Self Healing and Restoration in Smart Power Grids

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by

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THESIS CERTIFICATE

This is to certify that the thesis entitled "**SELF HEALING AND RESTORATION IN SMART POWER GRIDS**" submitted by **TEJAVATH JAGADEESH** to the Department of Electrical Engineering, Indian Institute of Technology Madras for the award of the degree of **Master of Technology**, is a bonafide record of the research work carried by him under my supervision. The research work was carried out at the Indian Institute of Technology, Madras.

The content of this thesis, in full or in parts, have not been submitted to any other institute or university for the award of any other degree or diploma.

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ABSTRACT

KEYWORDS: New energy, power grid, smart grid, self-healing, automation, real-time-monitoring, self-adjustment, strategic power infrastructure defence (SPID)

The exploitation of new energy has been a global trend and common task throughout the world in recent years, which will deal with the energy crisis and environmental pollution. Solar energy technology, wind energy technology and other new energy technology have appeared and developed rapidly in this situation.

Most of these new energy resources will be transformed into electricity and join into the power system, which will raise all kinds of safety problems. In order to consume new energy, the power grid has to be updated to a smart grid which is more steady, flexible and compatible.

Having presented the status and development trend of new energy, the differences between new energy and traditional energy are proposed. Despite the advantages of new energy, the safety problems in the power grid caused by new energy are illustrated in detail.

Then the self-healing of the smart grid is important to the development of new energy. And the present situation and key technologies of self-healing are introduced. With self-healing and new energy, the smart grid will be further updated to energy internet. Energy internet will bring sharing economy mode into resource and power areas, which will also support the utilization of new energy.

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CHAPTER-1

1.1 INTRODUCTION

Electricity has become such an essential part of our daily lives, so much that its role is as basic and fundamental as that of food, water, or shelter. Electric energy is used to power up the domestic, industrial and commercial loads as a key source of energy in today's world. The electrical grid is the electrical power system network comprised of the generating plant, the transmission lines, the substation, transformers, the distribution lines and consumer. Despite this, countries across the globe continue to function and expand upon electric power grids that are based on technology dating back to the early twentieth century. With this ageing infrastructure creaking under the pressure of excessive transmission losses and ever-increasing demand for electricity, power grids are long overdue for a revamp.

1.2 CONVENTIONAL POWER GRID

The electric grid is the network through which power is generated, transmitted and distributed to consumers. The electric grid is broadly made up of three main components-generation, transmission or distribution and consumption. There are several key pieces of infrastructure built to avail the supply of electricity to consumers. The electricity is produced in the generating plants. Transmission lines are the infrastructures which allow electricity to be transported or distributed over long distances. In substations, this electricity voltage is increased or decreased. The transformers are the mechanisms which step up or step down the voltage levels. Distribution lines have similar infrastructure as transmission line but for lower voltages of electricity. The grid was created to solve the problem of geographic separation between electricity production and consumption.

Electricity is often produced far from where it is used, so infrastructure needs to be built to connect the two. After electricity is generated the voltage is stepped up at a substation, this voltage increase allows electricity to travel long distances minimizing the amount of electricity loss. The electricity then travels along transmission lines either overhead or underground. Once it reaches its destination another substation steps the voltage down to another level suitable for distribution lines to deliver electricity to consumers. The electric grid provides various consumers with varying needs. For instance, industrial consumers are large facilities like manufacturing plants, commercial consumers are office buildings and residential consumers are individual homes. The electrical grid is one of the most important inventions in our modern world. Prior to the invention of modern grid electricity producers each developed their own distribution systems for delivering electricity to customers.

This system was costly and often underused infrastructure and wasted electricity. The modern grid was invented to allow various producers to share infrastructure for production, distribution which led to increased reliability and lower costs. The centralized nature of the grid has made it an ideal structure for large scale electricity production. However, some of the grid infrastructures are outdated and are not capable of accommodating small scale electricity generation technologies growing demand for efficiently generated power will lead to a significant expansion of global capacities. By the year 2030 decentralized energy systems will account for almost one-half of the additionally required capacities. In global terms, wind and solar power will play a prominent role in this scenario, since the cost of electricity generated from renewables has been reduced as a result of government intervention. Thus, installed capacities have increased significantly since the last WEC in 2013.

The cost of photovoltaic energy fell by 7 percent annually between the year 2000 and 2015. As for offshore wind power, prices are expected to fall by one-third between 2015 and 2020. However, the expansion of renewable energy alone will not be sufficient. Expansion of the existing energy distribution networks into smart grids is essential in order to integrate all sources of energy. Only in this way can the flow of energy in several directions be controlled and fluctuations in supply balanced out by tapping into reserves of stored energy. Presently, the grid is facing a multitude of challenges that can be outlined in four categories. First, there are infrastructural problems due to the fact that the system is outdated and unfit to deal with increasing demand. As a result, network congestions are occurring much more frequently because it does not have the ability to react to such issues in a timely fashion.

Ultimately such imbalances can lead to blackouts which are extremely costly for utilities especially since they spread rapidly due to the lack of communication between the grid and its control centres. A second flaw is a need for more information and transparency for customers to make optimal decisions relative to the market, so as to reduce their consumption during the most expensive peak hours. Finally, a third problem is the inflexibility of the current grid, which can’t support the development of renewable energies or other forms of technologies that would make it more sustainable. In particular, the fact that renewable sources such as wind and solar are intermittent poses a significant problem for a grid that does not disseminate information to control centres rapidly. All of these problems are addressed by the smart grid through improved communications technology, with numerous benefits for both the supply and demand sides of the electricity market. The smart grid is this generation's answer to the electrical grid's shortcomings. Ultimately the concept of the smart grid is raised concerning the drawbacks of the old grid system and the necessity for a new intelligent grid system that has improved reliability, security, and efficiency.

1.3 RESILIENCY IN SMART POWER GRID:

Extreme weather and other natural disasters can threaten lives, disable communities and devastate electric utility generation, transmission and distribution systems. The majority of outage result from damage to the millions of miles of distribution lines. Utilities and their crews have continued to improve disaster response, focusing on upgraded equipment, advanced communications, rapid deployment of staged resources from their own and other utilities and the systematic applications of the lessons learned. However, customers expectation of service reliability has changed dramatically with the evolution of 24/7, digitally connected society. Even with enhanced response and heroic efforts by crews, a restoration that stretches to days or long duration of hours is no longer acceptable. The resilience of the grid is based on three elements: prevention, recovery and survivability

- **Damage prevention:** refers to the application of engineering designs and advanced technologies That hardens the distribution system to limit the damage.
- **System recovery:** refers to the use of tools and techniques to quickly restore service to as many affected customers as possible.
- **Survivability:** refers to the ability to maintain some basic level of electrical functionality to individual consumers or communities in the event of grid disturbance without complete access to the grid.

Distribution management systems:

1. Smart capacitors
2. Reclosers
3. Automated Metering Infrastructure
4. Sensor technology
5. Supervisory control and distribution automation switches

1.4 CONCLUSION:

Generally, the installations were not easy. Many of the participating utilities reported among their lessons learned that the communications capabilities of various system components were not interoperable. The source of the incompatibility was sometimes different versions of rapidly evolving communication standards, but even system components that were said to use the same standard were not easily integrated. Some of the product vendors in the smart grid space, too, were found to be immature companies and were at risk of failing. Sets of skid-mounted battery energy storage systems were installed by two of the project's utilities but were unsupported and abandoned when the products' vendor ran into financial difficulties. Several vendors of small, renewable wind and solar generation systems were unable to deliver their products or delivered products that never generated significant energy.

CHAPTER 2

SELF HEALING IN SMART POWER GRID

2.1 INTRODUCTION

The Smart Grid represents an unprecedented opportunity to move the energy industry into a new era of reliability, availability, and efficiency that will contribute to our economic and environmental health. During the transition period, it will be critical to carry out testing, technology improvements, consumer education, development of standards and regulations, and information sharing between projects to ensure that the benefits we envision from the Smart Grid become a reality. The digital technology that allows for two-way communication between the utility and its customers, and the sensing along the transmission lines is what makes the grid smart. Like the Internet, the Smart Grid will consist of controls, computers, automation, and new technologies and equipment working together, but in this case, these technologies will work with the electrical grid to respond digitally to our quickly changing electric demand.

Today, an electricity disruption such as a blackout can have a domino effect—a series of failures that can affect banking, communications, traffic, and security. This is a particular threat in the winter when homeowners can be left without heat. A smarter grid will add resiliency to our electric power system and make it better prepared to address emergencies such as severe storms, earthquakes, large solar flares, and terrorist attacks. Because of its two-way interactive capacity, the Smart Grid will allow for automatic rerouting when equipment fails or outages occur. This will minimize outages and minimize the effects when they do happen. When a power outage occurs, Smart Grid technologies will detect and isolate the outages, containing them before they become large-scale blackouts.

The new technologies will also help ensure that electricity recovery resumes quickly and strategically after an emergency — routing electricity to emergency services first, for example. In addition, the Smart Grid will take greater advantage of customer-owned power generators to produce power when it is not available from utilities. By combining these 'Distributed Generation' resources, a community could keep its health centre, police department, traffic lights, phone system, and grocery store operating during emergencies. In addition, the Smart Grid is a way to address an ageing energy infrastructure that needs to be upgraded or replaced. It's a way to address energy efficiency, to bring increased awareness to consumers about the connection between electricity use and the environment. And it’s a way to bring increased national security to our energy System—drawing on greater amounts of home-grown electricity that is more resistant to natural disasters and attack

2.2 BENEFITS OF SMART POWER GRID:

The benefits associated with the Smart Grid include:

- More efficient transmission of electricity
- Quicker restoration of electricity after power disturbances
- Reduced operations and management costs for utilities, and ultimately lower power costs for consumers
- Reduced peak demand, which will also help lower electricity rates
- Increased integration of large-scale renewable energy systems
- Better integration of customer-owner power generation systems, including renewable energy system.
- Improved security

2.3 COMPONENTS OF SMART POWER GRID:

Sensor System: Current transformer (CT), Potential transformer(PT), Phasor measurements unit(PMU), smart meter, temperature, pressure, acoustic, and so on mainly

Looking to take the next step in advancing its grid, Orange and Rockland Utilities has been focused on understanding a sensor product from Micatu Inc. The utility sought to place the sensor in the field to collect global positioning system (GPS), time-aligned voltage and current data (minimum, maximum and average) every minute, to compare current transformers (CTs) and potential transformers (PTs) measuring the same photovoltaic (PV) output. The utility wanted long-term testing to be performed on an actual overhead line instead of in a controlled lab setting. The challenge would be to place the lab-grade data collection system in the field, connected to sensors and transformers on live conductors.

Communication Infrastructure: A communication infrastructure is an essential part of the success of the emerging smart grid. Scalable and pervasive communication infrastructure is crucial in both the construction and operation of a smart grid. In this paper, we present the background and motivation of communication infrastructures in smart grid systems. We also summarize major requirements that smart grid communications must meet. From the experience of several industrial trials on the smart grid with communication infrastructures, we expect that the traditional carbon fuel-based power plants can cooperate with emerging distributed renewable energy such as wind, solar, etc, to reduce the carbon fuel consumption and consequent greenhouse gas such as carbon dioxide emission. The consumers can minimize their expense on energy by adjusting their intelligent home appliance operations to avoid peak hours and utilize renewable energy instead. We further explore the challenges for a communication infrastructure as part of a complex smart grid system. Since a smart grid system might have over millions of consumers and devices, the demand for its reliability and security is extremely critical. Through a communication infrastructure, a smart grid can improve power reliability and quality to eliminate electricity blackout. Security is a challenging issue since the on-going smart grid systems facing increasing vulnerabilities as more and more automation, remote monitoring/controlling and supervision entities are interconnected.

Control algorithms:

Wide area monitoring and control microgrid management, distribution load balancing and reconfiguration. Demand response, optimal power flow (OPF), voltage and var optimization (VVO) Fault detection, identification, and recovery (FDIR), automatic.

Actuator System:

HVDC, FACTS, DG, energy storage systems, reclosers, automatic, switches, breakers, switchable shunts, on-load tap changers, hybrid transformers, and so on.

- Energy flow- breaker, switch, dimmer.
- Working condition- valve, break, motor.
- User interface- light, speaker, display.

2.4 COMPARISION OF PRESENT GRID AND SMART POWER GRID:

Table 2.1: comparisons between conventional grid and a smart power grid

CHARACTERISTICS	PRESENT GRID	SMART POWER GRID
Enable active participation by consumers	Consumers are uninformed and non-participative with power system	Informed, involved and active consumers-demand response and distributed energy resources
Accommodates all general and storage options	Dominated by central generation-many obstacles exist for distributed energy sources interconnection	Many distributed energy resources with plug and play convenience focus on renewables
Enables new products, services and markets	Limited wholesale markets, not well integrated-limited opportunities for consumers	Mature, well-integrated wholesale markets, growth of new electricity markets for consumers
Provides power quality for the digital economy	Focus on outages-slow response to power quality issues	Power quality is a priority with a variety of quality/price options-rapid resolution of issues
Optimizes assets & operates efficiency	Little integration of operational data with asset management-business process silos	Greatly expanded data acquisition of grid parameters-focus on prevention, minimizing impact to consumers
Anticipates and responds to system disturbance (Self-heals)	Responds to prevent further damage-focus is on protecting assets following faults	Automatically detects and responds to problems-focus on prevention, minimizing impact to consumers
Operates resiliently against the attack and natural disaster	Vulnerable to malicious acts of terror and natural disasters	Resilient to attack and natural disasters with rapid restoration capabilities

2.5 THE SCENARIO IN INDIA

India has the world's largest single synchronous grid, with around 300 GW of installed capacity and expecting to reach 900 GW by 2032. To enhance the performance and reliability of the grid and also to support technical, economic and social development, India is adopting Smart Grid initiatives like; “Smart Grid Vision and Roadmap for India”, “National Smart Grid Mission”, “Nehru National Solar Mission”, etc. There are several ongoing global efforts that are put across the world for developing Smart Grid. The power industry is embracing higher versions of technology like smart grids to meet the obligations of the 21st century. Like any other technology, Smart Grids also has to face certain technical, social and economic barriers.

Technical challenges are basically bottlenecking in the integration of several devices with a grid network. While the economy is the primary factor for developing any technology, social acceptance also becomes crucial for its success. Considerable acceptance of technological advancements has been achieved in Smart Grids but still, there are issues that need to be addressed. Grid infrastructure is inadequate in several power pockets, cybersecurity is a very complex issue for utilities and other technical issues like storage and stability are also of high importance seeking speedy resolutions which pose greater demand for Smart Grid’s research.

Puducherry has been the site of a successful MoP, Smart Grid pilot designed and implemented by PGCIL in collaboration with the PED. Puducherry falls under the purview of the MNRE's ambitious Solar City program. For the preliminary study, a survey was done for 25 predominantly private, independent home-owners residing in areas covered by the PGCIL-PED Smart Grid pilot.

2.6 SELF HEALING:

A self-healing grid is designed to sense issues and automatically respond to them. It is designed to avert, confine and reduce harm by protecting both the power infrastructure, human beings working on the infrastructure and provide information to allow the right people or systems to make the right decisions at the right time. A self-healing grid uses digital components and real-time communications technologies to monitor its own electrical characteristics at all times and can provide a number of benefits that support a more stable and efficient system. Three of its primary functions include:

Real-time monitoring and reaction: It allows the system to constantly tune itself to an optimal state.

Anticipation: It enables the system to automatically look for problems that could trigger larger disturbances.

Rapid isolation: It allows the system to isolate parts of the network that experience failure from the rest of the system to avoid the spread of disruption and enables a more rapid restoration. As a result of these functions, a self-healing smart-grid system is able to reduce power outages and minimize their length when they do occur. And, because the system is self-healing, it has an end-to-end resilience that detects and overrides human errors that result in some power outages, such as when a worker’s error left millions of California residents without electricity in September 2011. Grid modernization is a global phenomenon but, on any given day in the United States, about a half million people are without power for two or more hours. Two-thirds of weather-related power disruptions have occurred in the past five years, affecting up to 178 million customers (meters) as changing weather patterns impact ageing infrastructure. The country’s electric power system still relies on technology developed in the 1960s and 1970s. the

2.7 CONCLUSION:

The self-healing in smart grid plays a vital role in present days. Since existing power systems

Are working with manual operations and self-healing smart power grids required digital automation. So, of changes happening with self-healing smart power grid.

Two severe power breakouts affected most of northern and eastern India on 30th and 31st July 2012. The 30th July 2012 blackout affected over 300 million people and was briefly the largest power outage in history by a number of people affected, beating the January 2001 blackout in Northern India (230 million affected). At 02:35 IST, circuit breakers on the 400 kV Bina-Gwalior line tripped. As this line fed into the Agra-Bareilly transmission section, breakers at the station also tripped, and power failures cascaded through the grid. All major power stations were shut down in the affected states, causing an estimated shortage of 32 GW. The blackout on 31st July is the largest power outage in history. The outage affected more than 620 million people, about 9% of the world population, or half of India's population, spread across 22 states in Northern, Eastern, and Northeast India. The system failed again at 13:02 IST, due to a relay problem near the Taj Mahal. As a result, power stations across the affected parts of India again went offline. NTPC Ltd. stopped 38% of its generation capacity. An estimated 32 gigawatts of generating capacity was taken offline. An article in The Wall Street Journal stated that of the affected population, 320 million initially had power, while the rest lacked direct access. Electric service was restored in the affected locations between 31st July and 1st August 2012.

CHAPTER 3
FAULT LOCATION ISOLATION AND SERVICE RESTORATION

3.1 INTRODUCTION:

Fault location, isolation, and service restoration (FLISR) technologies are one of the distribution automation (DA) tools SGIG projects are deploying to provide operators greater visibility into disturbances and automatically reroute power to reduce the number of affected customers from downed power lines, faults, or other disturbances. In addition to fewer and shorter outages for customers, FLISR technologies help utilities improve their standard reliability metrics, such as the System Average Interruption Frequency Index (SAIFI) or System Average Interruption Duration Index (SAIDI). In many states, improvements in these metrics are tied to utility financial incentives, often through performance standards or performance-based rates. This section provides an overview of how FLISR technologies improve reliability.

3.2 WHAT IS FLISR:

Fault location, isolation, and service restoration (FLISR) include automatic sectionalizing and restoration, and automatic circuit reconfiguration. These applications accomplish DA operations by coordinating the operation of field devices, software, and dedicated communication networks to automatically determine the location of a fault, and rapidly reconfigure the flow of electricity so that some or all of the customers can avoid experiencing outages. Because FLISR operations rely on rerouting power, they typically require feeder configurations that contain multiple paths to single or multiple other substations. This creates redundancies in power supply for customers located downstream or upstream of a downed power line, fault, or other grid disturbance.

3.3 HOW DOES FLISR RESULT IN FEWER AND SHORTER OUTAGES:

Figure 3.1 represents simplified examples (A-D) to show how FLISR operations typically work. In Figure 1-A, the FLISR system locates the fault, typically using line sensors that monitor the flow of electricity and measures the magnitudes of fault currents, and communicates conditions to other devices and grid operators.

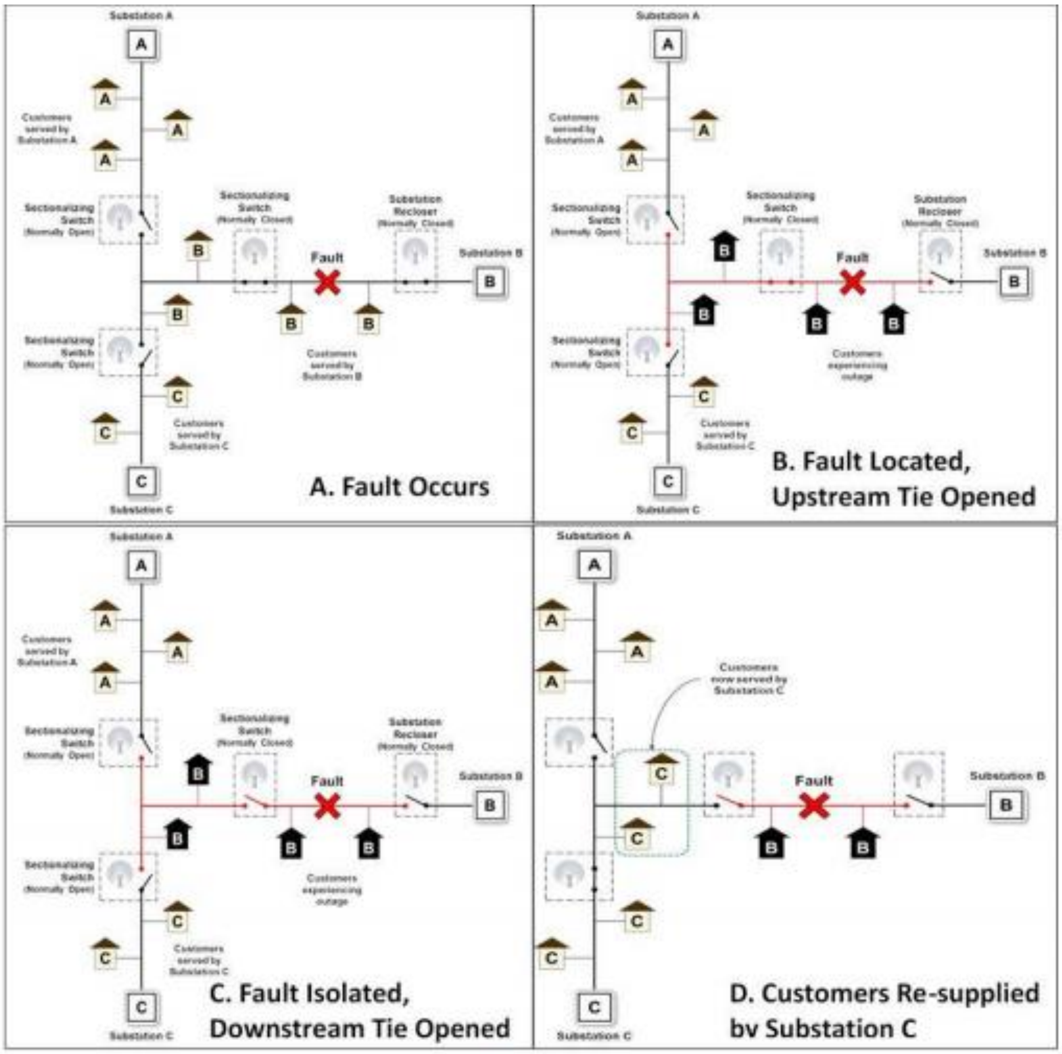

Figure 3.1 Schematic illustrations of FLISR Operation

Once located, FLISR opens switches on both sides of the fault: one immediately upstream and closer to the source of power supply (Figure 1-B), and one downstream and further away (Figure 1-C). The fault is now successfully isolated from the rest of the feeder. With the faulted portion of the feeder isolated, FLISR next closes the normally-open tie switches to the neighbouring feeder(s). This re-energizes un-faulted portion(s) of the feeder and restores services to all customers served by these un-faulted feeder sections from another substation/feeder (Figure 1-

D). The fault isolation feature of the technology can help crews located the trouble spots more quickly, resulting in shorter outage durations for the customers impacted by the faulted section.

FLISR systems can operate autonomously through a distributed or central control system (e.g., DMS), or can be set up to require manual validation by control room operators. Implementing autonomous, fully automated FLISR systems typically requires extensive validation and calibration processes to ensure effective and reliable operations. Automated FLISR actions typically take less than one minute, while manually validated FLISR actions can take five minutes or more. Two standard reliability metrics are typically used to evaluate FLISR operations:

1) The number of customers interrupted (CI), and

2) The number of customer minutes of interruption (CMI). Both of these metrics are components of the equations that are used to calculate SAIFI and SAIDI. CI is a measure of the number of customers interrupted by an outage. CMI is a measure of the duration of interruptions experienced by customers. The avoided CI and CMI can be used to measure the benefits of FLISR operations. It is important to note that FLISR does not avoid outages but works to minimize their impacts on customers when they do occur.

3.4 DISTRIBUTED AUTOMATION:

Distribution automation (DA) holds the rightful position as the foundation of a smart grid. This article starts by explaining transmission and DA. It then moves to a detailed definition of DA and its components. Understanding these components is important to appreciate what it takes to implement them. The components of DA drive a clear understanding of how DA is implemented in all of its forms and also which components of the smart grid are a part of this portfolio of capabilities. The dos and don'ts of DA section focuses on key considerations that need to be kept in mind as utilities worldwide focus on their own mechanisms for implementing DA in their grid. DA will form the underlying driver for the smart grid for the next 10+ years.

As the control of the grid becomes more complex, it is DA that provides the eyes, arms and legs to the utility and other operators to continue their path to a reliable and resilient grid. The grid today gets many attacks, some weather-related (storms, hurricanes and others) and some man-made (car hits an electric pole and the more recent cyber-security attacks as well). Most of these impact the grid in the form of outages which mean loss of power. This loss of power can be localized (e.g. one house or a block of houses), medium-sized (e.g. a neighbourhood or major parts of a city) or widespread (e.g. regional such as the 2003 blackout in the Northeast United States). It is believed that there would be more of these and the grid resiliency (the ability to recover readily from major attacks such as the ones identified above – a new term that is being used a lot) will become more and more of an issue in the future. Innovations in the smart grid arena are also resulting in the grid getting new distributed energy resources (DERs) components which include storage, distributed renewables (solar, wind and others), micro-grids and so on.

In the wake of the smart grid, the networks are increasingly being transformed from analogue-to-digital systems through the wide-spread deployment of intelligent electronic devices (IEDs). IEDs are the foundation of Transmission &Distribution automation and are used to control equipment such as circuit breakers, relays, transformers and capacitor banks. Examples of transmission-level automation technologies include phasor measurement units (PMUs), digital protective relays, and digital substations and so on.

Phasor Measurement Unit (PMU) is the most significant device provides information about the voltage and current phasor for observability of system in the future smart grid. A smart meter is one of the most important devices used in the smart grid (SG). The smart meter is an advanced energy meter that obtains information from the end users' load devices and measures the energy consumption of the consumers and then provides added information to the utility company and/or system operator. Several sensors and control devices, supported by dedicated communication infrastructure, are utilized in a smart meter. This paper outlines some smart meter's aspects and functions of the smart meter. In addition, it introduces two basic types of smart meter system's communication technologies: Radio Frequency (RF) and Power Line Carrier (PLC) and recent advances with regard to these two technologies. This paper also presents different policy and current status as well as future projects and objectives of SG development in several countries. Finally, the paper compares some main aspects of the latest products of smart meter from different companies.

3.5 FAULT DETECTION, ISOLATION AND SERVICE RESTORATION:

Fault Detection, Identification and Restoration (FDIR) is a class of technologies whose goal is to identify the occurrence of a fault, record the occurrence, determine the fault location, and aid in the restoration process. It is a combination of advanced DMS & OMS systems, as well as a close integration of feeder level assets with the Demand Management System. FDIR systems can also use automated switching e.g. reclosers, sectionalizers and switches, to help minimize the number of customers affected by a fault.

The FDIR system is tightly integrated with the Demand Management System so that measured values from the shunt capacitors, recloses, and sectionalizers are available for determining the location of the fault. Additionally, the capability exists to automatically reclose switches, reclosers and sectionalizes, which further reduce the length of the outage. The net result is that the system operates with recloses and sectionalizes and when a fault does occur, the time required to identify and locate the fault is reduced by 30%.

- The primary benefit of the implemented FDIR is increasing reliability; it does not affect the peak load or annual energy consumption except by the isolation of system faults.
- When coordinated with reclosers, sectionalizers, and the DMS & OMS, the FDIR system is one of the most effective ways to increase the reliability of a distribution feeder.
- Because of the significant amount of equipment that must be deployed, a fully coordinated FDIR system is only necessary on systems with low reliability. Broadly, two technology components are required to provide FDIR capabilities. These are field devices and algorithms.
- Field devices consist of sensors and switches - Sensors detect issues on the network, while switches are used to control the power flow in the network.
- Algorithms are the mathematical logic that guides the switching activities when isolating equipment on the network. Switching actions proposed by software algorithms could be applied by a system and/or human operator.

3.6 CONCLUSION:

1. Fault location, isolation, and service restoration (FLISR) are quickly becoming one of the hottest applications in distribution automation.

2. Utilities including Southern California Edison, Southern Company, and San Diego Gas and Electric are transitioning FLISR projects from pilots to large-scale rollouts. FLISR is a distribution automation application that networks groups of switches on a feeder to vastly improve the reliability of utility-delivered power by “localizing” outages. Localizing restores power to the majority of an affected circuit, minimizing interruptions to the customers on the faulted portion of the line between the two most local automated switches.

3. FLISR applications can utilize decentralized, substation, or control canter intelligence to locate, isolate, reconfigure, and restore power to healthy sections of a circuit. Each FLISR approach has benefits and drawbacks.

CHAPTER 4
SYSTEM UNDER STUDY

4.1 INTRODUCTION:

SINGLE LINE DIAGRAM FOR MATLAB MODEL

Distance protection is the most widely used method to protect transmission lines. The fundamental principle of distance relying is based on the local measurement of voltages and currents, where the relay responds to the impedance between the relay terminal and the fault location. There are many types of distance relay characteristic such as mho, reactance, admittance, quadrilateral polarized- mho, offset mho etc. Every type of characteristics has different intended function and theories behind.

In order to understand the function of relays, software relay models must be realized, modelling of protective relays offer an economic and feasible alternative to studying the performance of protective relays. Relay models have been long used in a variety of tasks, such as designing new relaying algorithms, optimizing relay settings. Electric power utilities use computer-based relay models to confirm how the relay would perform during systems disturbances and normal operating conditions and to make the necessary corrective adjustment on the relay settings. One of the worldwide recognized, powerful analysis software package, is a MATLAB/SIMULINK, which has the capability for modeling, simulating, and analyzing dynamic systems using Sim-Power Systems toolbox, inside Simulink package, different parts of a system such as three-phase transformer, three phase load, distributed parameters line, circuit breaker, etc. can be used for AC and DC applications.

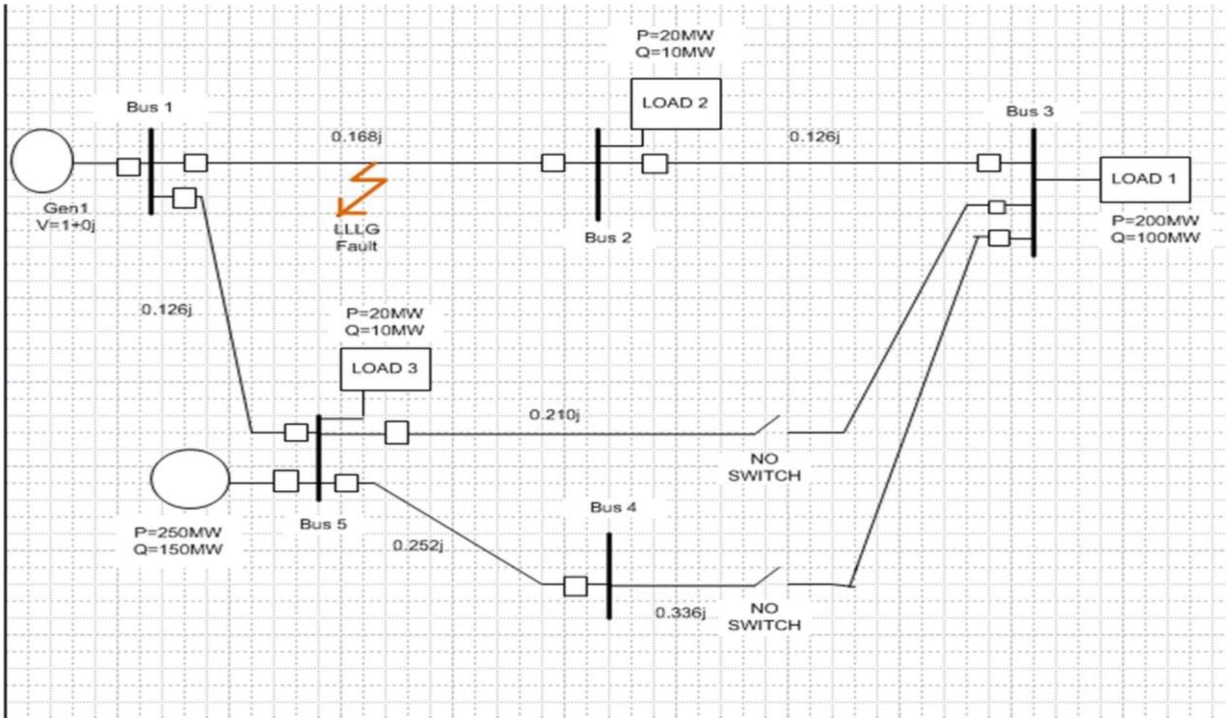

Fig 4.1: Network under study (Single line diagram)

4.2 DESCRIPTION & ALGORITHM:

The network under study consists of two generators, with an overall power supplying capacity of 250 MW and 150 MW. There are three loads present with an overall demand of 240 MW and 70 MW. The pi- model transmission lines are used. The bus bars are equipped with current and voltage measurement. Each line is equipped separately by two main circuit breaker at the sending and receiving ends. The parameters of the power system model, generator, line and load data are shown in the table below.

Algorithm system is mainly for generator model, line and load model of the power systems

Single line diagram represents the number of bus and load connections.

Generator data:

Table 4.1: Generator data

GENERATOR 1	V=1+0j	Z=0.111j(pu)
GENERATOR 2	P=250MW Q=150MW	Z=0.111j(pu)

Base MVA=100MVA, Voltage Base=11kV

Line data:

FROM BUS	TO BUS	IMPEDANCE(pu)
1	2	0.168j
2	3	0.126j
1	5	0.126j
5	3	0.210j
5	4	0.252j
4	3	0.336j

Table 4.2: Line Data

Load data:

Table 4.3: load Data

BUS	LOAD
3	Load 1 : P=200 MW Q=50 MW
2	Load 2: P=20 MW Q=10 MW
5	Load 3: P=20 MW Q=10 MW

The above tables represent generator, line and load models to calculate their impedance values.

The above Table shows the different algorithm used to compute the apparent impedance at the relay location for various type of fault. An illustration of computed impedance line to line fault is developed in SIMULINK environment.

ALGORITHM

Table 4.4: Fault Impedance Algorithm for various fault types

FAULT TYPE	ALGORITHM
ABC or ABCG	(Va/Ia) or (Vb/Ib) or (Vc/Ic)
AB or ABG	(Va-Vb)/(Ia-Ib)
AC or ACG	(Va-Vc)/(Ia-Ic)
BC or BCG	(Vb-Vc)/(Ib-Ic)
AG	Va/(Ia+k*I0)
BG	Vb/(Ib+k*I0)
CG	Vc/(Ic+k*I0)

Where:

A B and C indicates faulty phases, G indicates ground

fault. Va, Vb and Vc indicate voltage phases

Ia, Ib and Ic indicate current

phases Z0 = line zero-sequence

impedance

Z1 = line positive-sequence impedance

Vs is phase voltage during the phase to ground fault

K1= residual compensation factor where k0 = (Z0-Z1)/KZ1. K can be 1 or3 depend on the relay design.

I0 = (Vs / Z0+2Z1)

Vs is phase voltage during the phase to ground fault.

(From reference 3)

4.3 MATLAB MODELS FOR VARIOUS BUSES:

The relay model developed in SIMULINK is integrated with the power system model in the MATLAB/SIMULINK is shown below:

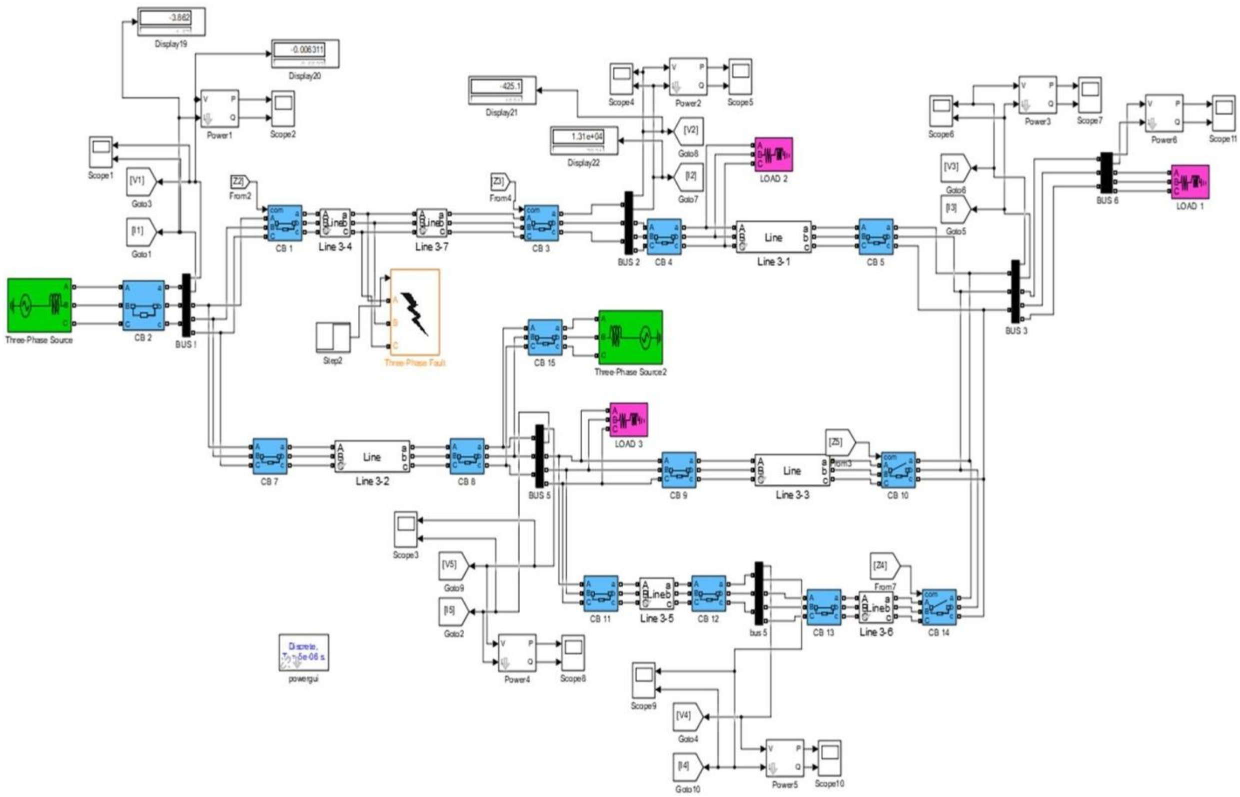

Fig 4.2: Simulink model of the distribution network under study

Table 4.1 shows the different algorithm used to compute the apparent impedance at the relay location for various type of fault. An illustration of computed impedance for LLLG fault is developed in SIMULINK environment, shown in fig 4.3. (From reference 9)

The relay model developed in SIMULINK is integrated with the power system model in the MATLAB/SIMULINK is shown below:

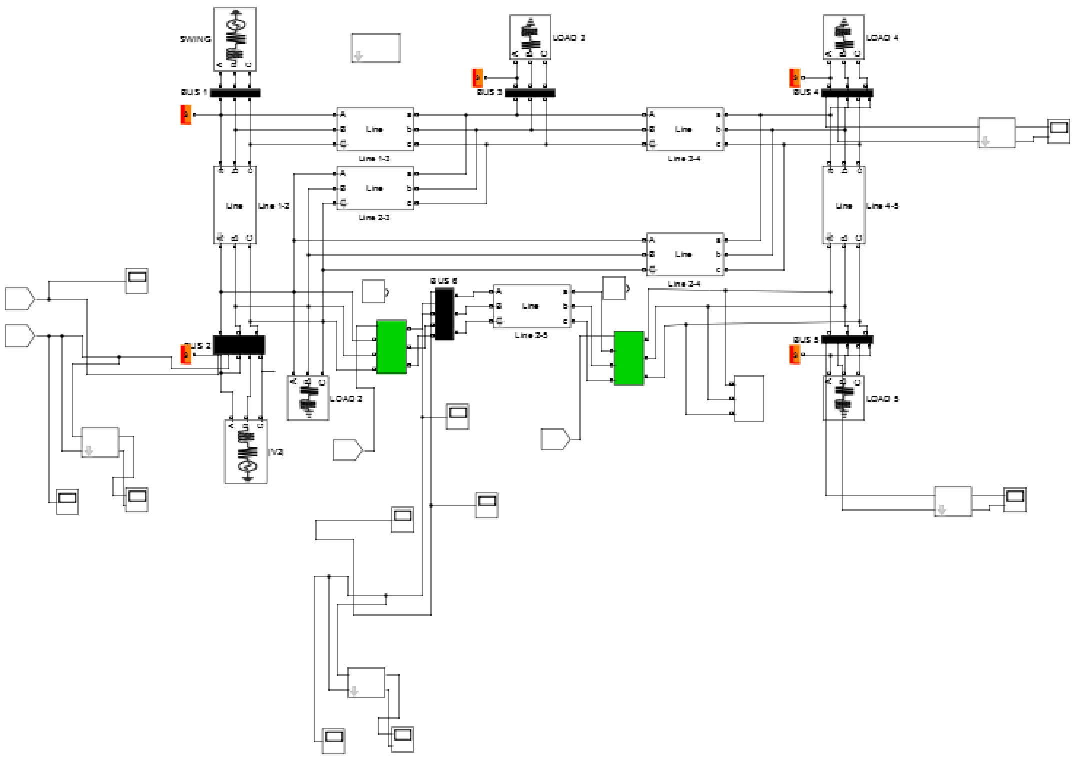

Fig 4.3: Simulink model of the distribution network under study with one fault location

The relay model developed in SIMULINK is integrated with the power system model in the MATLAB/SIMULINK is shown below:

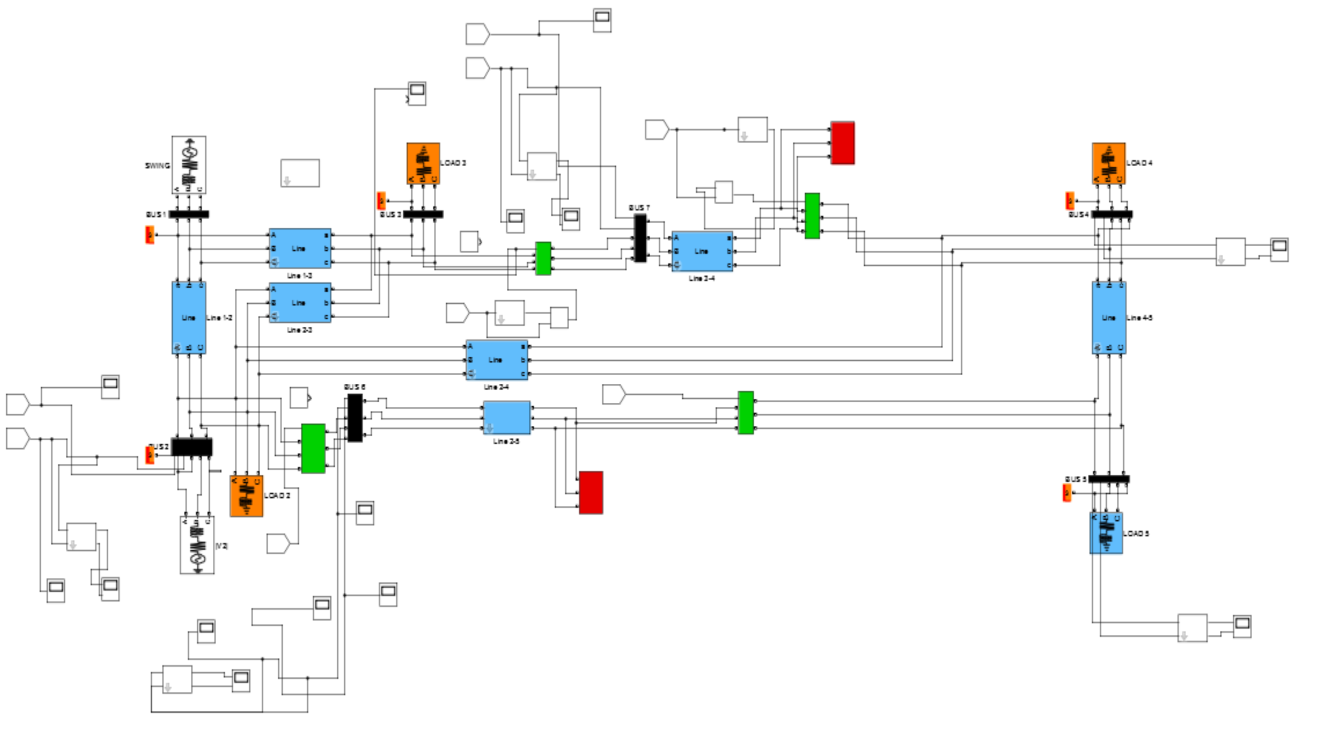

Fig 4.4: Simulink model of the distribution network under study with multiple fault location

IMPEDANCE CALCULATION: FOR 9 BUS MODEL WITH TRIPPING SIGNALS

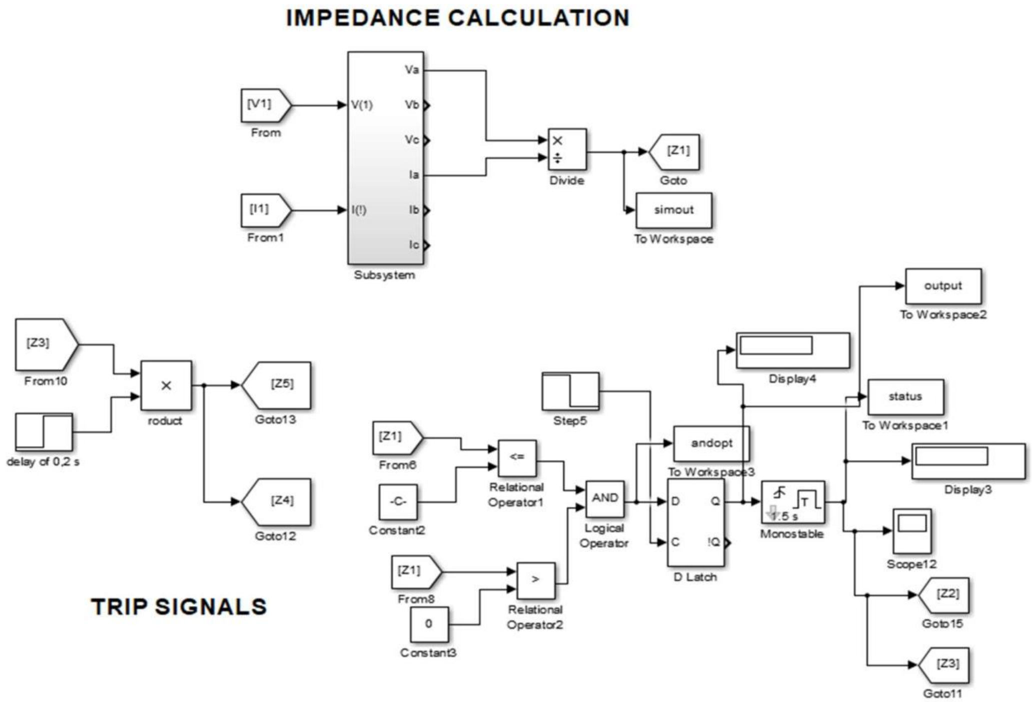

Fig 4.5: Impedance calculation for line to line fault

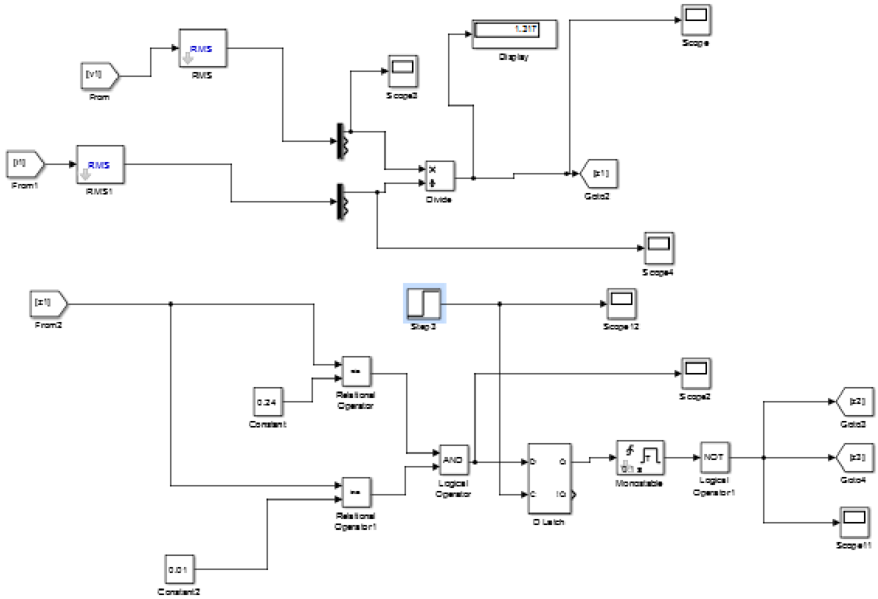

Figure 4.6 Impedance calculations for line 2-5

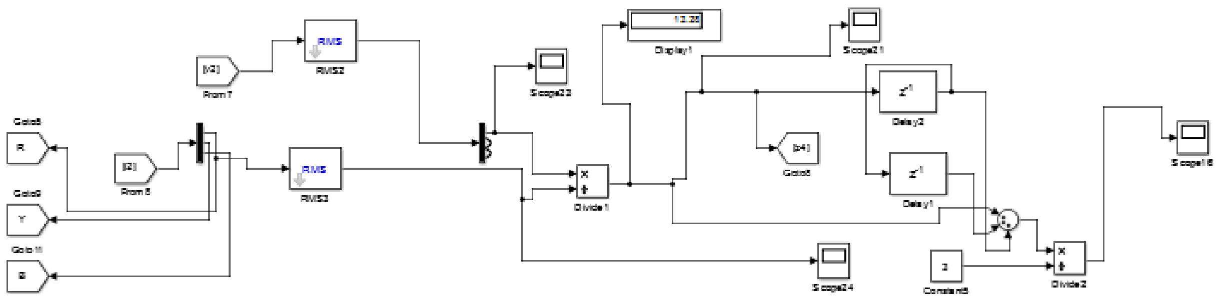

Fig 4.7: (a) Impedance calculation for line 3-4

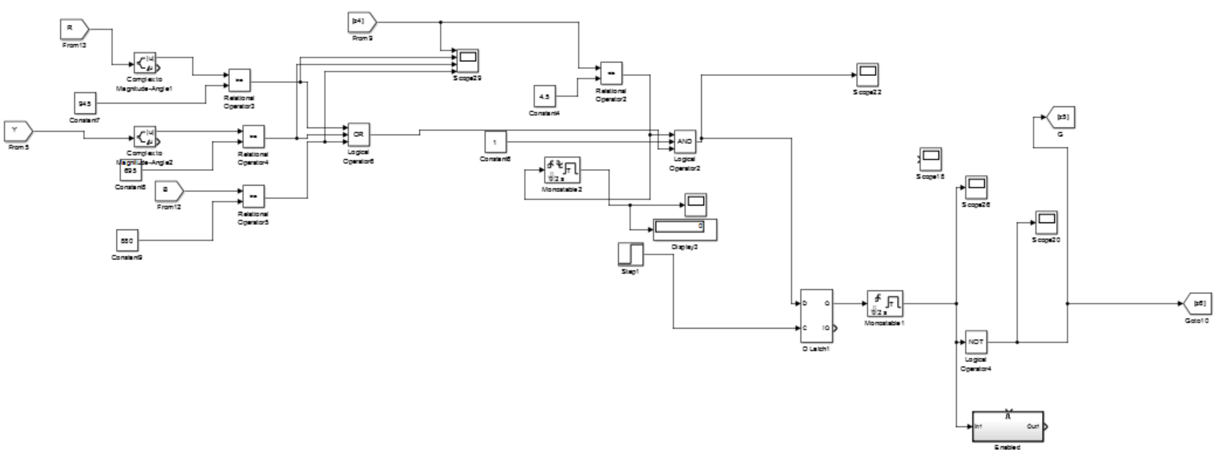

Fig 4.7: (b) Impedance calculation for line 3-4

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4.4 SIMULATION RESULTS:

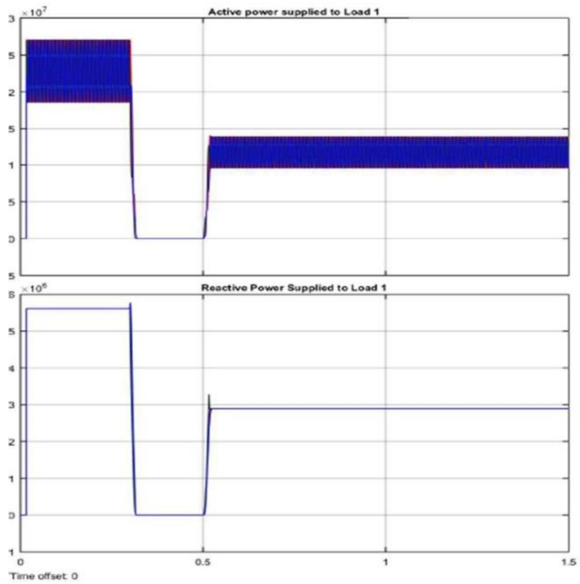


Fig 4.8: Active and Reactive Power versus Time for Load 1

(At time t=0.3 sec, the fault occurs and the line between bus 1 & 2 opens, resulting in interruption of power supply. After 0.2 sec the NO switches close and thus power is restored)

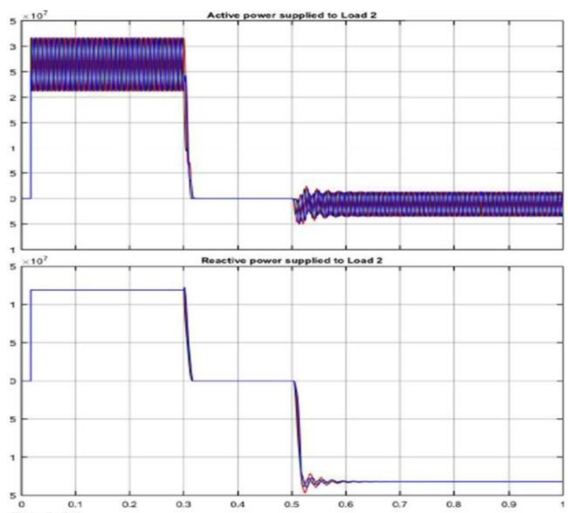


Fig 4.9: Active and Reactive Power versus Time for Load 2

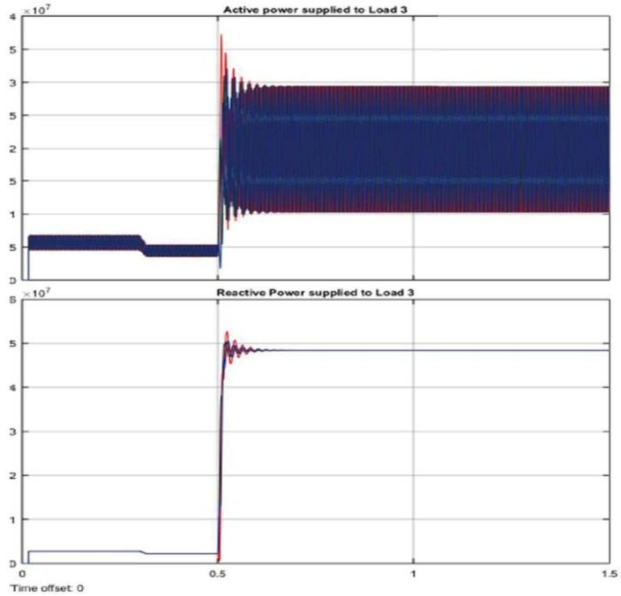


Fig 4.10: Active and Reactive Power versus Time for Load 3

(Before the fault, power is supplied by gen2, after 0.5 sec as NO switches closed, power supplied by both gen 1 & 2)

4.5 CONCLUSION:

A three-phase to ground fault occurs at 0.3 sec on the line between bus 1 and 2. By using distance protection, the fault is sensed and the circuit breakers CB1 and CB3 trip. Meanwhile, CB12 and CB14, which are initially in Normally Open state, are sent a trip signal after a delay of 0.2 seconds and thus change their status. In this way, by switching of redundant paths, the loads experience an interruption of power, only for a duration of 0.2 sec and hereby the power is restored again. The line between bus 1 and bus 2, that is the faulted line, is isolated and the power to load 1 and load 4 is restored by switching of breakers, thus introducing a redundant path for the power flow, thus maintaining uninterrupted power supply. The delay of 0.2 seconds is just given taking into consideration the time required for the carrier wave to carry the information, in carrier aided distance protection.

The same above point holds good for three-phase faults can occur in Standard 5 BUS Model with one fault location and with multiple fault locations. In case of this Standard 5 bus model, we are mostly checking fault measurement between bus 2-5 and bus 3-4. With different time locations.

At 0.3sec 3Ø fault occurring by the algorithm then appropriate tripping done.
Power is becoming zero at 3Ø faults. After circuit breaker tripping power is restored with lower values and it will come to the original position.

From the above results obtained, at the instance of fault that is at t=0.3 seconds, the supply to the loads 1 &2 is interrupted, while load 3 is supplied by generator 1 & 2. The lines between bus 5 &3 and 4 & 3 come into picture as the switches change their status from normally closed to normally open, thus it is seen that power is restored to loads 1 & 2, after an interruption time of 0.2 seconds, thus maintaining almost uninterrupted power supply to the loads by switching of redundant paths.
It is observed that the impedance measured initially is varying due to the transient effect. Thus, to remove this effect and thus to prevent the false tripping of the circuit breakers, a delay is introduced, wherein the impedance measurement will after the transients have passed by. This helps to measure the impedance without any error.

CHAPTER 5

5.1 INTRODUCTION

STANDARD IEEE 5 BUS MODEL WITH SIMULATION RESULTS:

A load flow study should be performed during the planning design stages of a power system and when evaluating changes to an existing system. A load flow study calculates the voltage drop on each feeder, the voltage at each bus, and the power flow and losses in all branch and feeder circuits.

DC power flow is a commonly used tool for contingency analysis. Especially the implementation of power flow controlling devices is not trivial since standard DC power flow fundamentally neglects their effects.

Power systems analysis is a critical part of any transmission or distribution system. Using physical properties of a system to perform calculations on how the entire system behaves is paramount to not only the design, but the maintenance and care of such a system.

This report does such calculations from provided data on a 5-bus system. Additionally, fault analysis are performed for two types of faults: having a three-phase symmetrical bus fault to ground, and having a symmetrical fault on a line between two buses that results in the line being taken out of service.

The latter fault is very important and is used to determine what would happen to not only the stability of the system, but also the overall effect on load flow to each remaining line in service.

IEEE 5-Bus System Single Line Diagram

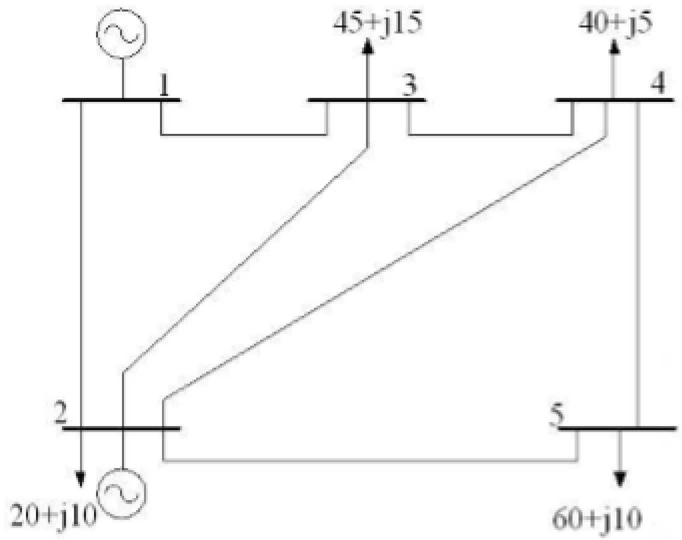


Figure 5.1: IEEE 5 Bus system single line diagram

Table 5.1: Generator Bus Voltage and angle for 5 Bus system

BUS	VOLTAGE	P.U	DEGREE
1	10eV	1.06pu	0
2	10eV	1.047pu	-2.806
3	10eV	1.024pu	-4.997
4	10eV	1.024pu	-5.329
5	10eV	1.018pu	-6.15

Table 5.2 : Line data of RL and Susceptance

Line	Frequency	Resistance	Inductance	Susceptance
1-2	60Hz	0.02pu	0.06	0.03
1-3	60Hz	0.08pu	0.24	0.024
2-3	60Hz	0.06pu	0.18	0.02
2-4	60Hz	0.06pu	0.18	0.02
2-5	60Hz	0.04pu	0.12	0.015
3-4	60Hz	0.01pu	0.03	0.01
4-5	60Hz	0.08pu	0.24	0.025

Table 5.3: Load Active and Reactive power

Load	Vrms	Active power(w)	Q_L (VAr)	Q_C (VAr)	Frequency (Hz)
5	1.06	60 e^6	10 e^6	0	60
4	1.047	40 e^6	5 e^6	0	60
2	1.0242	20 e^6	10 e^6	0	60
3	1.0236	45 e^6	15 e^6	0	60

5.2 RELAY SETTING CALCULATION & IMPEDANCE CALCULATION:

For calculation of fault current, the system is further simplified as follows:

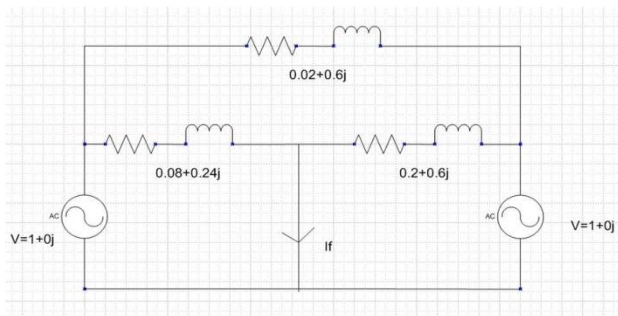
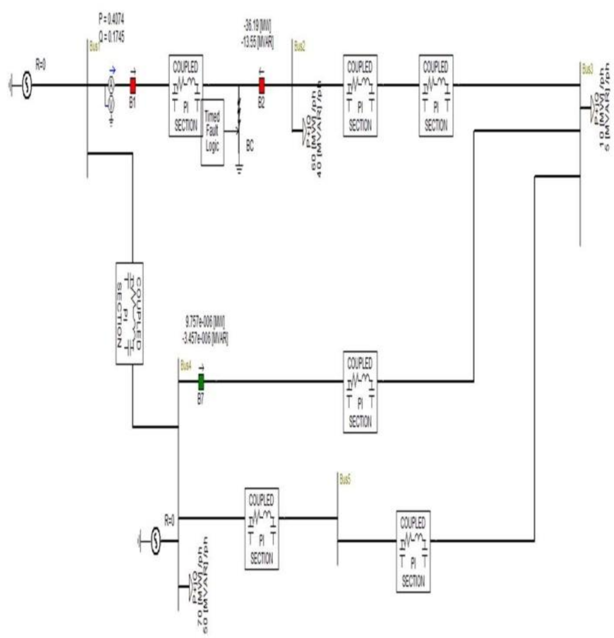


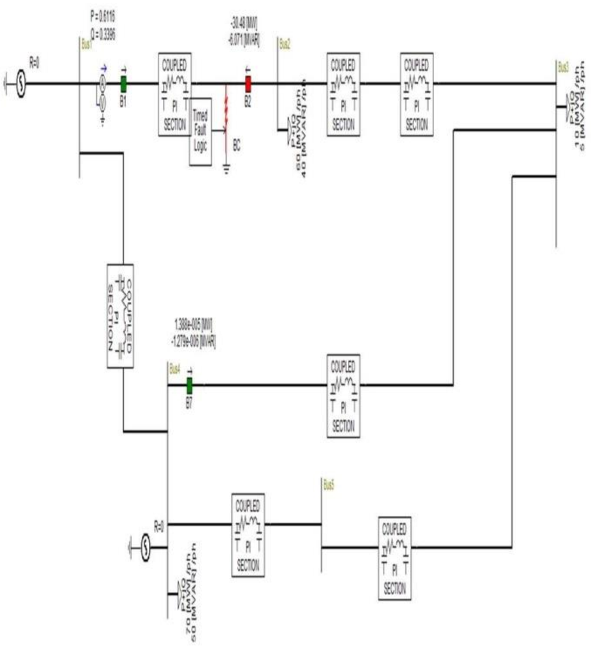
Fig 5.2 Simplified Networks

Solving the above network, the fault current turns out to be 30.59 kA. Thus, we get the impedance as 0.3. Thus, we keep the threshold value for relay 1 as 0.3, which can be seen in the impedance measurement system shown below.

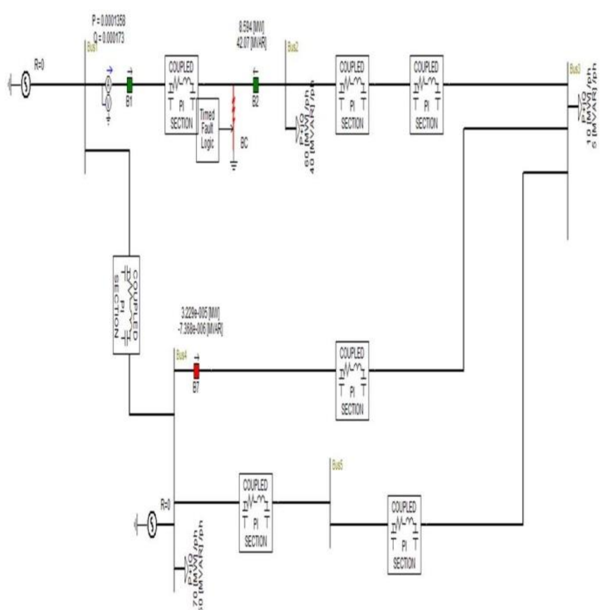
And above network consists of resistances and inductance which are connected in series and current source is connected in series and voltage source is connected in shunt.

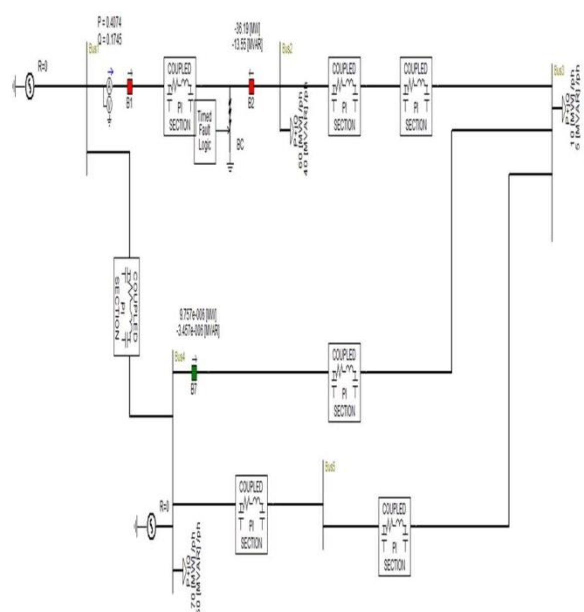
5.2.1 RESULTS & EVENT DIAGRAM:





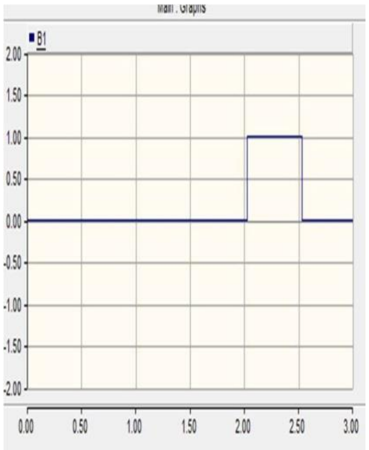
Event 1: At t=0 sec(System under normal condition) Event 2: At t=2 sec(Fault occurs and B1 opens)





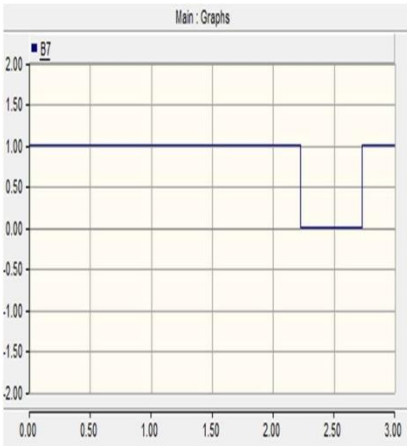
Event 3: At t=2.2 sec (after delay of 0.2 sec, B2 opens) Event 4: At t= 2.5 sec (fault cleared & system retains original configuration)

The trip signals for breakers B1, B2 and B7 are as follows:



Trip signal to B1

Trip signal to B2



Trip signal to B7

5.3: CASE-I GENERALIZED SYSTEM WITH ALL RELAYS PROGRAMMED:

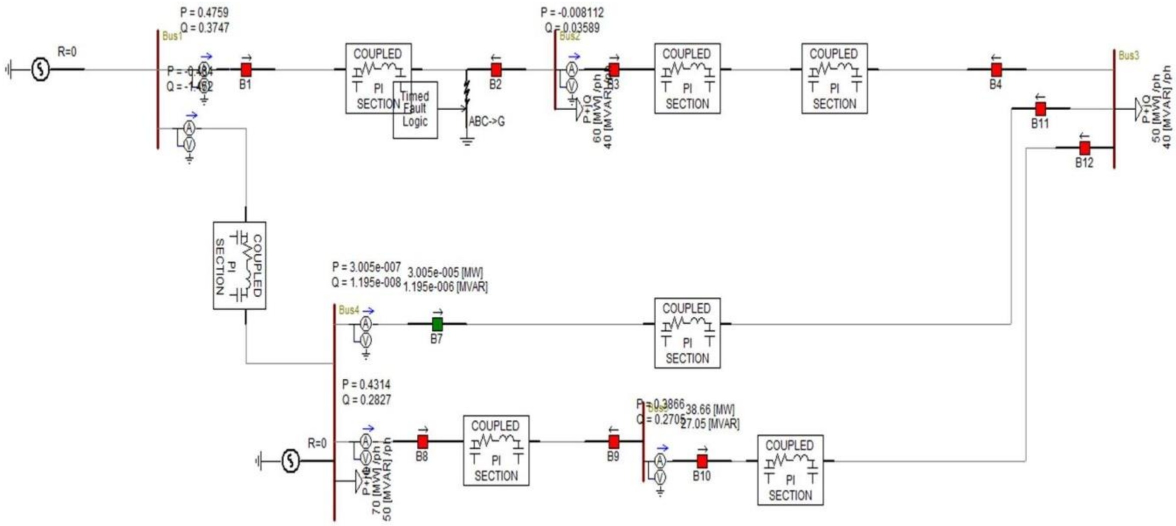
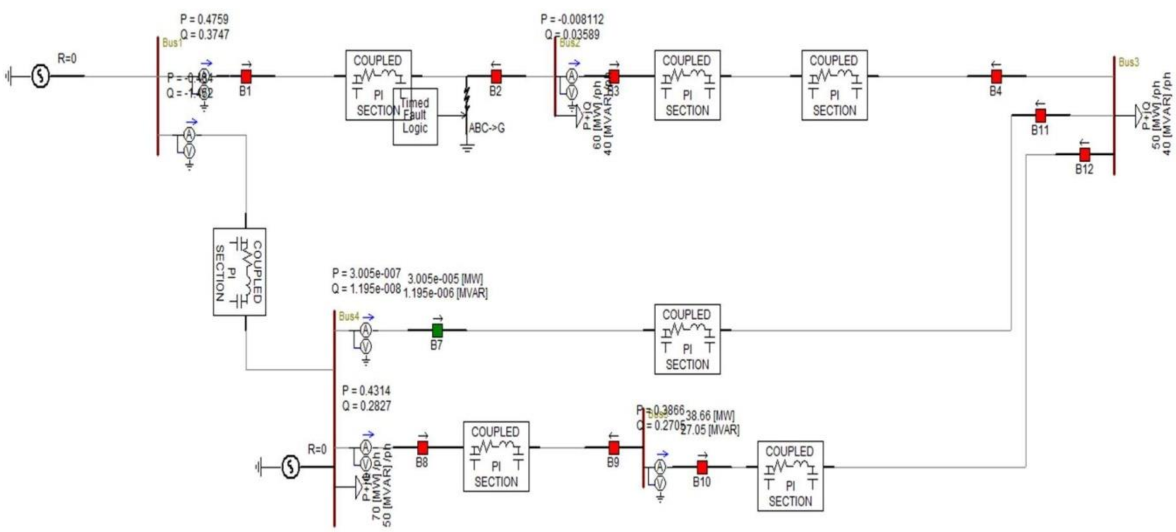


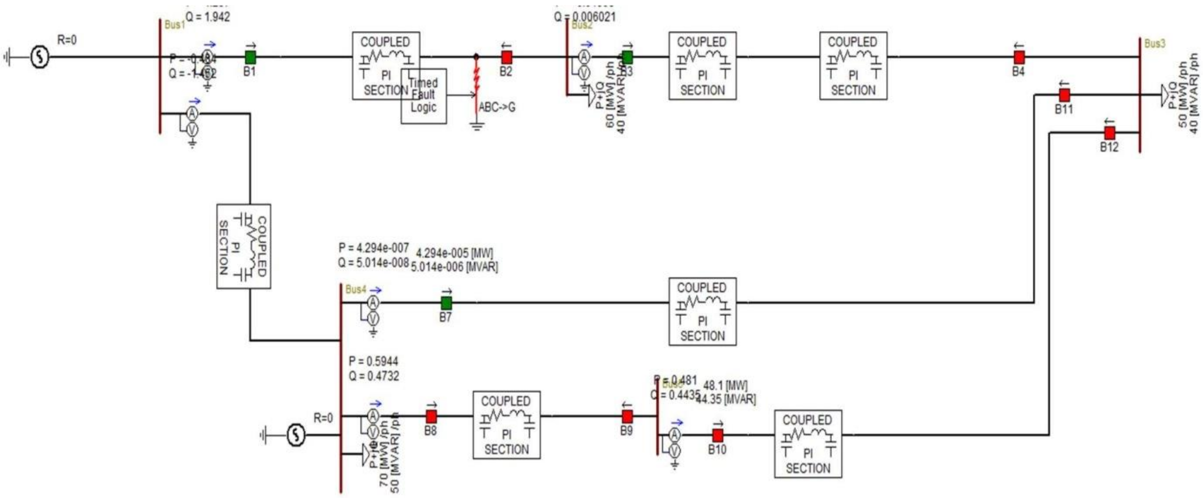
Fig 5.3: Network under study: Case II

In the above network, when a fault occurs at 2 sec at the end of line between buses 1 & 2. For the impedance measurement system, set value is entered for each relay. When fault occurs at 2 sec, the relay B1 opens, sending signal to B2 to open and B7 to close, after a communication delay of

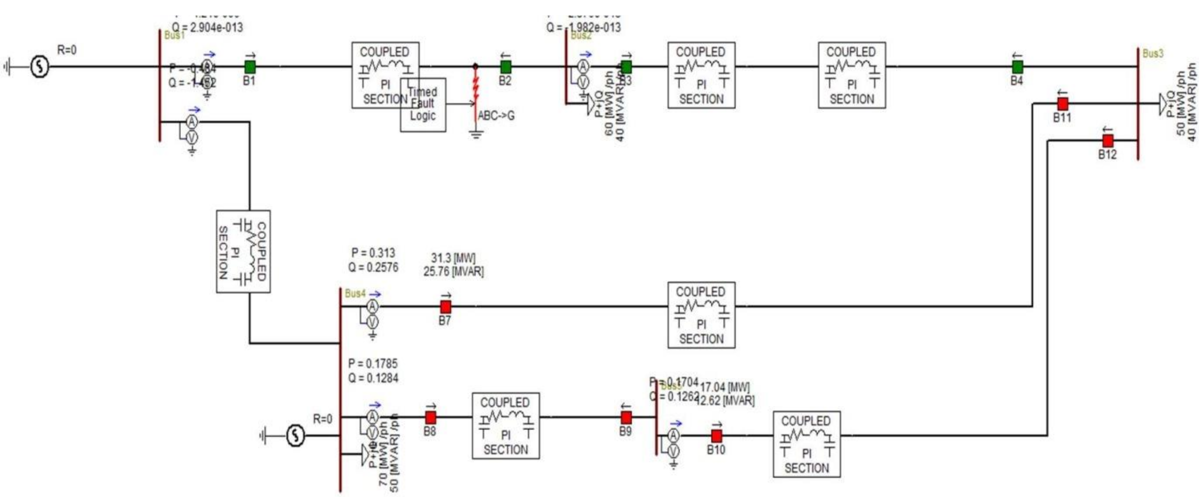
0.2 sec. at t=2.2 sec, line between buses 1 & 2 is isolated and this creates a sudden disturbance Thus in the voltage and current measured by relay 2 at bus 2. This causes a sudden decrease in the impedance measured by relay 2, whose value goes below the relay setting value and thus results in mal-operation of relay 2 and isolation of line 2 between buses 2 & 3. The events are shown as below:



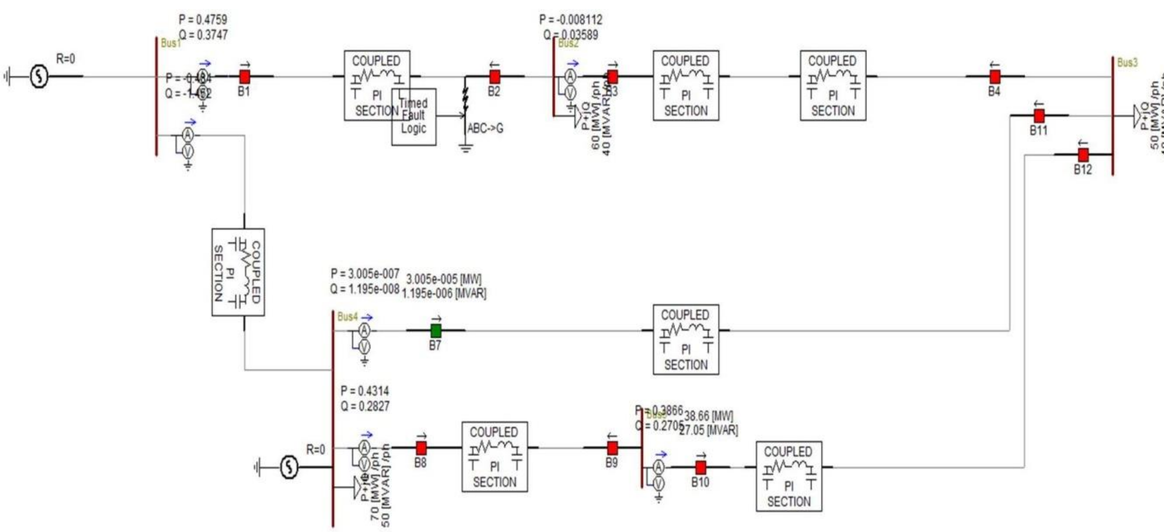
System under study case-2



Event 2: At t=2 sec (Fault occurs and B1 opens)



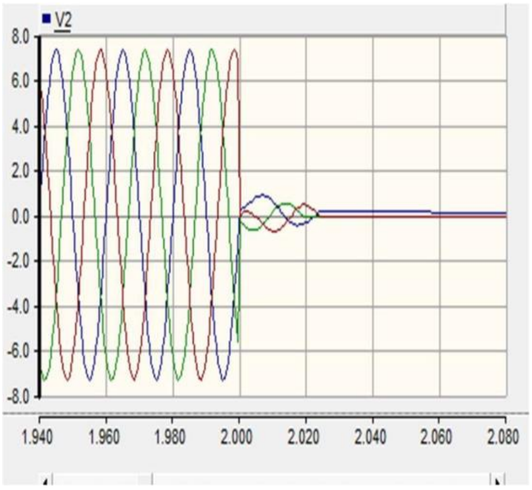
At t=2.2 sec (trip signal sent to B2 and faulted line isolated)



At t= 2.5 sec (fault cleared and system retains original configuration)

5.4 SIMULATION RESULTS:

The voltage & current measured at bus 2 by relay 2 are illustrated as follows:



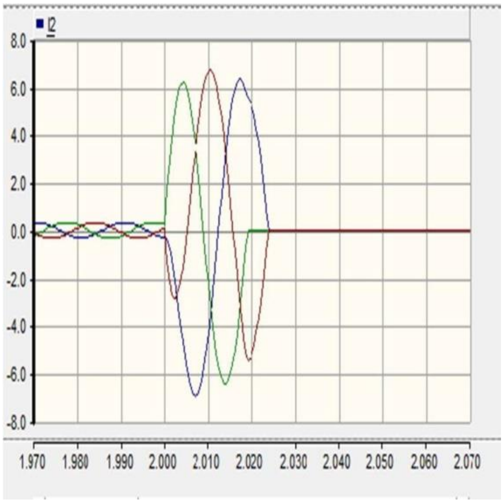


Fig 5.4: Voltage measured by relay 1

Fig 5.5: Current measured by relay 1

Due to these disturbances in the voltage and current measured, the impedance is suddenly decreased as shown below:

Fig 5.6: Impedance measured by relay 2 vs time

5.5 STANDARD IEEE 5 BUS MATLAB MODEL SIMULATION RESULTS

Simulation results for standard 5 Bus model with one fault location (Line 2-5):

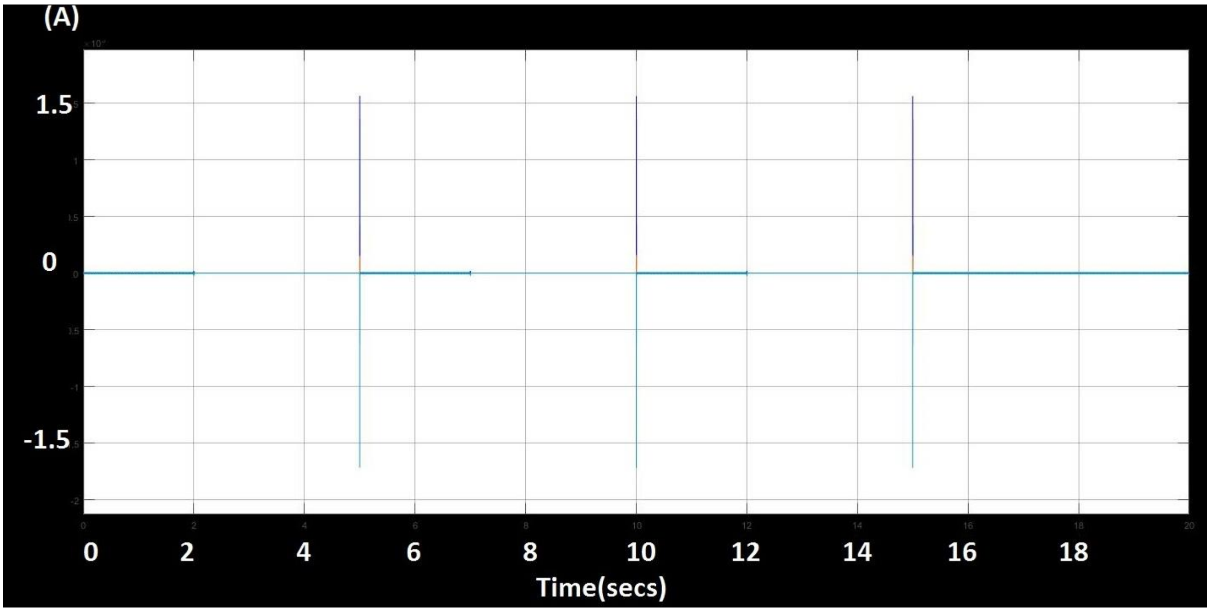


Fig 5.7: Tripping line current value between line 2-5

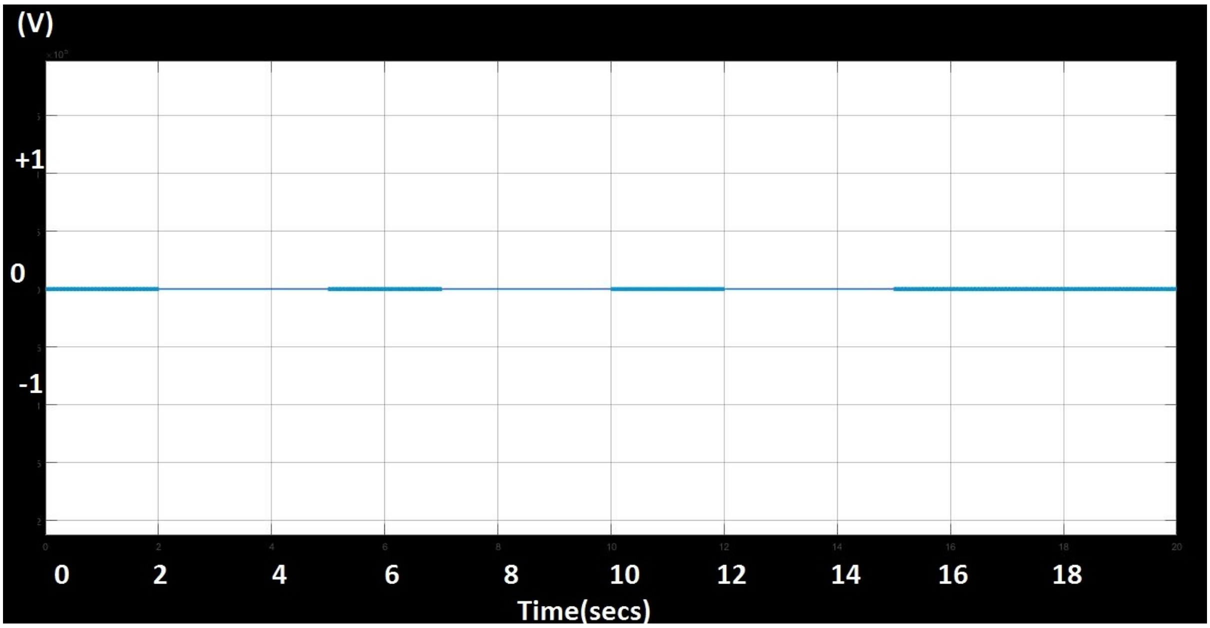


Fig 5.8: Tripping line voltage value between line 2-5

ACTIVE AND REACTIVE POWERS

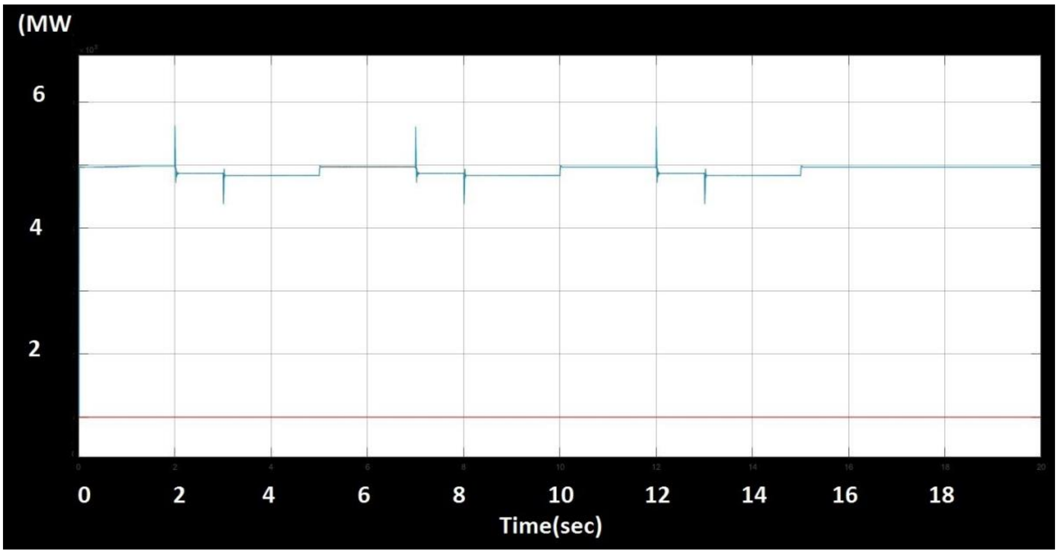


Fig 5.9: Load-1 Active and reactive powers- at Bus 2

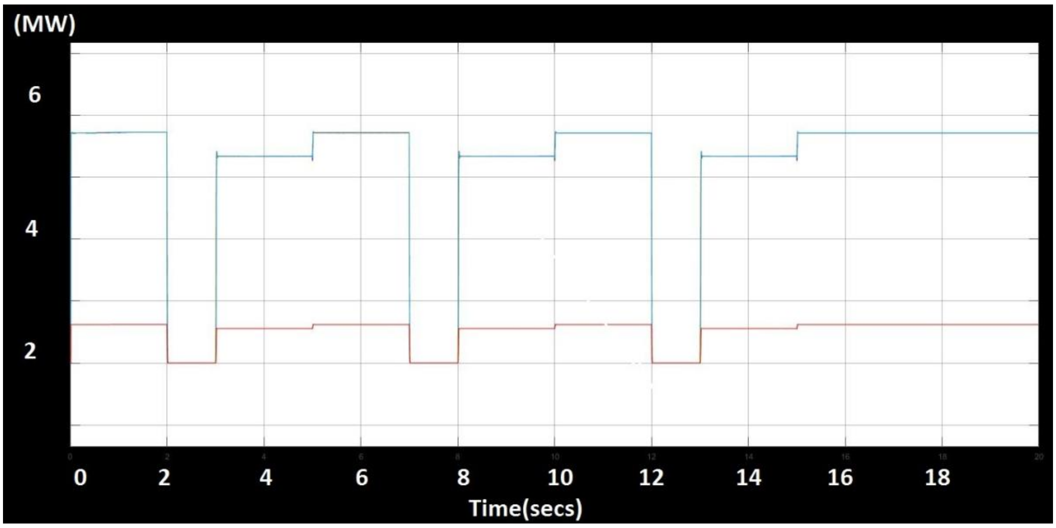


Fig 5.10: Load-2 Active and reactive powers- at Bus 5

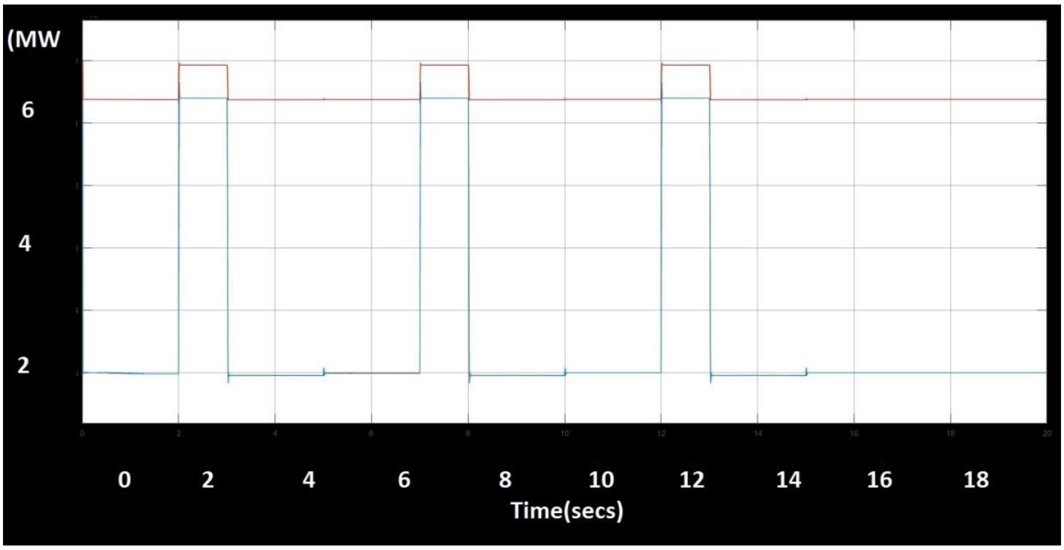


Fig 5.11: Load-3 Active and reactive powers at -Bus 7

POWER LINE VALUE FOR 5 BUS SYSTEMS

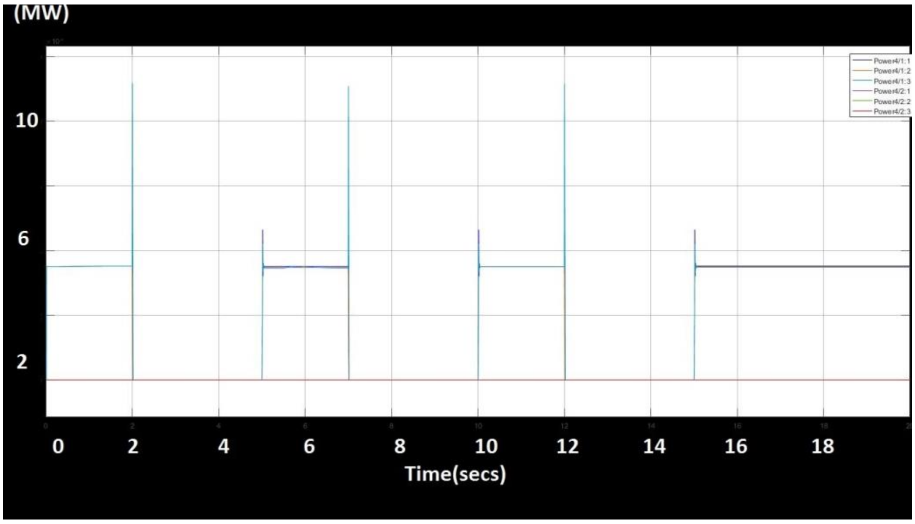


Fig 5.12: Active and reactive Power between line 2-5

WITHOUT FAULT 5 BUS SYSTEMS NO TRIPPING

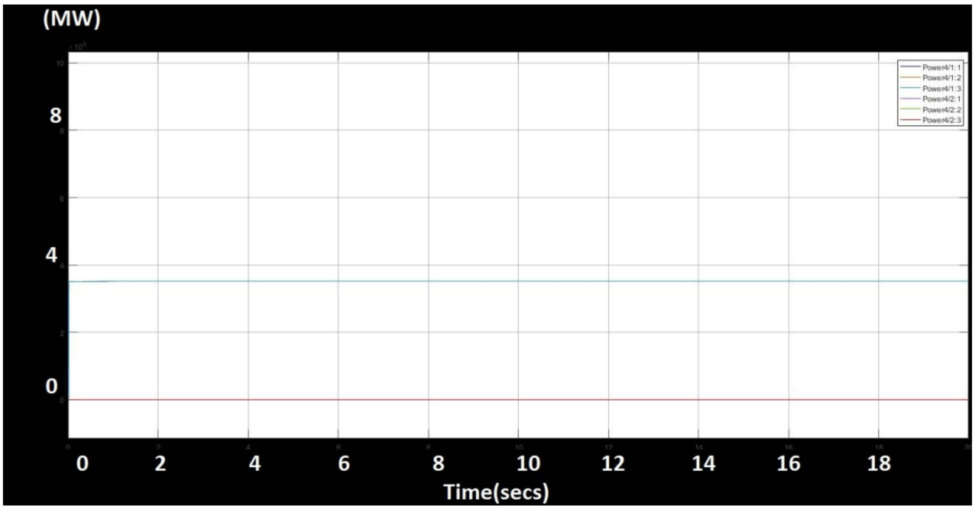


Fig 5.13: Without fault no tripping signal line 2-5

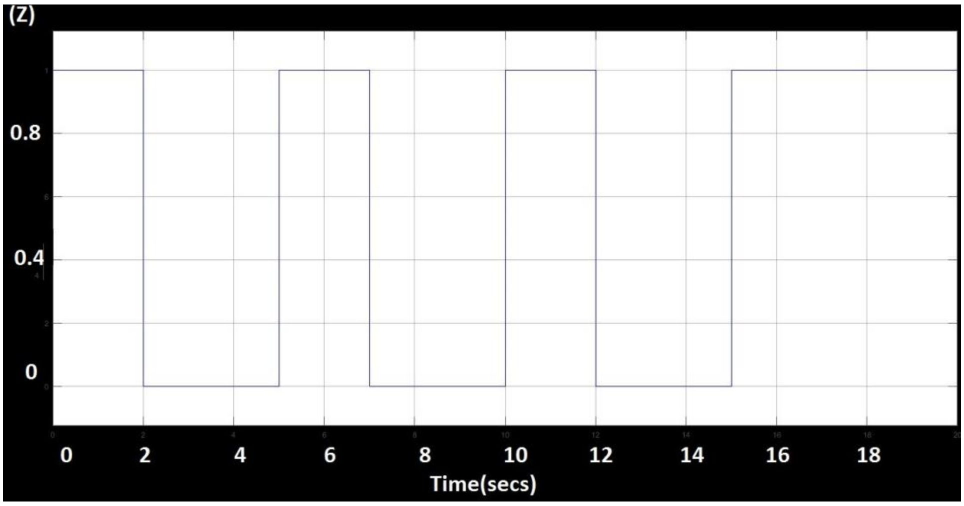


Fig 5.14: Tripping impedance value between line 2-5

5.6 STANDARD IEEE 5 BUS MODEL WITH MULTIPLE FAULT (line 2-5, line 3-4):
SWITCHING SIGNALS

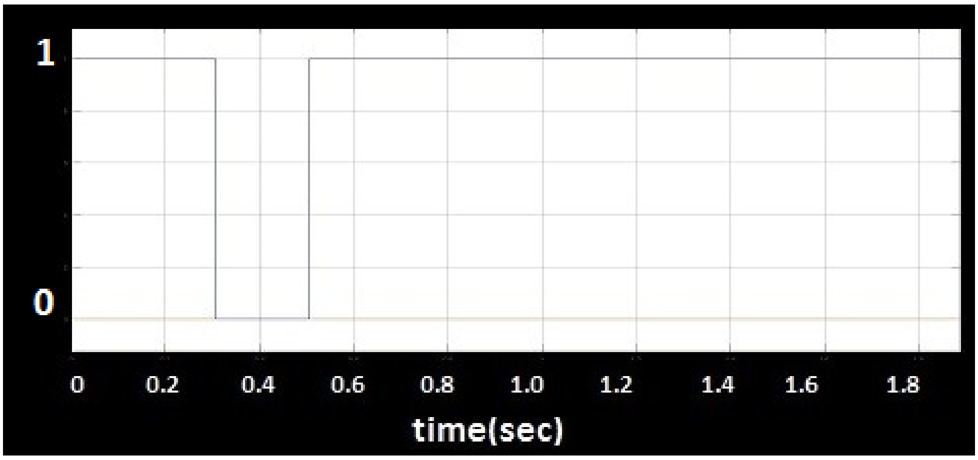


Fig 5.15: Tripping signal between line 2-5

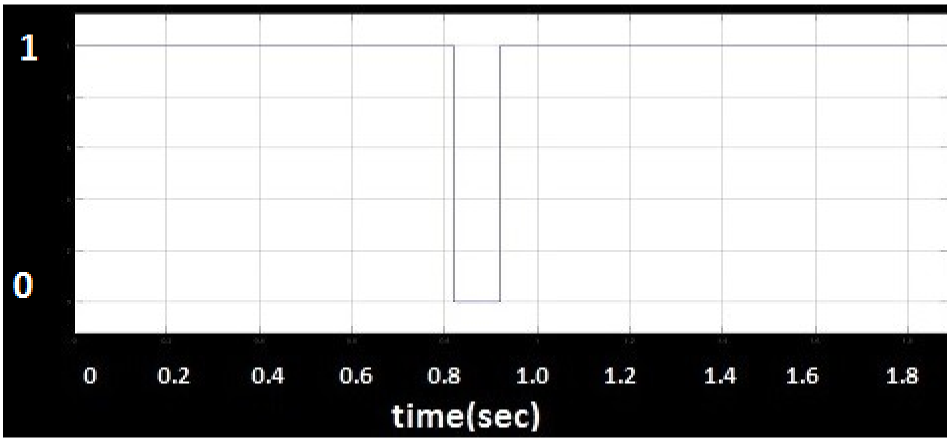


Fig 5.16: Tripping signal between line 3

ACTIVE AND REACTIVE POWERS FOR MULTIPLE FAULT CREATIONS

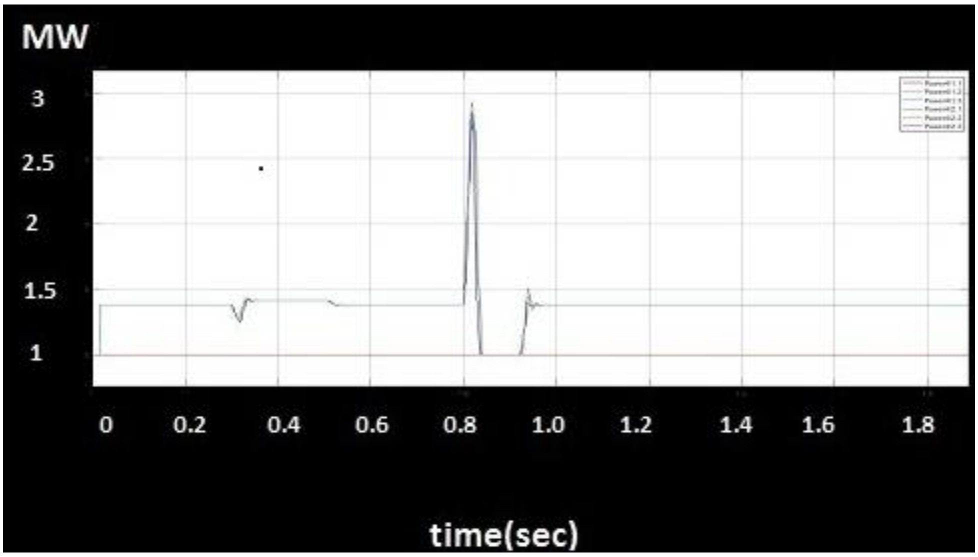


Fig 5.17: Active and reactive power load between line 2-5

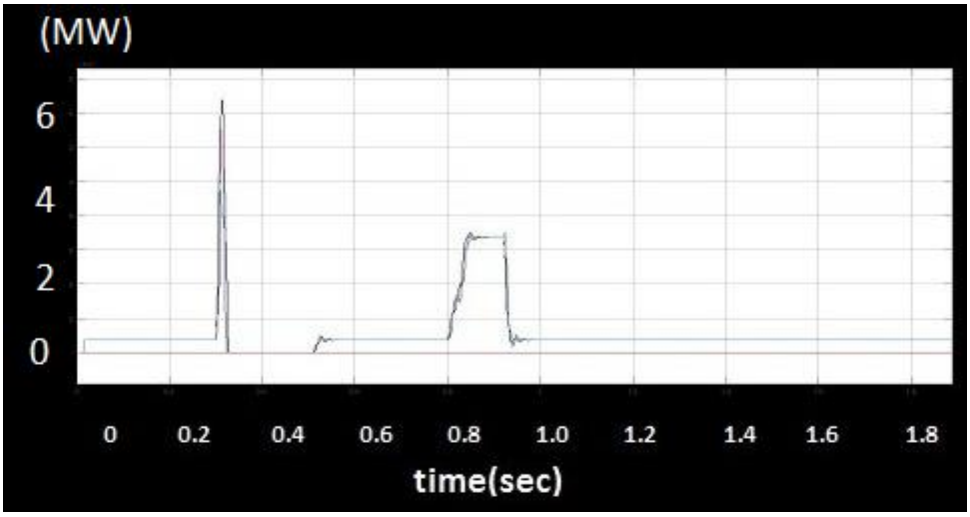


Fig 5.18: Active and reactive power load between line 3-4

5.7 CONCLUSIONS

1. Whenever 3-∅ fault occurs at Bus 2-5 with time t=2sec and time t=3sec it will automatically come to original position

Within 1 sec and circuit breaker will trip at time t=3sec in first case.

2. Whenever 3-∅ fault occurs at Bus 2-5 with time t=7sec and time t=8sec it will automatically come to original position

Within 1 sec and circuit breaker will trip at time t=3sec in second case.

3. Whenever 3-∅ fault occurs at Bus 2-5 with time t=12sec and time t=13sec it will automatically come to original position

Within 1 sec and circuit breaker will trip at time t=3sec in third case.

4. At time t=2-5 sec the power flow at bus 5 is completely become zero hence operation is off.

5. At time t=7-8 sec the power flow at bus 5 is completely become zero hence operation is off.

6. Impedance at fault location between 2-3-line current value will dip and when fault cleared by 1 sec automatically circuit breaker will open at time t=3sec.

Multiple faults occur at different locations:

Case: 1

Fault occurs between bus 3-4 at time t=3 sec

Case: 2

Fault occurs between bus 2-5 at time t=8 sec

FAULT LOCATIONS AT DIFFERENT LINES:

Case1: Between line 2-5

1. At time t=0.2 sec to time=0.3 sec load is increased because the circuit breaker which is connected between bus 3-4 is tripped.

2. At time t=0.8 sec to time=0.9 sec load is decreased and power become zero, because the circuit breaker which is connected between bus 3-4 is tripped.

Case2: Between line 3-4

1. At time t=0.3 sec load is suddenly decreased and power becomes zero. At time t=0.5 sec power come back to original position and it will starts restoring the power and circuit breaker will trips.

2. At time t=0.8 sec to t=0.9 sec load is suddenly increased and power starts increases. And circuit breaker will trip here.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

CONCLUSION:

It is observed that using switching logic, various redundant paths can be enabled for the power flow, such that each or at least maximum number of loads receive uninterrupted power supply. The above distance protection shows abnormality which leads to the mal-operation. This abnormality can be removed by using an Anti-Aliasing Filter, followed by FFT block, and then sending the voltage and current signal to relay.

By using the above method stated, we can prevent the relays from mal-operating. An adaptive relay can vary its setting parameters or its operating characteristics in response to changes in the power system. Thus, adaptive relay settings can be done, such that with the change in configuration and type of fault, the relay settings will change accordingly. Thus all the relays can be programmed for the same.

Intelligent Electronic Devices (IED's), now have dual functionality, i.e. they behave as protection relay as well as are used for synchro-phasor measurement. These devices can be installed optimally and thus prove as a more accurate protection system, accompanied with good communication network and auto

FUTURE SCOPE:

1. Because of fault in either lines, the other line is not affected that is the reason faults tripping is removed for multiple faults.
2. Controllers was designed for multiple faults with immunity to faults tripping.
3. Controllers functioning automatically.
4. Tripping time can be controlled at different times at t=1sec,2sec ,3sec,4 sec…etc.
5. For different faults, we can use same controllers and we can check with 3-∅, 2LG, LG

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