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Validation of Results of Smart Grid Protection through Self-Healing

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Validation of Results of Smart Grid Protection through Self-Healing

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Electrical Engineering
Department of Electrical Engineering
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DEDICATION

I dedicate this work to my family, to Dr. Ralph Fehr, Dr. Wilfrido A. Moreno, Dr. Elias K. Stefanakos, and all professors of the University of South Florida.

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I would like to thank Professor Dr. Ralph Fehr, Dr. Wilfrido A. Moreno, Dr. Elias K. Stefanakos for all the professor of University of South Florida guidance and advice throughout my study.

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ABSTRACT

This is a verification of the results of “Smart Grid Protection through Self-Healing” from the publication of Chathurika Chandraratne, et al., that proposes a protection solution for the smart grid. The paper used as reference has as the main focus on three different protections; directional overcurrent protection, overcurrent protection, and transformer protection, which are validated through ETAP software simulation of IEEE- 9 bus and 14 bus electrical power systems, the same used by the author. It was validated after repeated simulation, that just as intended, self-healing increases system agility, and it helped prevent false-tripping 14 bus electrical power systems.

CHAPTER 1: INTRODUCTION

1.1 Theme Lining

This paper is based on the publication “*Smart Grid Protection through Self-Healing*” by Chathurika Chandraratne, R.T. Naayagi, Thillainathan Logenthiran [1].

The perceived importance of the theme explored by Chandraratne et al. for the evolution of power grid systems throughout economies of all development stages, especially for its self-sustainability and reliability, is the key motivator for the validation of the processes, seeking to ensure its efficacy when tested and applied to different locations.

1.2 Identified Conflict

It was noted that the original publication from the Newcastle University in Singapore, did not present a detailed report of the process that leads to the results and conclusion. Which is the reason for which this document is made. The simulations used in the reference text did not seem to be numerous enough, especially when referencing the 14 bus simulations, resulting in a less broad spectrum of simulations.

1.3 Objective

Analyze and verify all the procedures that have been done during the IEEE-9 Bus Electric Power System simulations, and create a complete protection utilizing self-healing for the IEEE-14 Bus Electric Power System simulations; and then verify how efficient the self-healing technique is for complex systems.

CHAPTER 2: TYPES OF PROTECTION

2.1 Protection Information

A power protection system was with objective keep the power system working by isolating any fault that occurs in it the fast as possible utilizing protection devices [15].

The smart protection system provides advanced grid reliability analysis, failure protection, and security and privacy protection [10]. Smart infrastructure permits the smart grid to recognize a smarter management system and give the smarter protection system that is more effectively and efficiently to support the failure of protection mechanisms, address cyber security issues and preserve privacy [1] [7].

Protective relays are a protective device that trip a circuit breaker when it detects fault, so it can isolate it as fast as possible without affecting unrelated areas [15]. This prevents equipment damage due to fault or overload and increase the system safety for people [11].

Relays can be divided into several types, by the protection characteristics. For example, the overcurrent relay verifies the current to detect if it is not higher than the normal value, if so, it will cause their respective circuit breaker to trip [4].

When selecting the protection solution, it is necessary to respect some requirements. The protection solution must give the maximum protection in an effective cost, it must reliable, make it easy to have a high-speed operation and isolate faults as fast as possible without compromising the operation of the neighboring areas.

To have a good relay performance, some attributes, such as reliability, sensitivity, selectivity, and speed are necessary. However, it is also important that a current transformer with a correct rate is selected.

Current transformer is a device that current being measured in its primary and it produces a proportional current in its secondary winding. [2]

2.2 Zone of Protection

A zone of protection can be defined as the zone that is protected by a relay, and if a fault occurs inside the zone, the protective device will active to isolate the fault. These zones can be divided into two types. The primary zone and the backup zone [2].

The primary protection zone relays are the first that will activate when a fault occurs, being the first to isolate the fault [12]. The backup protection zone only actives in case the primary protection zone fails to isolate the fault, be it by retripping the primary zone circuit breakers or by tripping the circuit breaker nearest to the fault [13].

That's why the backup protection can be divided into two types, local and remote. The local type's protection is located in the same zone as the fault, and the remote type's protection is located in the nearest zone where the fault occurs will trip only in that zone.

To protect the whole system, it is necessary to have overlapping zones in the neighboring parts of the zones by doing that it's possible to be sure that there is not any part of the system that is not protected. However, by overlapping zones if a fault occurs in an area the is protected by two or more zones all of them will by isolated, so to reduce this problem it is necessary to minimize the number of overlapping zones as much as possible so it will not interrupt the power in unaffected zones.

2.3 Overcurrent Relay Protection

Overcurrent relay is as described by its name a relay that is designed to operate it detect more current than the predetermined amount that was inputted in its settings and is mostly used as a protection system in a radial distribution [1].

Figure 2.1 represents an overcurrent relay, where the I is the current in the line, I' is the current in the secondary side of the current transformer that is detected by the relay, and there will be a pick-

up current or threshold current represented by I_{pickup} that corresponds to the value defined in the relay setting.

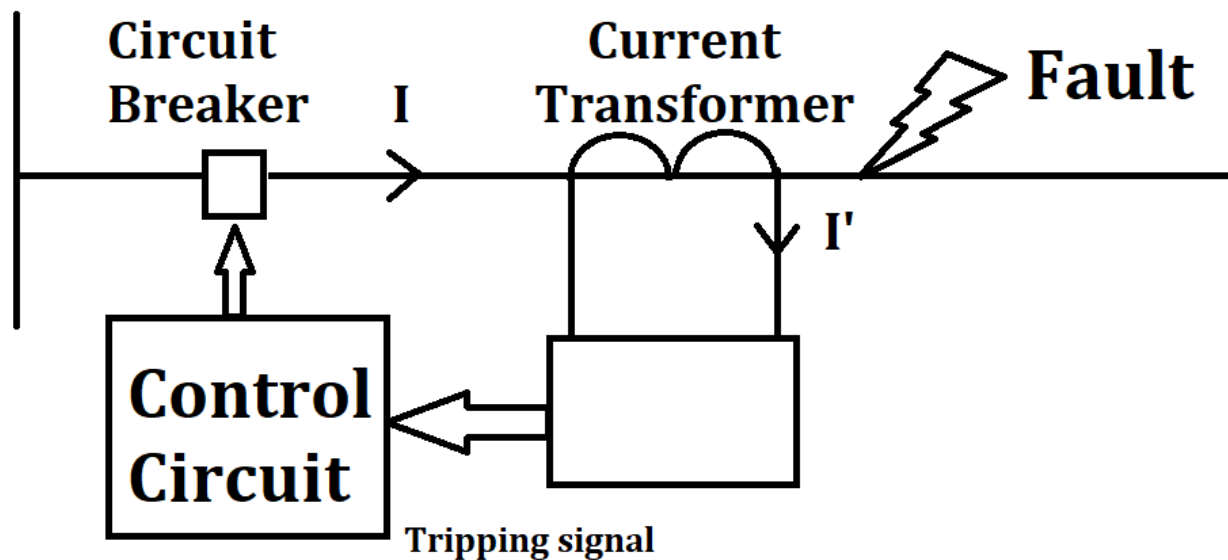


Figure 2.1 Representation of Overcurrent Relay

When the overcurrent relay operates in its normal condition, it means that I' is lower than I_{pickup} , and that the relay will not send a tripping signal to the circuit breaker that will stay closed.

If a fault occurs, it will cause I' to be greater than I_{pickup} , causing the relay to send a tripping signal to the circuit breaker that will open and isolate the line.

For the system to be protected, it is necessary for the relay to have a proper and accurate pick-up and time-dial setting set based on the fault current and required operating time.

There are two categories of overcurrent relay, that are defined by its operating settings, they are the instantaneous overcurrent relay and time-d-overcurrent relay.

The instantaneous overcurrent relay, as the name suggests, is designed so there will be no time in the operation when the current goes above the relay setting, causing the circuit breaker controlled by it to trip, the operating time for this case can go as low as 16 milliseconds to as high as 0.1 seconds [5].

The time-overcurrent relay is designed so the operating time changes inversely related to operating current, and three of these inverse characteristics are the most commonly used: inverse, very inverse, and extremely inverse [3].

2.4 Directional Relay Protection

As per IEEE standard, the directional overcurrent relay can be represented by Relay 67 [16]. Directional relays utilize an additional polarizing source of voltage or current to differentiate from with direction the fault occurred, allowing it to determinate if the fault occurred before or after where the relay is placed, permitting the appropriate protective devices to operate inside or outside of the protection zone.

The directional relay can be used for ground and phase faults, and it can utilize current, voltage and the angle between them to achieve the protection, but to find the directional fault by comparing the fault current, and the line current of the system, an intelligent electronic device is needed.

When there is a ground fault, the residual voltage is equal to three times the zero-sequence voltage drop on the source impedance, and stays as zero when the voltages phases are balanced. Having the possibility to cause a displacement from the residual current by the characteristic angle of the impedance source [9]. To have a correct directional protection it is necessary to have its values calculated.

Cases of false tripping can occur on several occasions, one of them is when a distributed generator is connected to the medium voltage feeder with an improper coordination and protection modification, even though the circuit breaker will correctly trip in the short circuit fault, it will cause circuit breaker of distributed generator to trip, even if it should not. This type of incorrect tripping is common when the synchronous generation is used as a distributed generator source [1]. However, by using directional protection, it can be fixed [6], since it identifies the direction in which the fault occurs, compared to the relay's location, setting to activate only when a fault occurs in one direction, and not in the other direction.

2.5 Transformer Differential Relay Protection

As per IEEE standard, the differential transformer relay can be represented by Relay 87T [16]. Transformer differential relay is a relay that compares the current between the two sides of a transformer, it makes use of Kirchhoff's current law that states that the total of current entering is equal to the total of the current existing the transformer when it is working correctly, and have the difference of the input and output current greater than zero when there is a fault, causing the relay to activate [5]. This relay can also protect generators, large motors, lines, buses, and cables but is unable to protect the equipment from external faults, and faults caused by overload [1].

2.6 Self-healing Smart Grid

Self-healing smart grids are systems composed by the sensor, automated controls and a software that can utilize real-time distribution data to detect and isolate faults, and can reconfigure the distribution network to reduce the number of customers impacted by a power outage [14] [8].

It is possible, by reconfiguring the protection equipment in the feeder, to isolate faults and re-establish the power to several customers as fast as possible by changing to an alternative source or feeder, by doing this, it is possible to increase the reliability of the system that is one of the objectives of the self-healing. To reconfigure a system from one to five minutes that is the requirement for a typical self-healing solution, a high bandwidth may be necessary [1].

Self-healing permits a system to identify if there are some parts of itself that is not working correctly and make the necessary adjustments so it can be restored to a normal condition. Usually, self-healing refers to controlling generator power output, reconfiguration and load shedding and its actions are multi-objective, nonlinear optimization problem with several limitations. To solve these problems, it is necessary to develop an advanced algorithm using artificial intelligence techniques and multi-agent systems.

Smart grid restoration problems are extremely complex due to several challenges, like limited capacities of distributed energy resources, bidirectional power flow, and mesh connected topologies.

The deployment of self-healing for the grid and for the consumers can be explained by distribution automation, recloser and fault circuit indicators. Distribution automation automatically reroutes power based on the generation level, fault conditions, and the load requirements. The communication feature of smart grids facilitates intelligent decision making. When using a recloser in a normal grid, and a fault occurs, the circuit breaker will open and after sometime, the circuit breaker will reclose to check whether the fault still persists in the system. In a smart grid, the recloser will report the failure over the communication network and wait for further instructions. Fault Circuit Indicators monitor the power lines and feeders by constantly sensing the current, voltage and fault conditions. In the case of a fault, it will communicate this information immediately for corrective actions to take place.

CHAPTER 3: SIMULATION STUDIES AND RESULTS

Utilizing ETAP software to do the simulation of IEEE-9 bus and IEEE-14 bus electrical power networks. The simulations used the load flow analysis, short circuit analysis and lastly, implemented protection solutions were tested. The system protection in this simulation used differential transformer relay protection, directional overcurrent relay protection, and overcurrent relay protection.

3.1 IEEE-9 Bus System

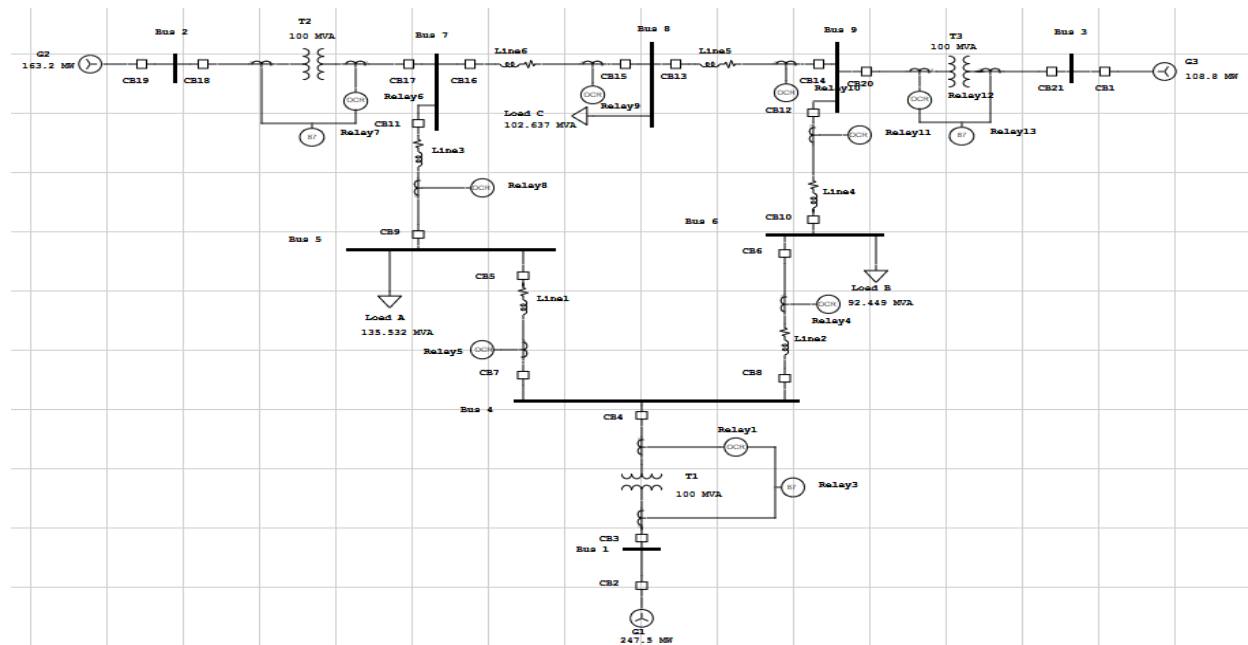


Figure 3.1 IEEE-9 Bus Electrical Power Network

Figure 3.1 shows the IEEE-9 bus electrical power network in ETAP. The IEEE-9 bus composed of three generators, three two-winding power transformers, nine buses, three loads and six lines. Since there are three generators powering the system there is a three-way electricity flow.

Figure 3.2 is the result of the power bus analysis. Figure 3.3 is the simulation results for overcurrent protection when a fault occurs between Bus 4 and Bus 6, and Figure 3.4 is the simulation results for remaining buses.

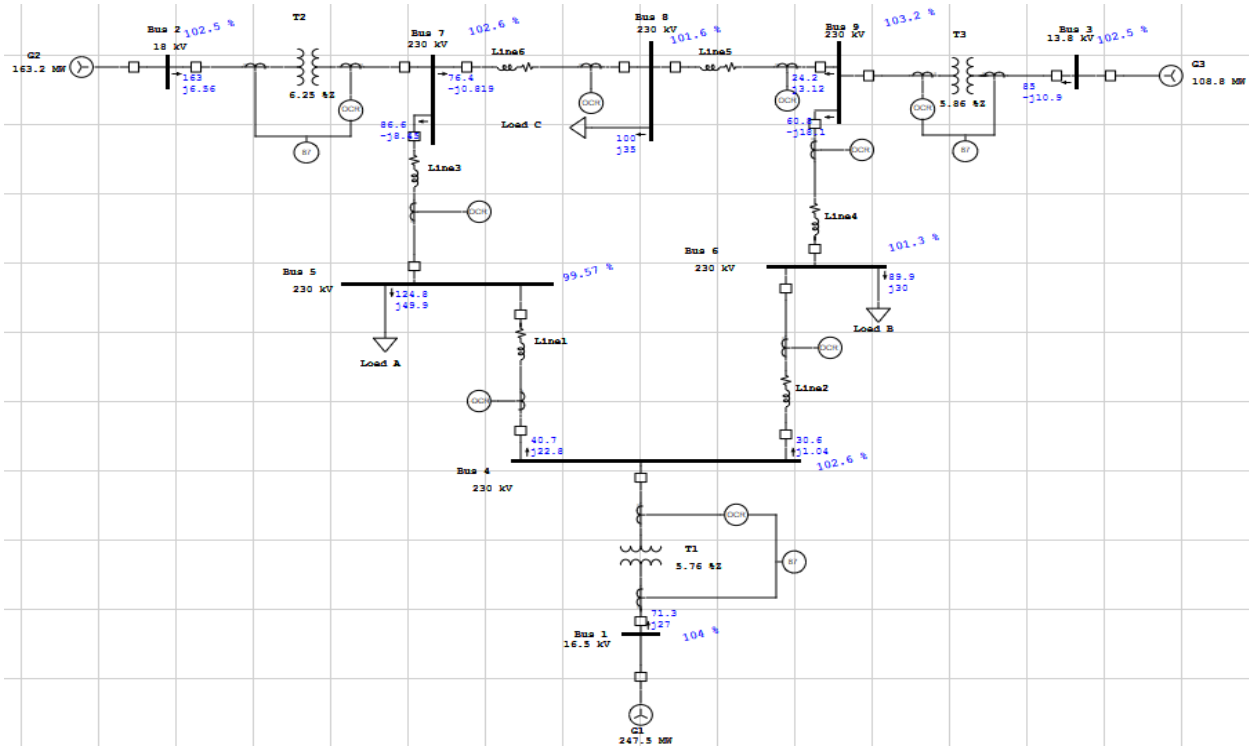


Figure 3.2 IEEE-9 Bus Power Bus Analysis Simulation

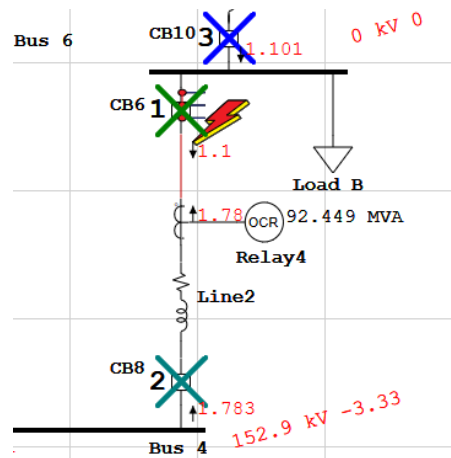


Figure 3.3 IEEE-9 Bus Overcurrent Protection Simulation Buses 4 & 6

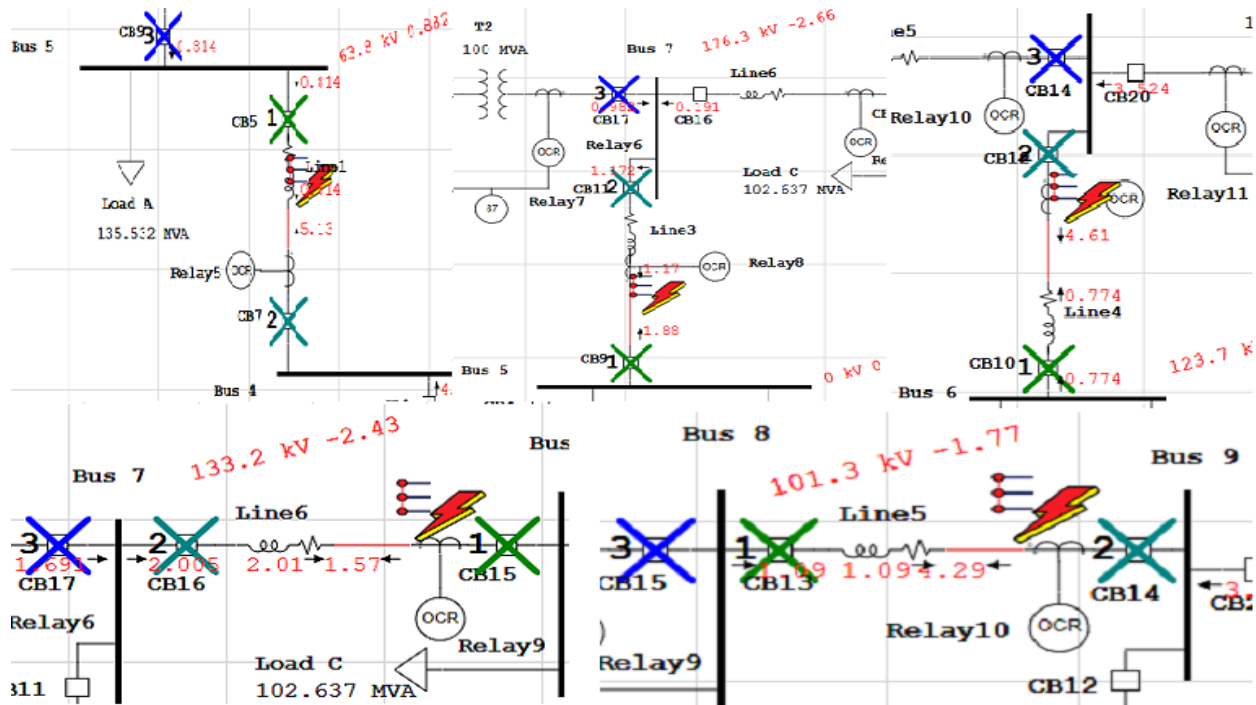


Figure 3.4 IEEE-9 Bus Overcurrent Protection Simulation Remaining Buses

Figure 3.5 is the simulation results in an external protection activation when there is an external fault in the transformer 1 and Figure 3.6 is the simulation results in an internal protection activation when there is an internal fault in the transformer 1. Figure 3.7 is the simulation results in external protection activation when there is an external fault for the transformers 2 and 3. and Figure 3.8 is the simulation results in an internal protection activation when there is an internal fault in the transformers 2 and 3.

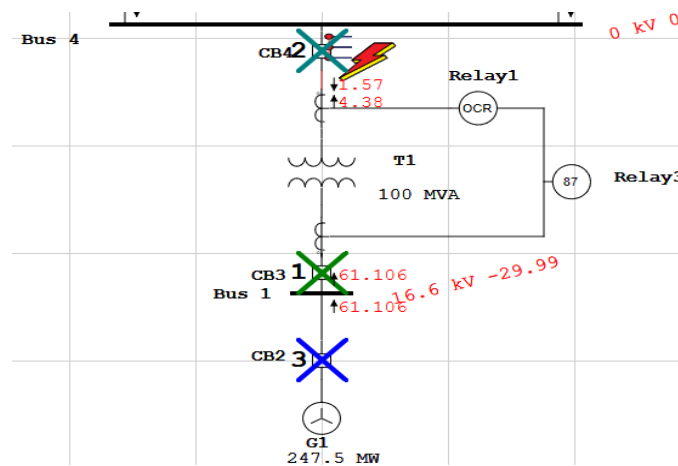


Figure 3.5 IEEE-9 Bus Protection External Simulation Transformer 1

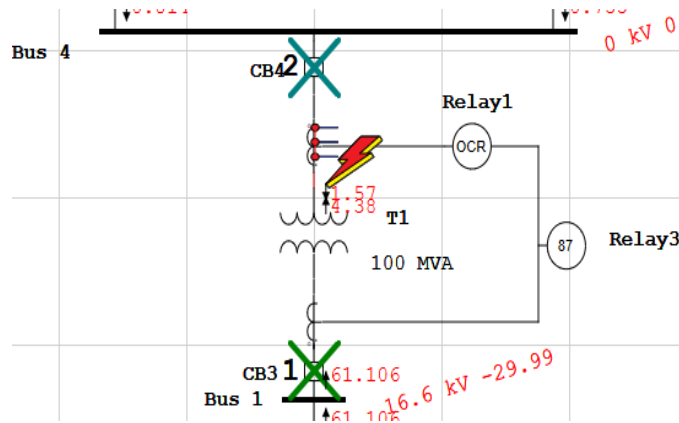


Figure 3.6 IEEE-9 Bus Internal Protection Simulation Transformer 1

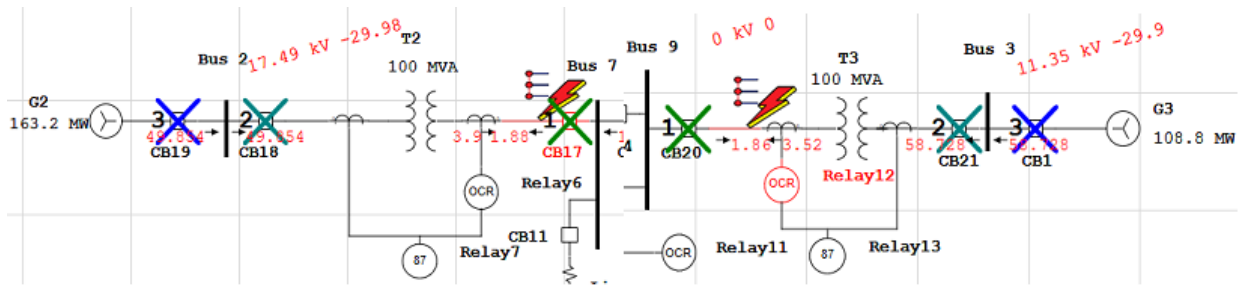


Figure 3.7 IEEE-9 Bus Protection External Simulation Transformer 2 & 3

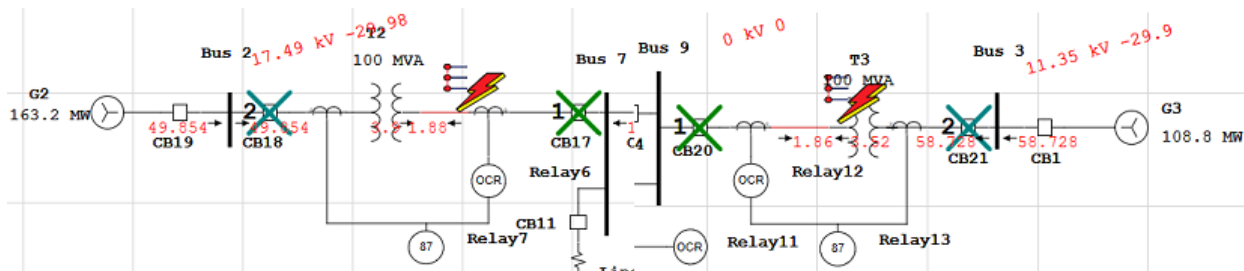


Figure 3.8 IEEE-9 Bus Internal Protection Simulation Transformer 2 & 3

In order to protect the transformer of external faults, an overcurrent is combined with a Relay that causes three breakers to trip; those breakers being two primary protection breakers and one as a backup in the transformer 1's case. The primary protection being the breakers CB3 and CB4, with the CB2 being the backup.

Tables 3.1 and 3.2 give the results of tripping sequences when a fault occurs in the system. The concept of Self-healing is applied to minimize the power disruption and improve the reliability. In a smart grid, when self-healing is used, it helps to detect the fault and isolate the affected area quickly permitting the restoration of energy to the non-affected areas.

Table 3.1 Tripping Sequences When a Fault Occurs Between Buses

Bus Number	Breakers Activated by Relay	Backup Breaker
Buses 4 & 6	CB6 & CB8	CB10
Buses 4 & 5	CB5 & CB7	CB9
Buses 5 & 7	CB9 & CB11	CB17
Buses 7 & 8	CB16 & CB15	CB17
Buses 6 & 9	CB12 & CB10	CB14
Buses 8 & 9	CB13 & CB14	CB15

Table 3.2 Tripping Sequences for Transformers Faults

Transformers	Breakers Activated by Relay	Breakers activated by	Backup Breaker
	(87) Internal Protection	Relay External Protection	External Protection
T1 (buses 1 & 4)	CB4 & CB3	CB3 & CB4	CB2
T2 (buses 2 & 7)	CB17 & CB18	CB17 & CB18	CB19
T3 (buses 9 & 3)	CB20 & CB21	CB20 & CB21	CB1

3.2 IEEE-14 Bus System

Figure 3.9 shows the IEEE-14 bus electrical power network in ETAP.

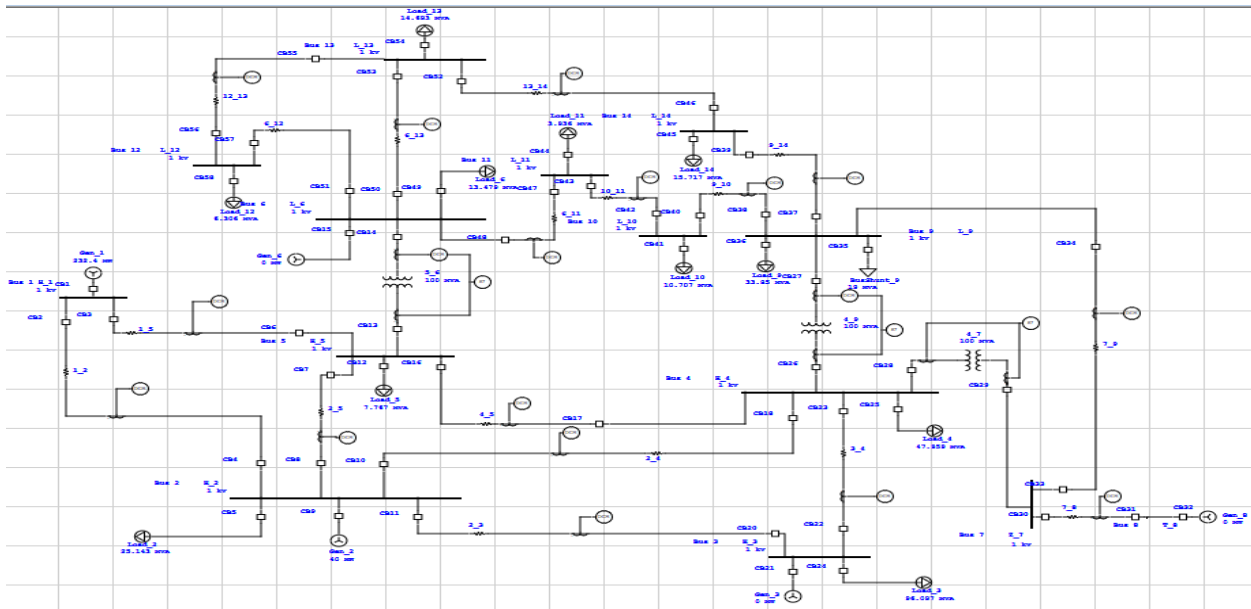


Figure 3.9 IEEE-14 Bus Electrical Power Network

This system consists of five generators, 14 buses, six lines, 11 loads and three two-winding power transformers. It has five ways of energy flow as it has five generators to power the system. The best kind of protection to be used in this system, in which one bus has several connections to other buses, is the directional overcurrent protection, since directional protection can control which direction the circuit breaker should trip when a fault occurs. In this simulation, the system is protected by employing the self-healing concept. Figure 3.10 and when the fault occurs between the buses Bus1 H_1 and Bus 5 H_5 trips the circuit breakers CB3 and CB6

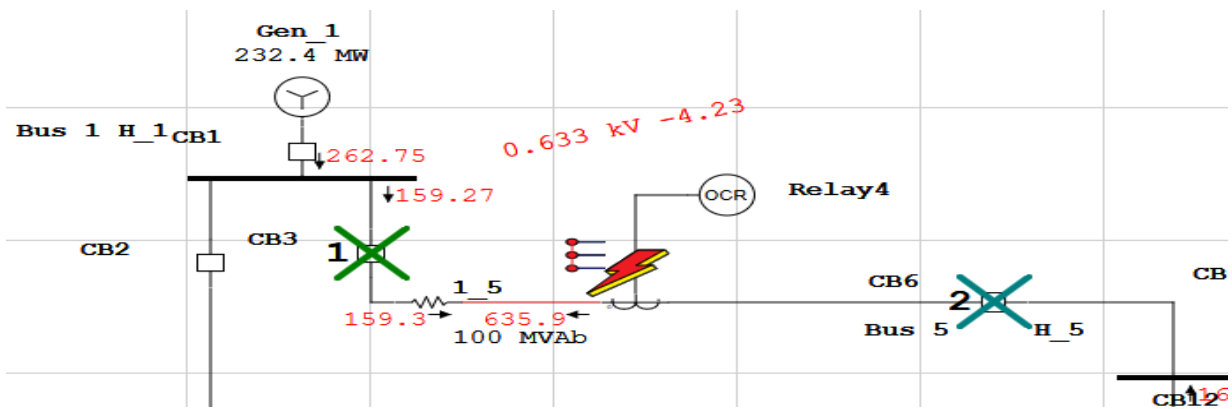


Figure 3.10 IEEE-14 Bus Overcurrent Protection Simulation Buses 1H_1 & 5H_5

The results of the transformer protection obtained from the simulation are shown in Table 3.3 and the activation sequence for between buses on table 3.4.

Table 3.3 Tripping Sequences for Transformers Faults

Transformer	Breakers activated by Relay
5_6	CB14 & CB13
4_9	CB27 & CB26
4_7	CB28 & CB29

Table 3.4 Tripping Sequences When a Fault Occurs Between Buses

Bus Number	Breakers Activated by Relay
Buses 1 & 5	CB3 & CB6
Buses 1 & 2	CB2 & CB4
Buses 2 & 5	CB7 & CB8
Buses 2 & 4	CB10 & CB18
Buses 2 & 3	CB11 & CB20
Buses 3 & 4	CB22 & CB23
Buses 4 & 5	CB16 & CB17
Buses 6 & 12	CB51 & CB57
Buses 6 & 13	CB50 & CB53
Buses 6 & 11	CB49 & CB43
Buses 7 & 8	CB30 & CB31
Buses 7 & 9	CB33 & CB34
Buses 9 & 14	CB37 & CB39
Buses 9 & 10	CB38 & CB40
Buses 10 & 11	CB43 & CB42
Buses 12 & 13	CB56 & CB55
Buses 13 & 14	CB52 & CB46

CHAPTER 4: CONCLUSION

It was possible, after reproducing the paper “Smart Grid Protection through Self-Healing” from Chathurika et al. [1], and further simulating the IEEE-14 bus electrical power, to verify that the Self-healing technic can be used in complex systems and it that increases their reliability.

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