpose of this section was to examine the performance of the hardwired and GOOSE solutions for faults in the outgoing feeder A. Red bar represent GOOS trip and Black bar represent Hardwired trip.

In the case of hardwired protection communications, three major issues cause time delays:

- The delay caused by the output circuitry
- Time it takes to handle and filter input
- Time taken to process an application

In these results below, it has been proven that signal time delay is one advantage that GOOSE has over other systems.
As well as simplifying the wiring of the system, it reduces its complexity. Communication between devices via horizontal channels improves response times. GOOSE is faster than hardwired when comparing these factors to those mentioned above, which were taken into account when hardwire was implemented.

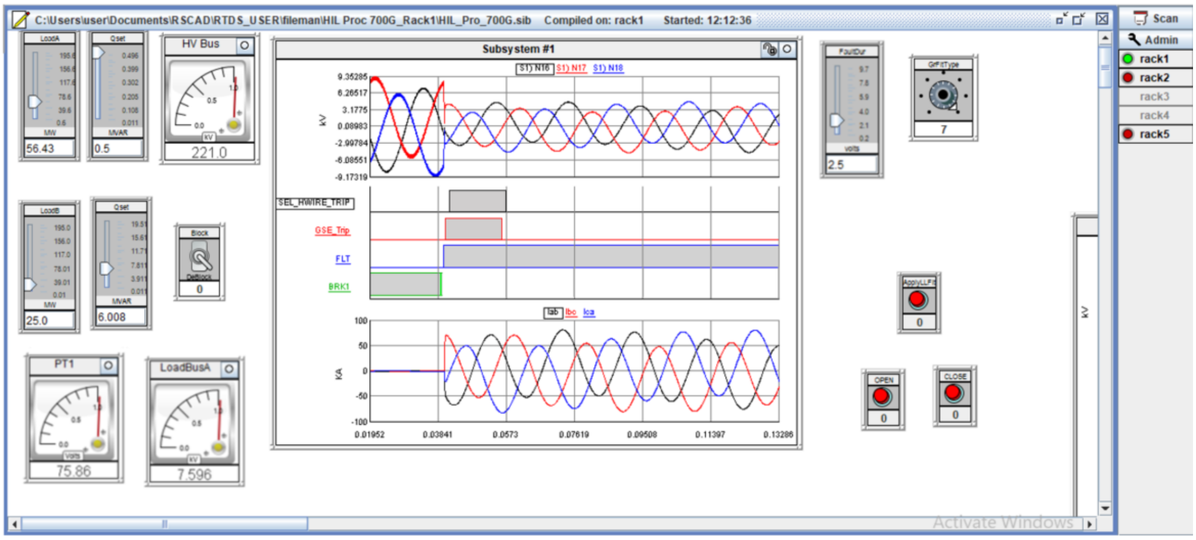

Figure 6. 46: GOOSE response when three phase short circuit fault applied on feeder A

The figure below represents the tripping time of the relay when three phase short circuit applied on feeder A, the relay was set to operate at t = 2.5 seconds for under voltage stage 1. The wave form on synchrowave does not show much different in terms of under voltage when the fault initiated but relay shows the correct operating time.

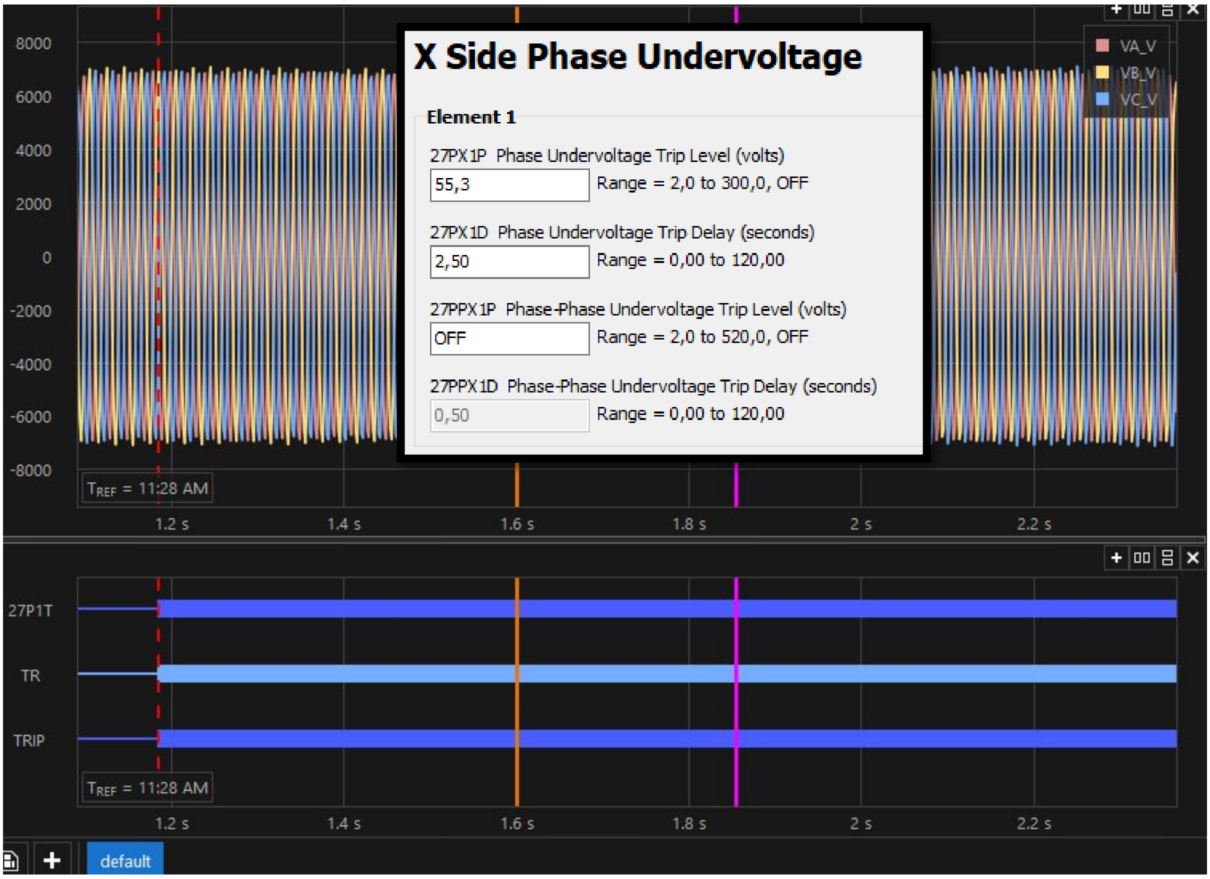

Figure 6. 47: Under voltage results and relay operating time

6.11 Discussion

The UK network was modelled using the using RTDS/RSCAD. The test was created using physical devices that were designed to interface with real-time RTDS racks. The major goal was to construct a practical scenario in which the Overvoltage and Under voltage protection functions were analysed suing the HIL simulation. The initial topology was tested, and all findings were achieved. HIL protection outperformed a hardwired arrangement in terms of performance and speed.

6.12 Conclusion

The practical test was carried out on the UK Network using the RTDS/RSCAD simulator, which provided a real-time view into how the protection scheme would operate if it were deployed in the field by utilities. The designed protection methods are fully implemented in HIL RTDS/RSCAD for real-time simulation under voltage stage 1, voltage stage 2, and over voltage stage 1, respectively. The schemes were designed with the real-time digital simulator and the protective intelligent electronic device to recover system voltage and optimize load buses after voltage variations. In the preceding case, a successful conclusion was attained. It is addressed how to test voltage element protection systems using IEC 61850 GOOSE signals, mostly for distribution networks.

CHAPTER SEVEN
CONCLUSION

7 Introduction

This research project aim to develop and implement a workable IEC61850 standard-based protection strategy for distribution systems operating for both grid-connected and islanded modes of operation with wind turbines. An analysis of the protection scheme for islanding detection was conducted on the 11kV distribution system as a case study.

Hardware-in-the-loop implementation and lab-scale testing for the islanded protection scheme were both done.

DigSilent simulation primarily uses voltage- and frequency-based protection for islanding detection protection using 11kV distribution network. The total load in the system is 20MW and the two Wind Turbines are producing 10MW each and this is to make sure that these wind turbines can be able to operate the micro grid network during load shedding when the external grid is out of service or maintenance mode.

Lab-scale testing for the voltage-based protection function and frequency-based protection function is done to perform the islanding detection scheme. The protection elements that are tested is under-voltage, over-voltage, under-frequency and protection scheme. The results are presented on chapter five. The AcSELerator Quickset software used to perform protection configuration settings to SEL IED and test universe software is a hardware interface for configuring and controlling Omicron CMC 356 test injectors.

Real-Time Digital simulation implementation is completed on RTDS. Tested two protection functional elements under-voltage stage 1&2 (27PP1, 27PP2), and over-voltage stage1&2 (59PP1, 59PP2) and protection hardwired-in-the-loop simulation is done using the CMS amplifier, SEL700G relay and RTDS.

The results achieved, key findings, and thesis deliverables are summarized in this chapter. The deliverables of the thesis are presented in section 7.2. Section 7.3 describes the possible academic, research and industry applications of the thesis deliverables. The future research work in this field will implement CHIL and PHIL simulation for the micro grid system is summarised in section 7.4. Section 7.5 gives list of the papers submitted for Journal publication.

7.1. Deliverables

This chapter has a key feature of the deliverables contributed which include literature review, lab-scale testing of the frequency-based protection function and voltage-based protection function, hardware-in-the-loop simulation of the protection testing using Real-Time Digital Simulator.

7.1.1. Literature review

The literature review analysed the various techniques used for islanding detection including active methods, passive methods and IEC61850 based HIL protection simulation. The literature review is part of chapter two in this thesis.

7.1.2. Theory on voltage and frequency protection scheme

The theoretical aspects of the voltage-based protection and frequency-based protection is summarized in part of chapter three. It provided the theory of islanding detection schemes for power systems distribution network, distribution generator connection arrangements. Theoretical aspect of Under voltage load shedding scheme, instrument transformers and voltage transformers are summarized. The use of generator protection relay is summarised in this chapter to monitor the voltage and frequency protection elements.

7.1.3. DigSilent implementation of the voltage and frequency protection schemes

The engineering configuration of the protection functions using the DigSilent software version of the SEL700G generator protection relay. Modelling of the 11kV distribution network and load flow simulation results were analysed. Different case studies were studied on testing voltage and frequency-based protection schemes within the DigSilent environment.

7.1.4. Lab-scale testing voltage-based and frequency-based protection functions

The project established the lab-scale protection functional testing setup using the CMC Omicron as test injection device for injecting voltages into the generator protection SEL 700G relay. The AcSELerator QuickSet software is used to perform the engineering configuration of the protection function for voltage and frequency-based protections. The lab-scale testing of under/over voltage and under/over frequency protection elements are performed. The simulation results are presented and analysed in that Chapter.

7.1.5. Implementation of the hardware-in-the-loop simulation for IEC61850 GOOSE message application

Hardware-in-the-loop Lab-scale setup established using RTDS, amplifier CMS, generator protection Relay SEL700G. Modelling of the network in RTDS and analysed the load flow simulation results and performed the fault study on the 11kV distribution system. GTAO engineering configuration performed to transfer the secondary voltages from RTDS GTAO card to CMS amplifier and then amplified voltage signals as input to generator protection relay SEL700G. The GTNET ICT600 tool used to perform IEC61850 engineering configuration includes the dataset and the logical node configurations for the GOOSE message applications. The voltage-based HIL protection functional testing performed using IEC61850 GOOSE message application and the simulation results are analysed.

7.2. Academic/Research and industrial application

The thesis provides details on microgrid modelling in grid connected and islanded modes of operation in both DigSilent and RTDS simulation. The voltage and frequency-based protection functional testing methods in DigSilent and HIL protection testing method using RTDS could be implemented for current and future teaching and learning activity at protective relaying courses at Higher Educational Institutions. It is recommended to use the developed IEC 61850 GOOSE messaging application for utility applications at distribution level which improves the protection speed, reliability, maintenance and operations.

7.3. Future work

This research project focused on the investigations of micro grid system both grid connected and islanded mode operation. The future research work in this field will implement Control and Protection (CHIL and PHIL) simulation for the micro grid system.

Publication

A Mpaka, S. Krishnamuthy, 2023. Lab-scale implementation, testing and experimental results of the IEC16850 standard-based islanding detection scheme for distributed generator integrated power systems. Paper submitted to International of Sustainable Energy, Grids and Networks, Science Direct.

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8 APPENDICES

8.1. APPENDIX A: Generator Protection Relay

SEL 700G Generator Protection Relay

The maximum number of GOOSE subscriptions has been increased to 64, making this relay the finest relay to rely on at the distribution level because it offers significant protection components and enhances industrial package. This Relay contains many Protection Elements/functions, but for my proposed research on develop new algorithm, The project focused on Overvoltage, Undervoltage, Over frequency, and Underfrequency protection elements.

Table 1: **SEL-700G Protection Elements**

Protection Element	**Slot Z 4 ACI Card With 1 A or 5 A Neutral Channel**	**Slot Z 4 ACI/3 AVI Card With 1 A or 5 A Neutral Channel**	**Slot Z 4 ACI/3 AVI Card With 200 mA Neutral Channel**
Max. Phase Overcurrent	X	X	X
Neg.-Seq. Overcurrent	X	X	X
Neg.-Seq. Overcurrent with Directional Control	X	X	X
Residual Overcurrent	X	X	X
Residual Overcurrent with Directional Control		X^a	X^b
Neutral Overcurrent	X	X	X
Max. Phase Time Overcurrent with Directional Control	X	X	X
Residual Time Overcurrent with	X	X	X
Neg. –Seq. Time Overcurrent with Directional Control		X^a	X^b
Neutral Time Overcurrent with Directional Control			X^b
Sensitive Earth Fault		X	X
Fault Locator		X	X
Undervoltage (Phase, Phase-to-Phase, Vsync)		X	X

Overvoltage (Phase, Phase-to-Phase, Seq., Vsync)		X	X
Inverse Time Undervoltage		X	X
Inverse Time Overvoltage		X	X
Loss of Potential		X	X
Directional Power		X	X
IEC Thermal (Line/cable)	X	X	X
Power Factor		X	X
Over- and Underfrequency	X	X	X
Frequency Breaker Failure RTDs	X^d	X^d	X^d
Reclosing	X^d	X^d	X^d
Arc- Flash Detection	X^d	X^d	X^d

8.2. APPENDIX B: DigSilent Results

In this appendix DigSilent results are presented which are not shown as part of chapter 4 but presented as appendix.

```
|-----------------------------------------------------------------------------------------------------------------
| Grid: Islanding Detection                                                     | Study Case: Study Case          |
| Equipment: Lines                                                              | Annex:                 /  1     |
-------------------------------------------------------------------------------------------------------------------
| Name            From          To           Type      Cross-Sec. Num-   R         X         B      Distance  In    Der. |
|                 Busbar        Busbar                    [mm^2]  ber [Ohm/km] [Ohm/km]  [uS/km]     [km]   [kA]  factor|
-------------------------------------------------------------------------------------------------------------------
|  Line 1      LV Bus        Load Bus B     10km           0,00   1   0,0000             0,0000   10,000  0,350  1,00 |
|  Line 2      33kV node     MV Bus         10km L2        0,00   1   0,1500             0,0000    5,000  1,000  1,00 |
|  Line 3      Bus 5         33kV node      10km L3        0,00   1   0,1500             0,0000    5,000  1,000  1,00 |
-------------------------------------------------------------------------------------------------------------------

-------------------------------------------------------------------------------------------------------------------
| Grid: Islanding Detection                                                     | Study Case: Study Case          |
| Equipment: Loads                                                              | Annex:                 /  2     |
-------------------------------------------------------------------------------------------------------------------
|                                Out                      S              P                          No            |
|                                 of                      P              Q        Voltage  System   of            |
| Name            Busbar       Service      Type          Q            cosphi     [p.u.]    Type   Phases   Conn.  |
-------------------------------------------------------------------------------------------------------------------
| Load A       Load Bus A         No                   52,00  MW       0,00 Mvar    1,00                           |
| Load A (B)   Load Bus A         No                   52,00  MW       0,00 Mvar    1,00                           |
| Load B       Load Bus B         No                    5,00  MW       0,00 Mvar    1,00                           |
-------------------------------------------------------------------------------------------------------------------

-------------------------------------------------------------------------------------------------------------------
| Grid: Islanding Detection                                                     | Study Case: Study Case          |
| Equipment: Synchronous Machines                                               | Annex:                 /  3     |
-------------------------------------------------------------------------------------------------------------------
| Name                      Type        Num-    Sn     Un    cos   xd"   xd"sat.   R2      x2      R0      x0      Re      xe  |
|                Busbar                  ber   [MVA]  [kV]   phi [p.u.] [p.u.] [p.u.]  [p.u.]  [p.u.]  [p.u.]  [Ohm ]  [Ohm ]|
-------------------------------------------------------------------------------------------------------------------
| Synchronou  HV            Synchronou  1    120,00 220,00  0,80   0,20   0,20   0,000   0,200   0,000   0,100   0,000   0,000|
-------------------------------------------------------------------------------------------------------------------
```

Grid: Islanding Detection | Study Case: Study Case
Equipment: Terminals | Annex: / 4

Name	Inside Element	Type	Un [kV]	System Type	No. of Phases	Ithlim [kA]	Iplim [kA]
33kV node		33kV	33,00	AC	3	0,00	0,00
Bus 5		Bus5	33,00	AC	3	0,00	0,00
HV			220,00	AC	3		
LV Bus		11kV Bus	11,00	AC	3	0,00	0,00
Load Bus A		DG Bus	11,00	AC	3	0,00	0,00
Load Bus B			11,00	AC	3		
MV Bus		33kV Bus	33,00	AC	3	0,00	0,00
WT Type 4A LV			0,69	AC	3		
WT Type 4A LV(1)			0,69	AC	3		

Grid: Islanding Detection | Study Case: Study Case
Equipment: 2-Winding Transformers | Annex: / 5

Name	From Busbar	To Busbar	Type	Number	Sn [MVA]	HV-Side [kV]	LV-Side [kV]	Uk [%]	Pcu [kW]	Io [%]	Voltage/Tap [%]	[deg]
T2	Bus 5	Load Bus A	33/11kV(1)	1	55,000	33,00	11,00			0,000	0,00	0,0
Trf WT Type	Load Bus A	WT Type 4A LV	Transforme	30	7,000	11,00	0,69			0,100	2,50	0,0
Trf WT Type	Load Bus A	WT Type 4A LV(1)	Transforme	25	7,000	11,00	0,69			0,100	2,50	0,0

Grid: Islanding Detection | Study Case: Study Case
Equipment: 3-Winding Transformers | Annex: / 6

Name		Busbar	Type	Number	Sn [MVA]	Un [kV]	Uk [%]	Pcu [kW]	Io [%]	Voltage/Tap [%]	[deg]
250MVA 220/3	HV-Side	HV	T1	1	280,00	220,00	18,50	0,00	0,00	0,00	0,0
	MV-Side	MV Bus			90,00	33,00	17,00	0,00		0,00	0,0
	LV-Side	LV Bus			60,00	11,00	5,00	0,00		0,00	0,0

Grid: Islanding Detection | Study Case: Study Case
Equipment: Lines | Annex: / 1

Name	From Busbar	To Busbar	Type	Cross-Sec. [mm^2]	Number	R [Ohm/km]	X [Ohm/km]	B [uS/km]	Distance [km]	In [kA]	Der. factor
Line 1	LV Bus	Load Bus B	10km	0,00	1	0,0000		0,0000	10,000	0,350	1,00
Line 2	33kV node	MV Bus	10km L2	0,00	1	0,1500		0,0000	5,000	1,000	1,00
Line 3	Bus 5	33kV node	10km L3	0,00	1	0,1500		0,0000	5,000	1,000	1,00

Grid: Islanding Detection | Study Case: Study Case
Equipment: Loads | Annex: / 2

Name	Busbar	Out of Service	Type	S P Q		P Q cosphi		Voltage [p.u.]	System Type	No of Phases	Conn.
Load A	Load Bus A	No		52,00	MW	0,00	Mvar	1,00			
Load A (B)	Load Bus A	No		52,00	MW	0,00	Mvar	1,00			
Load B	Load Bus B	No		5,00	MW	0,00	Mvar	1,00			

Grid: Islanding Detection | Study Case: Study Case
Equipment: 2-Winding Transformers | Annex: / 5

Name	From Busbar	To Busbar	Type	Number	Sn [MVA]	HV-Side [kV]	LV-Side [kV]	Uk [%]	Pcu [kW]	Io [%]	Voltage/Tap [%]	[deg]
T2	Bus 5	Load Bus A	33/11kV(1)	1	55,000	33,00	11,00			0,000	0,00	0,0
Trf WT Type	Load Bus A	WT Type 4A LV	Transforme	30	7,000	11,00	0,69			0,100	2,50	0,0
Trf WT Type	Load Bus A	WT Type 4A LV(1)	Transforme	25	7,000	11,00	0,69			0,100	2,50	0,0

Grid: Islanding Detection | Study Case: Study Case
Equipment: 3-Winding Transformers | Annex: / 6

Name		Busbar	Type	Number	Sn [MVA]	Un [kV]	Uk [%]	Pcu [kW]	Io [%]	Voltage/Tap [%]	[deg]
250MVA 220/3	HV-Side	HV	T1	1	280,00	220,00	18,50	0,00	0,00	0,00	0,0
	MV-Side	MV Bus			90,00	33,00	17,00	0,00		0,00	0,0
	LV-Side	LV Bus			60,00	11,00	5,00	0,00		0,00	0,0

```
----------------------------------------------------------------------------------------------------------------------------------
| Total System Summary                                     | Study Case: Study Case                   | Annex:                  / 1  |
----------------------------------------------------------------------------------------------------------------------------------
|                                                                                                                                 |
| No. of Substations     0          No. of Busbars       8          No. of Terminals     1          No. of Lines           3      |
| No. of 2-w Trfs.       3          No. of 3-w Trfs.     1          No. of syn. Machines  1         No. of asyn.Machines   0      |
| No. of Loads           3          No. of Shunts/Filters 0         No. of SVS            0                                        |
|                                                                                                                                 |
| Generation           =     109,33  MW          2,33   Mvar       109,35  MVA                                                   |
| External Infeed      =       0,00  MW          0,00   Mvar         0,00  MVA                                                   |
| Load P(U)            =     109,00  MW          0,00   Mvar       109,00  MVA                                                   |
| Load P(Un)           =     109,00  MW          0,00   Mvar       109,00  MVA                                                   |
| Load P(Un-U)         =      -0,00  MW         -0,00   Mvar                                                                     |
| Motor Load           =       0,00  MW          0,00   Mvar         0,00  MVA                                                   |
| Grid Losses          =       0,33  MW          2,33   Mvar                                                                     |
| Line Charging        =                         0,00   Mvar                                                                     |
| Compensation ind.    =                         0,00   Mvar                                                                     |
| Compensation cap.    =                         0,00   Mvar                                                                     |
|                                                                                                                                 |
| Installed Capacity   =     474,70  MW                                                                                           |
| Spinning Reserve     =      96,67  MW                                                                                           |
|                                                                                                                                 |
| Total Power Factor:                                                                                                             |
|   Generation         =         1,00  [-]                                                                                        |
|   Load/Motor         =  1,00 / 0,00  [-]                                                                                        |
|---------------------------------------------------------------------------------------------------------------------------------|

----------------------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                   Complete System Report: Substations, Voltage Profiles, Grid Interchange |
----------------------------------------------------------------------------------------------------------------------------------
|      AC Load Flow, balanced, positive sequence                 |    Automatic Model Adaptation for Convergence            No      |
|      Automatic tap adjustment of transformers         No       |    Max. Acceptable Load Flow Error                                |
|      Consider reactive power limits                   No       |       Bus Equations(HV)                                1,00 kVA  |
|                                                                |       Model Equations                                  0,10 %    |
----------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------------------------------------
| Grid: Islanding Detection  System Stage: Islanding Detec | Study Case: Study Case                   | Annex:                  / 1  |
----------------------------------------------------------------------------------------------------------------------------------
|           rated                                Active Reactive Power                    |                                        |
|          Voltage     Bus-voltage               Power   Power   Factor Current Loading|                Additional Data          |
|           [kV]  [p.u.]     [kV]    [deg]      [MW]    [Mvar]    [-]     [kA]    [%]   |                                        |
----------------------------------------------------------------------------------------------------------------------------------
|Bus 5                                                                                  |                                        |
|          33,00    1,00   33,10     0,84                                               |                                        |
|   Cub_2  /Tr2      T2                         -5,73     2,23  -0,93     0,11   11,14 |Tap:     0,00       Min:      0      Max:     0   |
|   Cub_3  /Lne      Line 3                      5,73    -2,23   0,93     0,11   10,72 |Pv:     25,86 kW    cLod:  0,00 Mvar L:    5,00 km|
|                                                                                       |                                        |
|HV                                                                                     |                                        |
|         220,00    1,00  220,00     0,00                                               |                                        |
|   Cub_3  /Sym      Synchronous Machin         -0,67     2,33  -0,28     0,01    2,02 |Typ:    SL                                      |
|   Cub_2  /Tr3      250MVA 220/33/11kV         -0,67     2,33  -0,28     0,01    8,33 |Tap:     0,00       Min:      0      Max:     0   |
|                                                                                       |                                        |
|LV Bus                                                                                 |                                        |
|          11,00    1,00   11,00    -0,23                                               |                                        |
|   Cub_1  /Lne      Line 1                      5,00     0,00   1,00     0,26   74,99 |Pv:      0,02 kW    cLod:  0,00 Mvar L:   10,00 km|
|   Cub_2  /Tr3      250MVA 220/33/11kV         -5,00    -0,00  -1,00     0,26    8,33 |Tap:     0,00       Min:      0      Max:     0   |
|                                                                                       |                                        |
----------------------------------------------------------------------------------------------------------------------------------
```

```
-------------------------------------------------------------------------------------------------------------------------------
| Grid: Islanding Detection  System Stage: Islanding Detec | Study Case: Study Case               | Annex:                 / 2  |
-------------------------------------------------------------------------------------------------------------------------------
|           rated                                 Active Reactive Power                      |                                 |
|          Voltage      Bus-voltage               Power   Power   Factor Current Loading|               Additional Data     |
|           [kV]  [p.u.]      [kV]    [deg]       [MW]    [Mvar]    [-]    [kA]     [%]  |                                   |
-------------------------------------------------------------------------------------------------------------------------------
|Load Bus A                                                                              |                                     |
|          11,00    1,00  11,03     0,84                                                 |                                     |
|   Cub_3  /Lod      Load A                   52,00     0,00   1,00     2,72            |P10:    52,00 MW    Q10:   0,00 Mvar  |
|   Cub_5  /Lod      Load A (B)               52,00     0,00   1,00     2,72            |P10:    52,00 MW    Q10:   0,00 Mvar  |
|   Cub_1  /Tr2      T2                        5,73    -2,23   0,93     0,32    11,14   |Tap:     0,00       Min:      0      Max:    0 |
|   Cub_2  /Tr2      Trf WT Type 4A          -59,85     1,22  -1,00     3,13    28,42   |Tap:     0,00       Min:     -2      Max:    2 |
|   Cub_4  /Tr2      Trf WT Type 4A(1)       -49,88     1,02  -1,00     2,61    28,42   |Tap:     0,00       Min:     -2      Max:    2 |
|                    Total                   -------  -------                           |                                     |
|                    Load:                   104,00     0,00                            |                                     |
|                                                                                       |                                     |
|Load Bus B                                                                             |                                     |
|          11,00    1,00  11,00    -0,23                                                 |                                     |
|   Cub_2  /Lod      Load B                    5,00     0,00   1,00     0,26            |P10:     5,00 MW    Q10:   0,00 Mvar  |
|   Cub_3  /Lne      Line 1                   -5,00     0,00  -1,00     0,26    74,99   |Pv:      0,02 kW    cLod:  0,00 Mvar L:   10,00 km|
|                                                                                       |                                     |
|MV Bus                                                                                 |                                     |
|          33,00    1,00  32,85     0,66                                                 |                                     |
|   Cub_2  /Tr3      250MVA 220/33/11kV        5,67    -2,23   0,93     0,11     8,33   |Tap:     0,00       Min:      0      Max:    0 |
|   Cub_3  /Lne      Line 2                   -5,67     2,23  -0,93     0,11    10,72   |Pv:     25,86 kW    cLod:  0,00 Mvar L:    5,00 km|
|                                                                                       |                                     |
|WT Type 4A LV                                                                          |                                     |
|           0,69    1,01    0,69 -148,19                                                |                                     |
|   Cub_2  /Genstat  WT Type 4A               60,00    -0,00   1,00    49,93    28,57   |                                     |
|   Cub_1  /Tr2      Trf WT Type 4A           60,00     0,00   1,00    49,93    28,42   |Tap:     0,00       Min:     -2      Max:    2 |
|                                                                                       |                                     |
|WT Type 4A LV(1)                                                                       |                                     |
|           0,69    1,01    0,69 -148,19                                                |                                     |
|   Cub_2  /Genstat  WT Type 4A(2)            50,00     0,00   1,00    41,61    28,57   |                                     |
|   Cub_1  /Tr2      Trf WT Type 4A(1)        50,00     0,00   1,00    41,61    28,42   |Tap:     0,00       Min:     -2      Max:    2 |
|                                                                                       |                                     |
-------------------------------------------------------------------------------------------------------------------------------
```

```
-------------------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                   Complete System Report: Substations, Voltage Profiles, Grid Interchange |
-------------------------------------------------------------------------------------------------------------------------------
|      AC Load Flow, balanced, positive sequence                 |   Automatic Model Adaptation for Convergence            No     |
|      Automatic tap adjustment of transformers          No      |   Max. Acceptable Load Flow Error                              |
|      Consider reactive power limits                    No      |      Bus Equations(HV)                                1,00 kVA |
|                                                                |      Model Equations                                  0,10 %   |
-------------------------------------------------------------------------------------------------------------------------------
```

```
-------------------------------------------------------------------------------------------------------------------------------
| Grid: Islanding Detection  System Stage: Islanding Detec | Study Case: Study Case               | Annex:                 / 3  |
-------------------------------------------------------------------------------------------------------------------------------
|                          rtd.V        Bus - voltage                                   Voltage - Deviation [%]                 |
|                           [kV]   [p.u.]        [kV]   [deg]              -10          -5          0           +5         +10   |
-------------------------------------------------------------------------------------------------------------------------------
|Bus 5                                                                                                                        |
|                         33,00    1,003      33,10     0,84                                                                   |
|HV                                                                                                                           |
|                        220,00    1,000     220,00     0,00                                                                   |
|LV Bus                                                                                                                       |
|                         11,00    1,000      11,00    -0,23                                                                   |
|Load Bus A                                                                                                                   |
|                         11,00    1,003      11,03     0,84                                                                   |
|Load Bus B                                                                                                                   |
|                         11,00    1,000      11,00    -0,23                                                                   |
|MV Bus                                                                                                                       |
|                         33,00    0,995      32,85     0,66                                                                   |
|WT Type 4A LV                                                                                                                |
|                          0,69    1,005       0,69-148,19                                                                   |
|WT Type 4A LV(1)                                                                                                             |
|                          0,69    1,005       0,69-148,19                                                                   |
-------------------------------------------------------------------------------------------------------------------------------
```

```
-------------------------------------------------------------------------------------------------------------------------------
| Grid: Islanding Detection  System Stage: Islanding Detec | Study Case: Study Case               | Annex:                 / 4  |
-------------------------------------------------------------------------------------------------------------------------------
|   Volt. Generation   Motor      Load     Compen-   External                    Power       Total      Load      No load     |
|   Level               Load                sation    Infeed     Interchange   Interchange   Losses     Losses     Losses     |
|            [MW]/      [MW]/      [MW]/     [MW]/     [MW]/          to           [MW]/       [MW]/      [MW]/      [MW]/    |
|    [kV]   [Mvar]     [Mvar]     [Mvar]    [Mvar]    [Mvar]                       [Mvar]      [Mvar]     [Mvar]     [Mvar]    |
-------------------------------------------------------------------------------------------------------------------------------
|   0,69    110,00      0,00       0,00      0,00      0,00                                    0,00       0,00       0,00       |
|            -0,00      0,00       0,00      0,00      0,00                                    0,00       0,00       0,00       |
|                                                                11,00 kV      110,00         0,27       0,27      -0,00       |
|                                                                                0,00         2,23       1,85       0,39       |
-------------------------------------------------------------------------------------------------------------------------------
|  11,00      0,00      0,00     109,00      0,00      0,00                                    0,00       0,00       0,00       |
|             0,00      0,00       0,00      0,00      0,00                                    0,00       0,00       0,00       |
|                                                                 0,69 kV     -109,73         0,27       0,27      -0,00       |
|                                                                                2,23         2,23       1,85       0,39       |
|                                                                33,00 kV        5,47         0,00       0,00       0,00       |
|                                                                               -2,16         0,00       0,00       0,00       |
|                                                               220,00 kV       -4,75         0,00       0,00       0,00       |
|                                                                               -0,08         0,02       0,02       0,00       |
-------------------------------------------------------------------------------------------------------------------------------
```

Grid: Islanding Detection System Stage: Islanding Detec	Study Case: Study Case	Annex: / 5

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	No load Losses [MW]/ [Mvar]
33,00	0,00	0,00	0,00	0,00	0,00			0,05	0,05	0,00
	0,00	0,00	0,00	0,00	0,00			0,00	0,00	0,00
						11,00 kV	-5,47	0,00	0,00	0,00
							2,16	0,00	0,00	0,00
						220,00 kV	5,42	0,00	0,00	0,00
							-2,16	0,07	0,07	0,00
220,00	-0,67	0,00	0,00	0,00	0,00			0,00	0,00	0,00
	2,33	0,00	0,00	0,00	0,00			0,00	0,00	0,00
						11,00 kV	4,75	0,00	0,00	0,00
							0,10	0,02	0,02	0,00
						33,00 kV	-5,42	0,00	0,00	0,00
							2,23	0,07	0,07	0,00
Total:	109,33	0,00	109,00	0,00	0,00		0,00	0,33	0,33	-0,00
	2,33	0,00	0,00	0,00	0,00		0,00	2,33	1,94	0,39

Load Flow Calculation		Complete System Report: Substations, Voltage Profiles, Grid Interchange	
AC Load Flow, balanced, positive sequence		Automatic Model Adaptation for Convergence	No
Automatic tap adjustment of transformers	No	Max. Acceptable Load Flow Error	
Consider reactive power limits	No	Bus Equations(HV)	1,00 kVA
		Model Equations	0,10 %

Total System Summary	Study Case: Study Case	Annex: / 6

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	No load Losses [MW]/ [Mvar]
\user\Mr.A Mpaka_MENG_DigSilent Simulation Syn\Network Model\Network Data\Islanding Detection									
	109,33	0,00	109,00	0,00	0,00	0,00	0,33	0,33	-0,00
	2,33	0,00	0,00	0,00	0,00	0,00	2,33	1,94	0,39
Total:									
	109,33	0,00	109,00	0,00	0,00		0,33	0,33	-0,00
	2,33	0,00	0,00	0,00	0,00		2,33	1,94	0,39

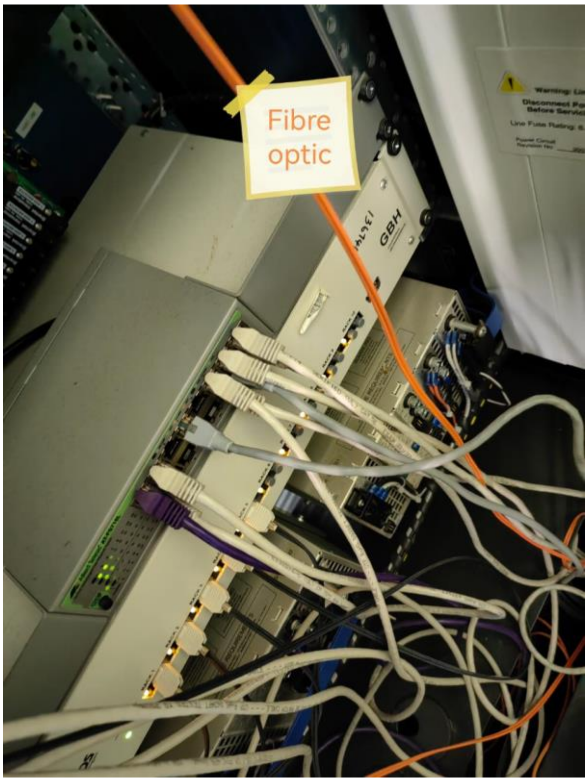
8.3.APPENDIX C: The Real Time Digital Simulator

This RTDS simulator is part of the Electrical Engineering Department's Center for Substation and Automation Management System, which is located in the Electrical Engineering Department at Cape Peninsula University of Technology.

Appendix 6. 1: The RTDS at CSAEMS lab, DEECE CPUT. (RTDS Manual, 2012)

The RTDS simulator solves electromagnetic transient equations by translating differential equations into linear algebraic equations using the trapezoidal technique of integration. As a consequence of the method, all components inside a given network may be duplicated by equivalent current sources, inductances, and the RTDS simulator's parallel processing architecture runs the algorithm to solve the power system during each time step.

The modeled power system is simplified in the simulator to a network of merely resistors and current sources, and a conductance matrix is developed for this network. The simulator determines an equal conductance and current contribution since each component in the network provides equivalent conductance’s and currents. Based on the data given by the solution processor, a network solution processor determines the voltage for the network. The voltage data is used by the auxiliary processor cards to determine current injections and conductance values for the following time step. All of these calculations are performed in parallel using processor cards. There is also an auxiliary device in the racks that contain the cubicles for interfacing with external equipment.



Appendix 6. 2: Fibre optic connections back of the panel

On the RTDS, there are input-output cards that can communicate with the simulator through fiber optic cable and interface with external devices utilizing optically separated analog and digital signals. The cards are installed to the DIN rail on the rear of the simulator rack. (Rtds psu M, 2012)

The real-time digital simulator (RTDS) Hardware

Power systems may be simulated at a typical time step of 25-50s utilizing RTDS simulator hardware. Alternatively, the hardware can mimic tiny power systems with time increments ranging from 1 to 4 seconds. In addition to the modular chassis, the hardware includes a multicore processor. When processor cards were initially launched, they were referred to as 3PCs. Today, PB5 processor cards are extensively utilized across the world as the next generation of processor cards. NovaCor, a new generation of simulation hardware, has been released. (Rtds psu M, 2012)

The real-time digital simulator Cubicle

RTDS cubicles are made up of racks containing processing cards, input/output cards, and power connections. (Rtds psu M, 2012)

Appendix 6. 3: Typical RTDS hardware setup

Appendix 6. 4: The latest NovaCor processor card

Appendix 6. 5: RTDS hardware configuration using the PB5 processor card

Giga Transceiver Work Station Interface Card

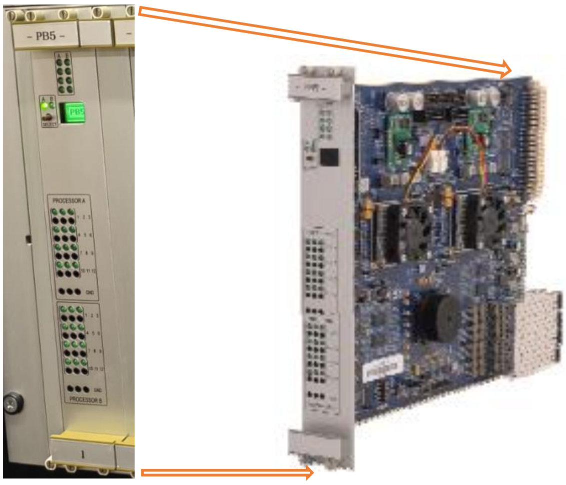
The main purpose and the main functions of the Giga Transceiver Work Station Interface Card are: (Rtds psu M, 2012)

- A communication device allows the RTDS rack to be connected to computer workstations running RSCAD. For communication, an Ethernet-based LAN is employed. RSCAD/RunTime software communicates with the GTWIF card's real-time operating system to send and receive plot updates and user-initiated events. Furthermore, the GTWIF card permits communication between the computer workstation and the SIM card in order to initiate and terminate simulations as well as load new simulation instances.
-
- It also aids in the synchronization of racks when dealing with multi-rack simulations. The GTWIF put in the simulation case's first rack synchronizes each time-step as well as the communication intervals inside each time-step. In the simulation example, master racks are assigned as the first racks. (Rtds psu M, 2012)
- Racks in simulation situations communicate with one another. The simulation case can communicate with up to six other racks while it is operating.

Appendix 6. 6: Real Time Digital Simulator GTWIF card

PB5 Processor Card

The PB5 processor cards used in the RTDS racks for this training module are shown in Appendix 6.7. These processing cards solve the equations for power and control that are expressed in the RTDS models. In each slot, it contains two Freescale PowerPC MPC7448 processors that run at 1.7 GHz. In a single rack, two PB5 cards may be mounted, allowing 144 nodes to share a network solution processor. The newly added fiber enhanced backplane capability allows 90 nodes per network solution processor to be shared, allowing 180 nodes to share a rack. (Rtds psu M, 2012)



Appendix 6. 7: Real Time Digital Simulator PB5 processor card

Inter-Rack Communication Card

For multi-rack RTDS systems with WIF cards, which offer direct, bi-directional communication between two racks, a WIF Inter-Rack-Communication (IRC) card is required. Because the GTWIF cards provided with RTDS systems contain an IRC capability that allows direct data transmission between 60 racks, they do not require IRC cards. (Rtds psu M, 2012)

Gigabit Transceiver Analogue Input and Output Cards

The Gigabit Transceiver Analogue Input and Output cards may interface analogue signals from RTDS to external devices (figures 6.8A & 6.8B). The board includes twelve 16-bit analogue output channels with a +/-10 volt output range. The input/output channels are synchronously updated at 1 microsecond intervals. The cards are oversampled every 1 microsecond. (Rtds psu M, 2012)

Appendix 6. 8a: GTAI card

Appendix 6. 9b: GTAO card