Design of Power System Protection Laboratory at PTUK

Tareq Foqha, Muhammed Dradi, Samer Alsadi, and Hani Attar

Abstract The Power Systems Protection Lab is intended to allow students to apply theory learned in lectures to the devices studied in the lab. Protecting power systems from faults within the network is a crucial aspect of power system protection, as it helps to isolate the faulted components and keep as much of the remaining electrical network operational as possible. This helps to reduce the likelihood of fires and other expensive and catastrophic system failures. It is important for power engineers to understand the underlying concepts and practices of power protection in order to provide superior protection and mitigate the effects of disruptions on system stability. The creation of the Power System Protection Lab at Palestine Technical University-Kadoorie (PTUK) provides students with the opportunity to gain real-world experience in protection, as well as facilitating educational opportunities and research. The project's aim is to test devices in the lab, conduct experiments on them, and develop a laboratory manual.

Keywords Power Systems Protection Lab · PTUK · Matlab Simulink

1 Introduction

Protective relaying is crucial in identifying faults or disturbances in power systems and quickly isolating affected parts of the network. Effective use of protective relays can prevent damage to utility equipment, reduce electricity interruptions for larger

T. Foqha · M. Dradi · S. Alsadi (✉)
Electrical Engineering Department, Faculty of Engineering and Technology, Palestine Technical University-Kadoorie, Tulkarm, Palestine
e-mail: s.alsadi@ptuk.edu.ps

T. Foqha
e-mail: tariq.foqha@ptuk.edu.ps

H. Attar
Department of Energy Engineer, Zarqa University, Zarqa, Jordan
e-mail: Hattar@zu.edu.jo

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areas and more customers, and minimize hazards for utility personnel. Due to the significance of protective relaying, the principles of power system protection are typically taught to electrical engineering students as part of a power system protection course [1].

Future engineers must have knowledge that goes beyond more theory as Power System Protection is a compulsory subject for Bachelor degree in electrical engineering in PTUK. The subject aims to provide students with the knowledge and exposure of electrical power protection equipment. A power system protection lab is very important in providing a better understanding for the subject of power system protection [2].

Laboratory experiments are crucial for enhancing students' learning experience and are highly valuable for educational purposes, making advancements in this area of education essential. By working in power system protection laboratories, students have the opportunity to apply the theories they have learned in lectures by designing the appropriate settings for physical relays and observing their functionality [1].

The Power System Protection Laboratory in Palestine Technical University is equipped with the protective relays for protection of generators, advanced numerical based relays for protection of transmission lines, fuses, magnetothermal switches, and differential magnetothermal switches to protect distribution systems. The laboratory offers a platform for coursework that focuses on the basics of fault protection and relay settings. Students apply these fundamentals of protection theory to identify faults in generators, transmission lines, and distribution systems. Through experiments in relay programming and logic, event reporting and analysis, fault detection and clearing, relay-operated circuit breakers, and communication-based protection schemes, all using modern microprocessor relays, the lab allows students to familiarize themselves with the capabilities of these intelligent electronic devices.

Laboratory education bridges the gap between theory and practical application, providing students with valuable hands-on experience. The labs are considered a complement to lectures, giving students the chance to engage in the learning process by experimenting with physical equipment and observing the characteristics, operation, and performance of systems and equipment discussed in class. The motivation behind this project originates from the protection system is considered the most important because any fault in the electrical power system, if it is not isolated quickly, can lead to the collapse of this system, the protection system is the most inclusive. Those studying protection system topics need a thorough knowledge of all parts of the electrical system and this system is considered the most exciting, because faults that occur in the electric power system are many, varied and variable at the same time, so researchers in this field find pleasure in learning electrical protection systems because they discover that this science does not end. Experiments were carried out on the Power Systems Laboratory at the Palestine Technical University and a manual of the laboratory was established, but no experiments were conducted on the protection systems of the Power Systems Laboratory due to Corona.

Our project objectives can be summarized as:

- Test protective devices in the laboratory and conduct experiments on them.

- Simulate the experiments of the generator protection using Matlab Simulink.
- Prepare a user-friendly manual for the Power System Protection laboratory.

2 Methodology

Due to our desire to discover more and more of Power System World and enter a scientific, and practical experience. Moreover, trying to exploit all university available resources such as the power system laboratory which is highly equipped but not activated as it should be, we have decided that our graduation project will be in one of the power system aspects. Therefore, we have chosen "Power system Protection lab" because we have previous knowledge about it from theoretical university courses and we are already familiar with the importance of it. Figures 1 and 2 show the flow charts of project methodology.

3 Protection of Three-Phase Generator Simulation

The three-phase synchronous machine is a crucial and significant component of power generating units, used in captive, co-generation, and independent power plants in various capacities. In order to ensure the stability of the power system, it is important to quickly isolate the generator from the rest of the system in case of power system abnormalities or faults within the generator itself. As generators are subjected to more harmful operating conditions than any other equipment in the power system, sensitive and selective protection schemes are necessary [3].

Electrical generators may experience internal faults, external faults, or both. As generators are typically connected to electrical power systems, any faults occurring in the power system should be cleared from the generator quickly to avoid causing permanent damage. There are numerous types and variations of faults that can occur in a generator, which is why multiple protective schemes are employed to protect the generator or alternator [4].

Matlab is a highly capable analysis software that can model power system components using the Sim Power Systems toolbox in the Simulink package. The toolbox includes numerous power system components such as three-phase transformers, three-phase loads, distributed parameter lines, three-phase sources, and circuit breakers, which can be utilized for both AC and DC applications. These components are pre-designed and ready to use, allowing users to easily incorporate them into their model files and input parameter values.

Simulink package offers a convenient feature where a developed model can be included in a single block set by creating a subsystem for it. This helps to reduce the space used within the file, particularly for complex systems. Additionally, the subsystem block set can be easily copied and pasted into any location or file, eliminating the need to build the model multiple times [5].

Fig. 1 Flow chart of the research methodology

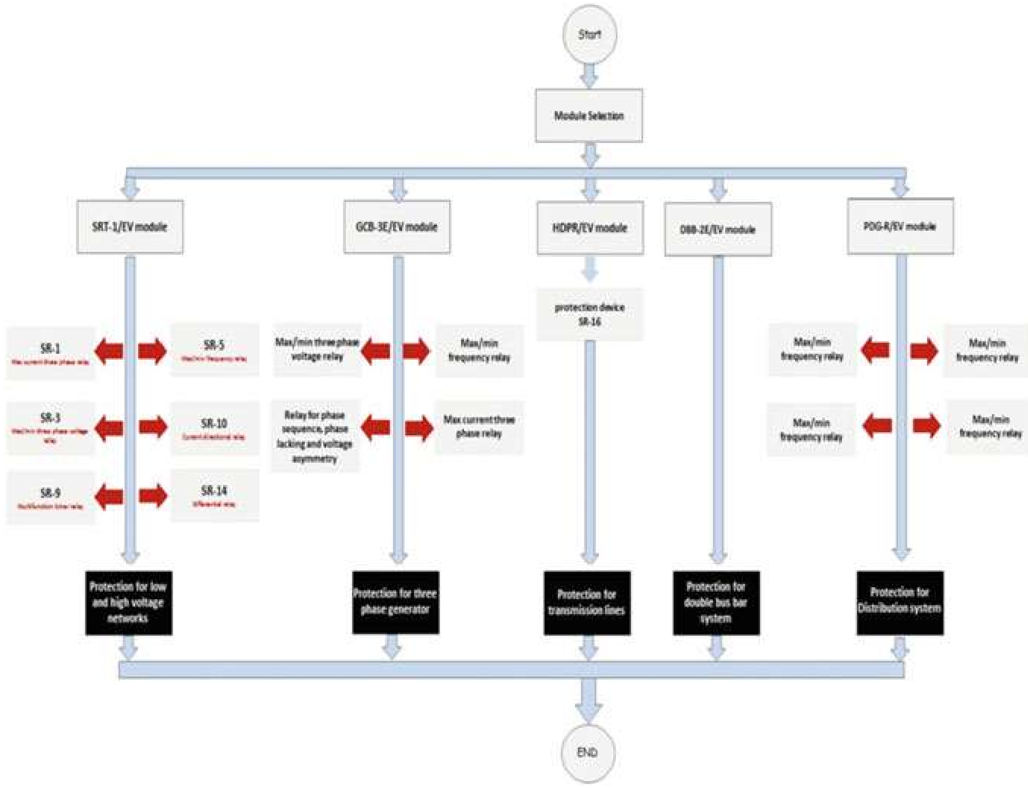

Fig. 2 Flow chart of module selection

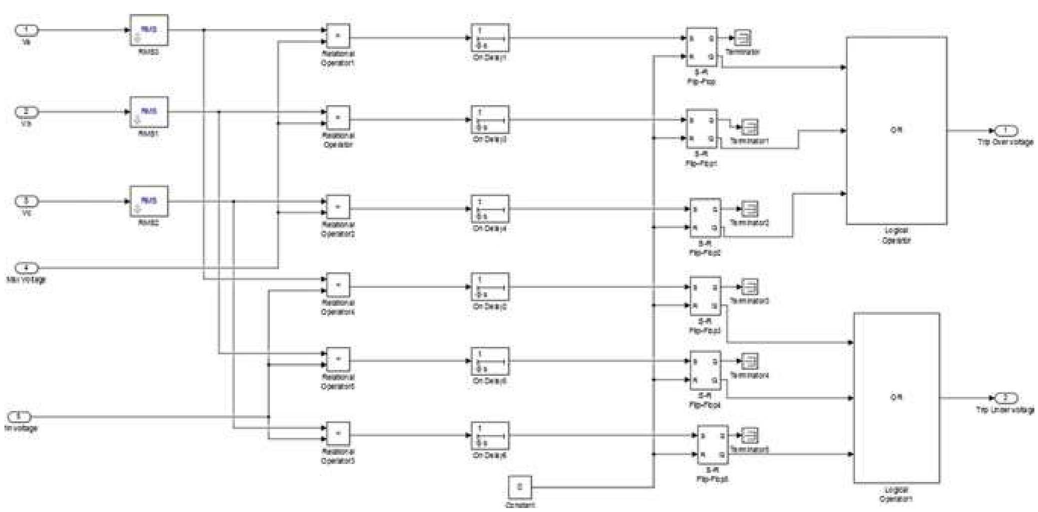

Fig. 3 Internal logic of under/over voltage relay

3.1 Under/Over Voltage Relay Modeling

Figure 3 shows the internal logic of under/over voltage relay developed using comparators, relational operators etc. Table 1 shows the power system and load data used in this simulation (normal condition).

Figure 4 shows the overall 3-Phase model of a power system Network developed along with Under/over Voltage Relay Model which investigates its operation when the voltage is below 90% of the rated value of the line voltage, or when the increase in the rms. value of the voltage up to a 105% of the rated line voltage.

The waveform shown in Fig. 5 is for the generated voltage and trip signals – over-voltage and undervoltage– during normal working condition. When the supply voltage is 400 V, the control circuit sees that there is no undervoltage and overvoltage problem. So the relay allows the supply voltage to be fed to the load.

The waveform displayed in Fig. 6 clearly indicates that the supply voltage is below the lower limit of the circuit, which is 360 V, placing it in the undervoltage region. As a result, after a certain time delay, the supply to the load is disconnected.

In the waveform shown in Fig. 7 the supply voltage is 430 V, which crosses the upper voltage limit. So it falls in overvoltage criteria. The relay will see this overvoltage problem and disconnect the supply from the load after the time delay.

Table 1 Power system and load data in normal condition

Power system data	Value	Unit
Rated voltage	400	V
Frequency	50	Hz
Base voltage	400	V
Load data		
Active power	500	W
Inductive reactive power	0	Var
Capacitive reactive power	0	Var

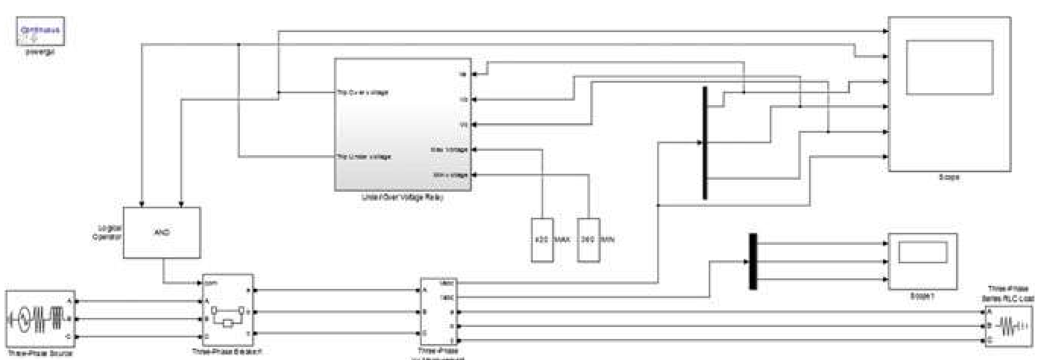

Fig. 4 Overall 3-phase model of a power system network

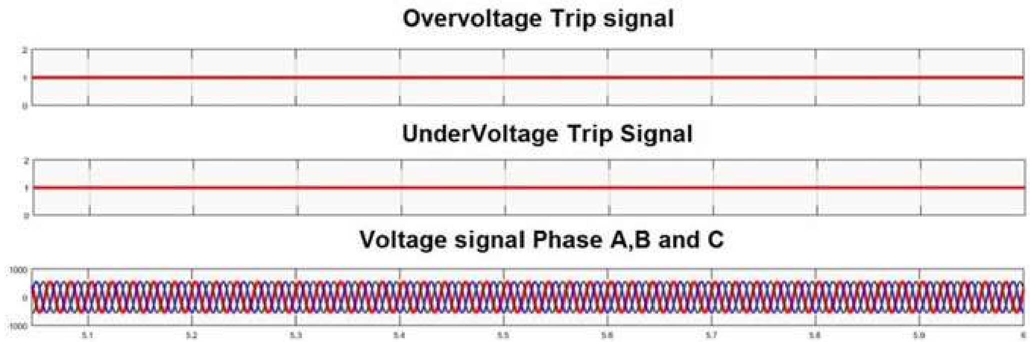

Fig. 5 Voltage and trip signals-overvoltage and undervoltage-during normal working condition

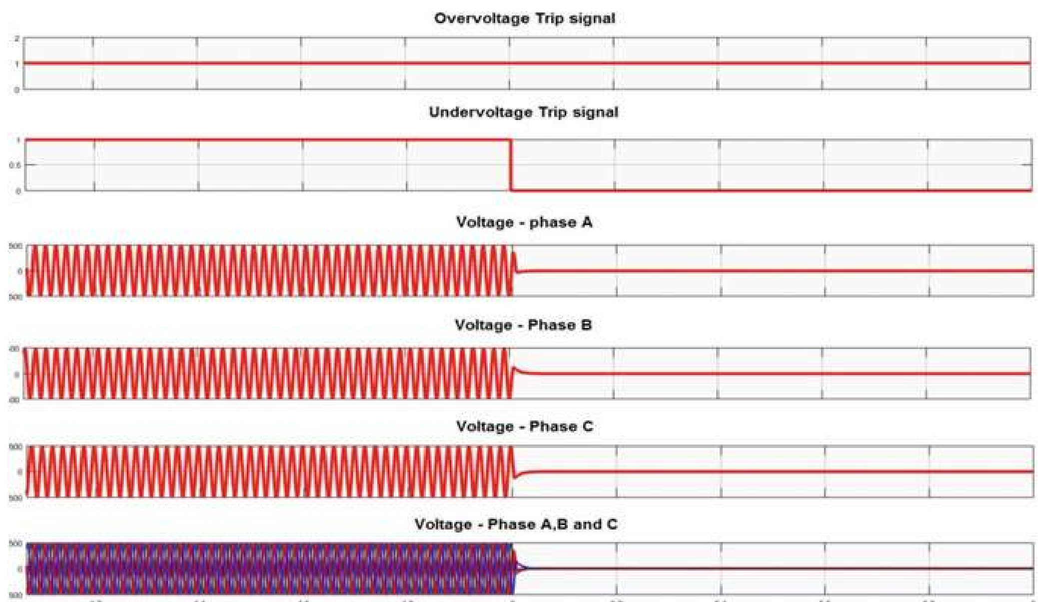

Fig. 6 Voltage and trip signals-overvoltage and undervoltage-during undervoltage condition

3.2 Overcurrent Relay Modeling

Overcurrent Relay is a type of relay that operates when the current exceeds a predetermined value known as the setting value. Its primary function is to provide protection to electrical power systems against excessive currents resulting from ground faults, short circuits, overloads, and other similar conditions [5].

Instantaneous relays are designed to detect faults in power systems and send a trip command to the breaker immediately after the fault is detected, without any intentional time delay. These relays are usually installed near the source where the fault current level is high, and any delay in their operation can result in severe damage to the equipment. Therefore, instantaneous relays are used in such areas to detect and respond to faults within a few cycles [6].

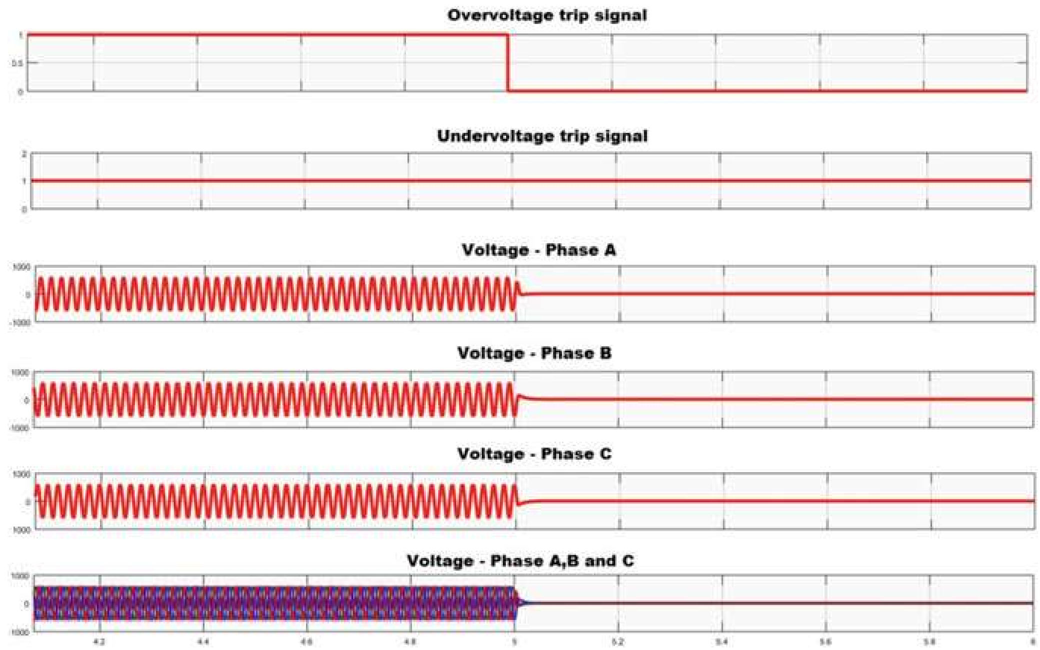

Fig. 7 Voltage and trip signals-overvoltage and undervoltage-during overvoltage condition

The internal logic of an overcurrent relay is presented in Fig. 8, which is designed using flip-flops, relational operators, and other elements. Table 1 displays the power system and load data employed in this simulation for normal conditions. Nonetheless, users can modify these parameters as needed.

The figure depicted as Fig. 9 represents a comprehensive model of a 3-Phase power system network that includes the Over Current Relay Model. The purpose of this model is to analyze the behavior of the system when a 3-phase fault is introduced into it.

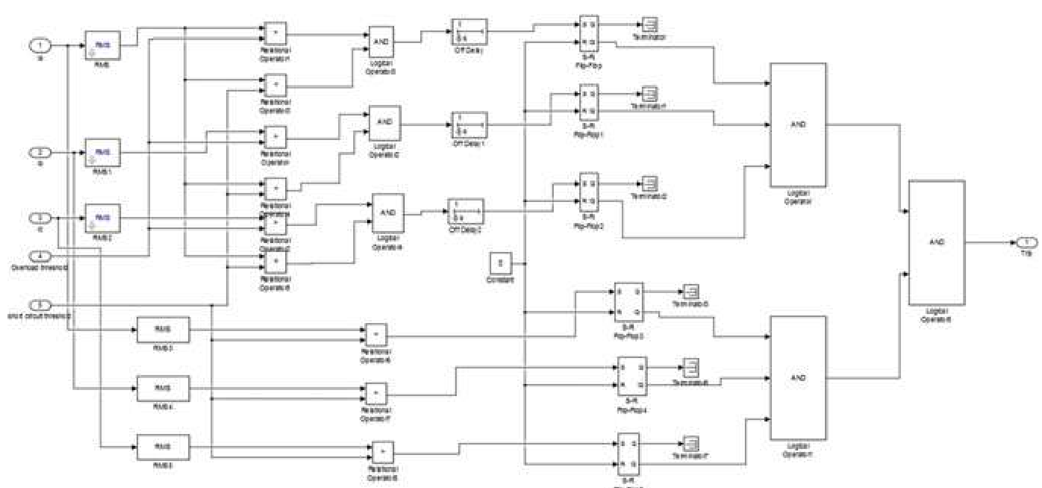

Fig. 8 Internal logic of over current relay (overload and short circuit)

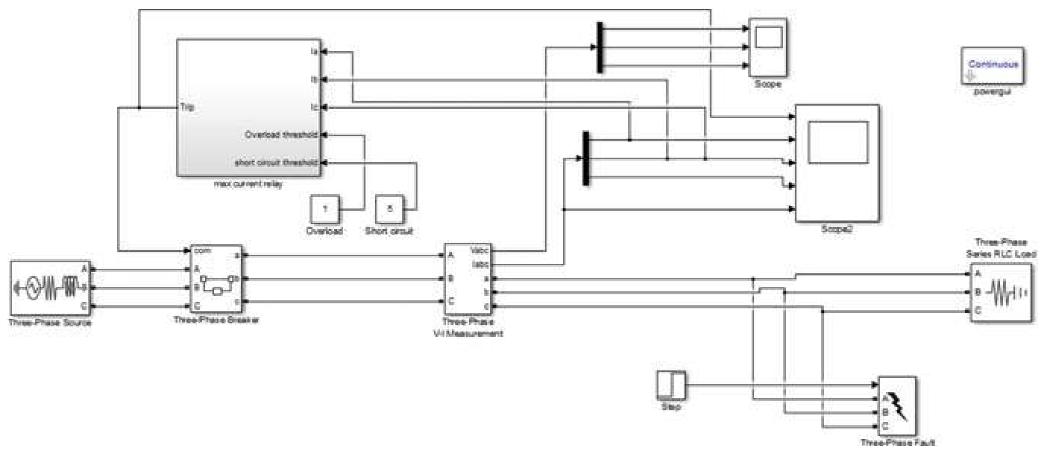

Fig. 9 Overall 3-phase model of a power system network

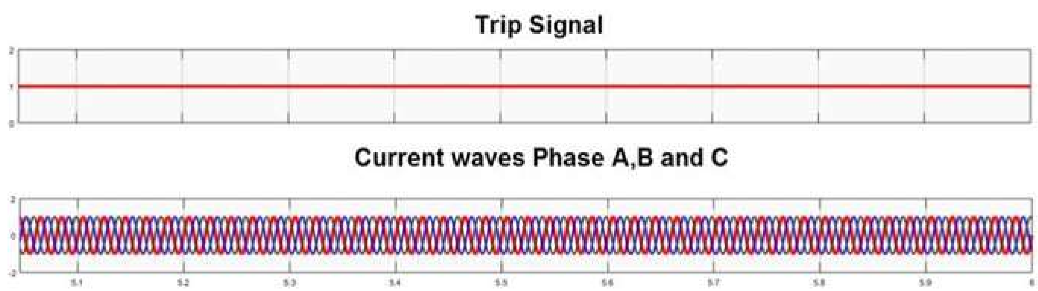

Fig. 10 Current and trip signals during normal working condition

The graphs displayed in Fig. 10 illustrate the load current and trip signal waveforms under normal operating conditions. If the load current is under 1A, the control circuit detects that there is no short-circuit or overload issue, and therefore the relay permits the supply current to flow to the load.

Increase the load to 831.4 W, The waveforms shown in Fig. 11 is for the load current and trip signal during overload condition. When the load current is 1.2 A, the control circuit sees that there is overload. So the relay will see this overload problem and disconnect the supply from the load after the time delay.

The 3-phase fault block in Fig. 9 introduces a fault after a delay of 2.0 s using a step signal. When the fault current enters the relay block, it passes through the relational operator block, which compares it with the preset value. If the fault current exceeds the pickup value, the Boolean output goes to the AND gate via an S-R flip flop. If all three inputs to the AND gate are low, then the output from the AND gate is also low, which is called the trip signal. This signal eventually goes to the 3-phase circuit breaker, interrupting the 3-phase transmission line, as shown in Fig. 12. If the phase current is below the pickup value, then the three outputs of the S-R flip flop are high, and the output of the AND gate is also high. Therefore, no trip signal is generated from the relay block, ensuring uninterrupted supply in the transmission line.

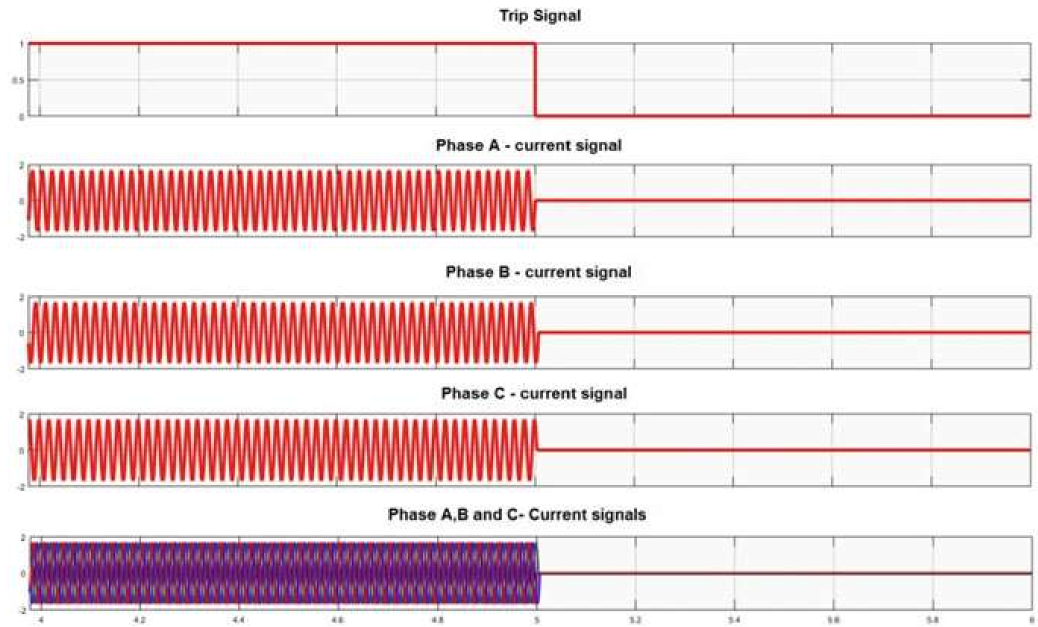

Fig. 11 Current and trip signals during overload condition

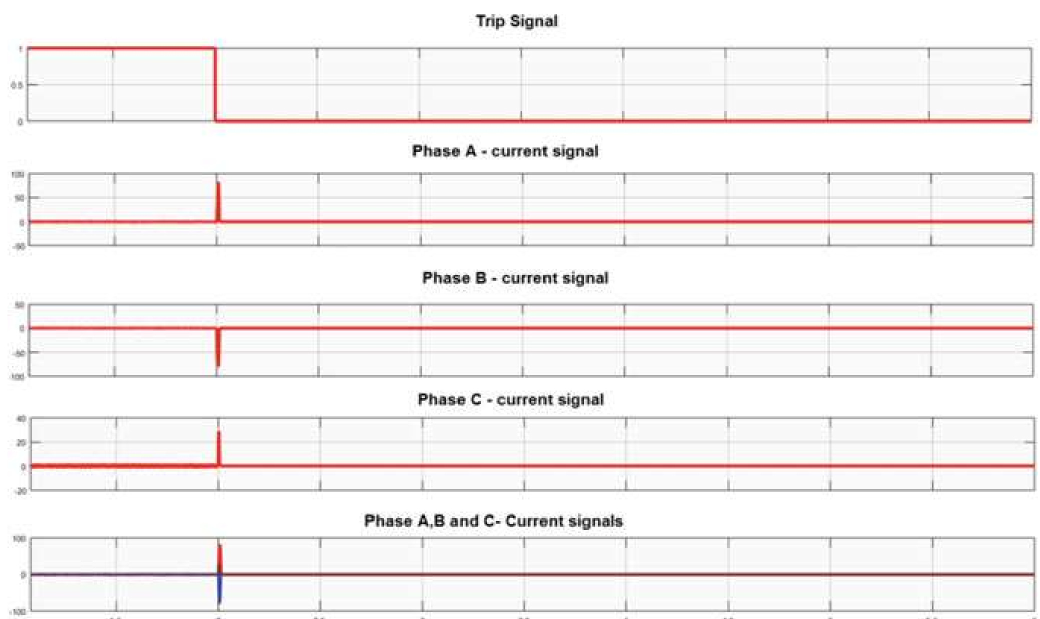

Fig. 12 Current and trip signals during short-circuit condition

3.3 Under/over Frequency Relay Modeling

Figure 13 shows the internal logic of under/over frequency relay developed using Phase Lock Loop, comparators, flip-flops etc. Table 1 shows the power system and load data used in this simulation (normal condition).

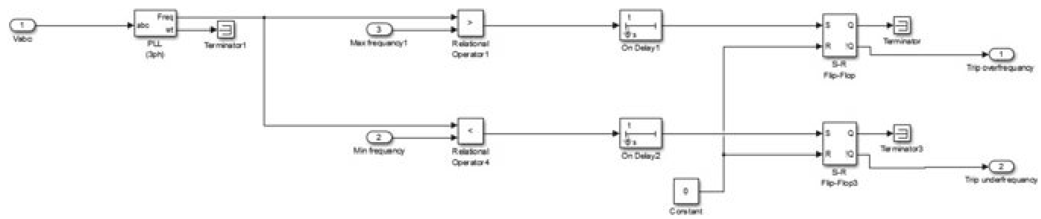

Fig. 13 Internal logic of under/over frequency relay

Over frequency and under frequency settings are 52 and 48 Hz respectively. If the system frequency goes above or below these set values, the frequency relay sends trip signal. Relay is tested under three conditions (1) Normal condition, (2) Under frequency condition, (3) Over frequency condition. Over frequency and Underfrequency conditions are tested under time delay settings.

Figure 14 shows the overall 3-Phase model of a power system Network developed along with Under/over Frequency Relay Model which investigates its operation when the frequency of the system is below 48 Hz or when the increase in the frequency up to a 52 Hz.

The waveform shown in Fig. 15 is for the frequency and trip signals –overfrequency and Underfrequency–during normal working condition. When the frequency of the system is 50 Hz, the control circuit sees that there is no overfrequency and Underfrequency problem. So the relay allows the supply voltage to be fed to the load.

As it can be easily depicted from the waveform as shown in Fig. 16 that the frequency is less than the lower limit of the circuit which is 47 Hz, is falls in underfrequency region. So it disconnects the supply to the load after the time delay.

In this waveform as shown in Fig. 17 the frequency is 53 Hz, which crosses the upper frequency limit. So it falls in overfrequency criteria. The relay will see this overfrequency problem and disconnect the supply from the load after the time delay.

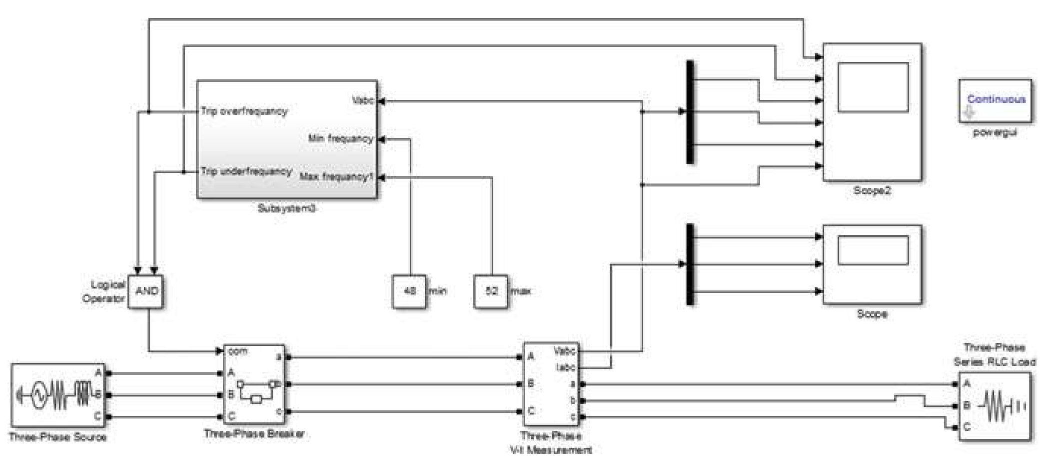

Fig. 14 Overall 3-phase model of a power system network

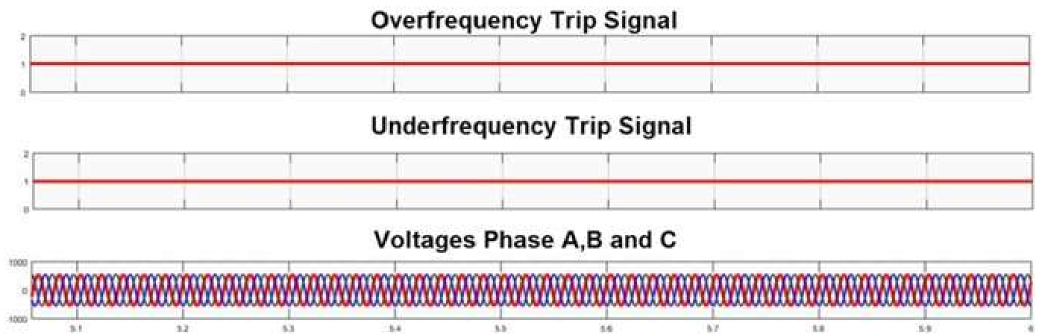

Fig. 15 Voltage and trip signals—overfrequency and underfrequency—during normal working condition

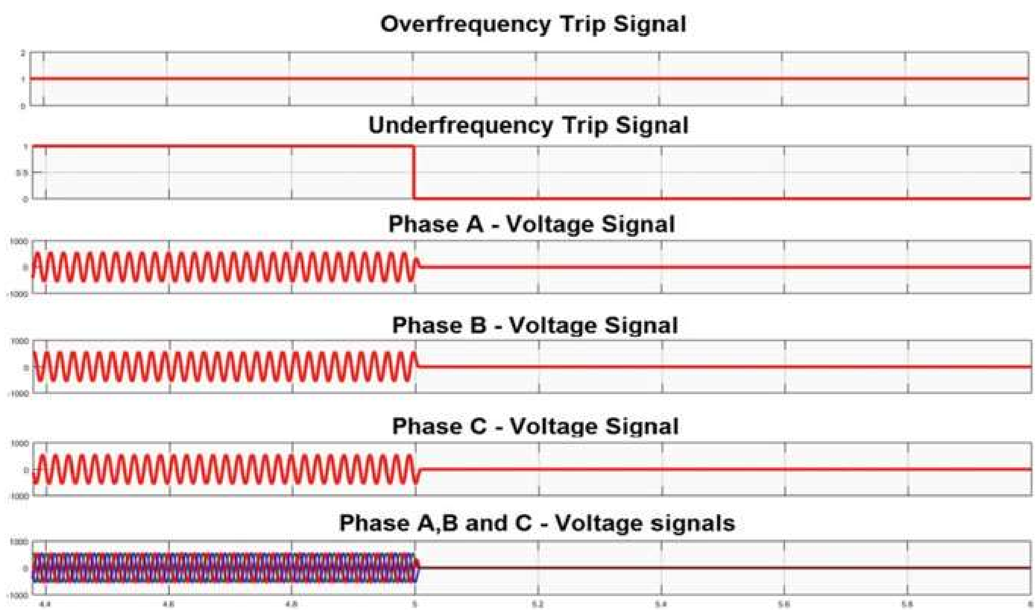

Fig. 16 Voltage and trip signal-overfrequency and underfrequency-during underfrequency condition

4 Power System Protection Lab at PTUK

The main objective of this laboratory is to provide students with practical, hands-on experience applying concepts learned in lectures to protection equipment. To meet this objective the Power System Protection Laboratory at Palestine Technical University was equipped with all the necessary protection equipment to protect the major components of the power system. In this chapter, we will discuss in brief modules that used in protecting the power system and we will talk about the content of the manual of this laboratory.

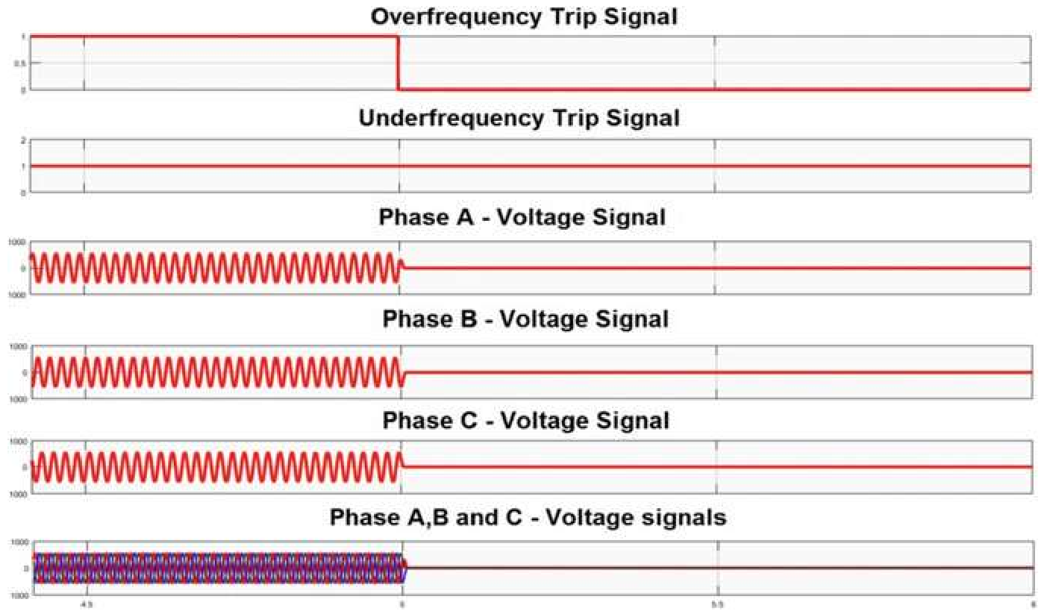

Fig. 17 Voltage and trip signals-overfrequency and underfrequency-during overfrequency condition.

The power system protection laboratory consists of vital elements like protection relays designed for both high and low voltage networks. These relays include overcurrent, maximum/minimum voltage, maximum/minimum frequency, and differential relays. The lab also has a protection module that controls all power supply and control devices of the generation set, allowing for hands-on experimentation with real industrial components related to power production and protection systems. These devices are easy to operate and can be quickly connected to safety terminals, allowing users to create, modify, and test the quality of generated power. Additionally, the electrical machines used in the lab are equipped with the same protection and control devices found in industrial control stations. The lab also features a high-speed distance protection relay and a double bus-bar system.

The lab experiments should give students insight in the practical world of power system protection. The experiments should demonstrate the different protection principles and the function of modern relays. Setting of parameters for the relays based on calculated values is also an important part. The students should have knowledge of the lab experiment topic before entering the lab. The manual of this laboratory organized to five chapters (see Table 2); the first chapter consists of 9 experiments, and the purpose of these experiments is to obtain an introduction and knowledge of the protective relays used in protection for high and low voltage networks. Chapter "The Impact of Internal Auditing Activity on the Effectiveness of Digital Risk Management in Banks Registered on the Palestine Exchange" demonstrates the basic protection equipment of alternators. Chapter "The Impact of Digital Transformation on Reducing the Costs of Banking Services in Jordanian Islamic Banks" covers the use of numerical relays in the protection of transmission lines.

Chapter "Stability of Jordanian Dinar Supports Electronic Trading System"

Table 2 List of experiments to be conducted in the laboratory

Chapter (1)	Introduction
Experiment (1)	General considerations on protection devices
Chapter (2)	Protection relays for high and low voltage networks
Experiment (1)	Overcurrent relay (SR1)
Experiment (2)	Max/Min three-phase voltage relay (SR3)
Experiment (3)	Directional relay (SR10)
Experiment (4)	Differential relay (SR14)
Chapter (3)	Synchronous generators protection
Experiment (1):	Protection of synchronous generator using protective relays
Chapter (4)	Transmission lines protection
Experiment (1)	Protection of transmission lines using electromechanical relays
Experiment (2)	Protection of transmission lines using digital relays
Chapter (5)	Distribution systems protection
Experiment (1)	Checking the operation the protection devices with differential current
Experiment (2)	Selectivity among protection devices

provides a description of the use of protective relays to protect the Double bus bar system. Chapter "The Role of M/BV Ratio in the Liquidity of Amman Stock Exchange" describes the distribution systems, study of neutral points connections, and demonstrates the protection equipment used to protect these systems.

5 Conclusion and Recommendations

During the project, it became evident that the lab had significant potential, with access to specialized equipment for students. As many of these ideas and equipment as possible were incorporated into the lab experiments and systems. Nevertheless, due to time constraints, it was not feasible to include everything in the lab at this time. Below are some ideas for future projects that could be incorporated into the Power Systems Protection Lab course as experiments or as part of experiments in the future.

- Load shedding experiment: By using synchronous generator-motor module MSG-3/EV, control board for generating set module GCB-3/EV and SR-5 max/min frequency relays.
- Using static protective relays for protection of generators, Transmission lines and transformers.

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