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Design of a New Digital Relay for Transmission Line Fault Detection, Classification and Localization Based on a New Composite Relay and Artificial Neural Network Approach

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DESIGN OF A NEW DIGITAL RELAY FOR TRANSMISSION LINE FAULT DETECTION, CLASSIFICATION AND LOCALIZATION BASED ON A NEW COMPOSITE RELAY AND ARTIFICIAL NEURAL NETWORK APPROACH

by

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This thesis focuses on new approach to detect, classify, and localize the fault in transmission line. Firstly, fault detection was carried out using the New Composite Relay (CR) which, has different characteristics and the ability to detect any type of fault including series faults. Secondly, fault classification was conducted using the Feed Forward Artificial Neural Network (FFANN). In addition, the fault classification led to the investigation of the best use of the FFANN. The data used come from MATLAB/SIMULINK three phase series compensated network. The results obtained using FFANN, were compared with the type of the fault that have been actually applied on the system. Finally, a digital controller was combined with FFANN to appropriately select the type of fault localization that should be used.

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1. INTRODUCTION

1.1 Background Review

Electrical Power System (EPS) is divided into several parts and each part classified as a system [1]. Transmission line considered one of the main parts of the EPS networks [2]. However, Overhead Transmission line is more prone to the fault than the other parts [3], because it is long and out of the room. Hence, there are two types of fault normal and abnormal faults, the normal caused by the external influences while, the reasons of the abnormal faults come from the internal influences due to the flow design. Therefore, this research will introduce three major tasks as a fault detection, classification and localization.

Design of the fast, accurate and reliable protection relay to detect, classify and localize the fault is the first goal of all research, articles and proposals for the faults in the high voltage transmission line (TL) [4-16]. Many research were presented for the fault, classification and localization and many of them used to adopt the conventional protection method throughout the new technique [4, 5, and 7]. Therefore, there are few general methods to detect the fault in the TL. Hence the new technique mostly used the Artificial Neural Network (ANN) [5-7, 9-10, 13-16], Wavelet [11, 15], Support Vector Machine [8], Adaptive Nero Fuzzy Inference system [4], etc. Also, these methods were applied on three phase single and double circuit TL [9]. Thus, the proposed research are focusing on the voltage and current signals together [4, 5, 7, 9] or the current signals only [10]. These research have advantages and disadvantages. So, one disadvantages may cause a big problem. Furthermore, one of the major problem on the protection system is the time from the detecting till the clearing fault on TL. While many proposals did not mention it on their research. Also, many of these research did not applied on system with a compensating or any additional components. For the ANN it is very popular algorithm for the fault classification on the high voltage TL, and the reason due to the capability of this algorithm to learn and recognize the pattern and the behavior of the system under any circumstances with high efficiency [5, 11]. Therefore, it has earned much interest by the researcher [13, 16]. While, using of the classical methods with new technique will give new analytic for the situations, but no longer included all of the transient time analysis in a very short time [8]. Also, the conventional approach detects and classifies the fault depending on the fundamental component of each signal might not achieve the desire analysis. Hence, many researches did not addressed the series faults or not proposed a general ANN system, but divided the system into few parts each one for similar fault type different phase.

Therefore, in this research the New Composite technique has been adopted and tested to detect the fault on TL with a very short time and no one use it earlier. On the other hand, using of the feed forward Neural Network was built to classify and localize the fault on TL. This system was strongly classify all types of fault whether it is series like (one line open and two line open) or even shunt fault like (Single Line to ground SLG, Double line DL, double line to ground DLG, Three phase 3PH and Three Phase to Ground 3PH-G). Furthermore, this system will identify which line was particularly. This method is based on the theory that the input value of any variable should be equaled or closed to the output value of the same variable like the output current has to be same value of the input current, which delivered to the load under the normal operation. It has to be in the same zone to be protected, but when the fault or any abnormal behavior happen in specific zone some of this current will pass through the fault point. So, the current out of the zone will be less than the current into the zone. Thus, the summation of both currents (taking into consideration the direction of both currents) gives a value in fact no zero, this magnitude will make the relay to operate and make a decision if there is a fault or not depending on the pre-set value. As a result, the sensitivity of the relay to the fault can be adjusted due to many factors. So, the accuracy of the equipment and the method that is used to transfer the information from the end side to the sending side, which will compare and make a decision will play a vital role in this process. Therefore, these factors effect on the sensitivity of the relay. Above all, this method is used to detect the fault immediately and it is very sensitive for the sudden rising of the current in and out of the zone [17]. In this paper the new composite of three types of relays was adopted to detect the fault for the long and short high voltage TL.

1.2 Research Goals

Fault in transmission line can be defined as unwanted situations process causes many problems in the Electrical Power System and this unwanted situation cannot avoid all of them because some of them happen out of control. The high percentage of these faults happens when the transmission line is overhead transmission line and less with underground transmission line, but for each one some of the factors effect on each type. So, the protection has to be presenting in each point and there has to have no unprotect point to keep the system stable continued all the time. This study is focusing in four sections as below:

1. Detecting the fault using the new composite relay.
2. Disconnecting the faulty area.
3. Classifying the type of the fault using ANN and
4. Localizing the fault.

Thus, chapter three discussing the Electrical Power System, chapter four focusing on the Power System Protection, chapter five will present Types of Faults in Transmission Line and Fault Indices Calculation, Types of Protection Methods Used in Transmission Line are presenting in chapter six and finally the Model and Simulation of Three-Phase Differential Relay With Compensated Network will demonstrate the model for all possible faults in overhead transmission line.

2. PERTINENT LITERATURE

2.1 Protection

There are several types of methods used to protect the Electrical Power System against the undesirable, but unavoidable faults [18-23]. So, the protection is the second process that must work in case of fault [24], which can be considered an adaptive system based on the nature of its work. Moreover, this system response to all abnormal situations that are affected on the stability and continuity of the Electrical Power Flow and start the process to decide whether the system will disconnect or not depending on the information and comparing this information with the setting value. Thus, this system has to make an accurate fast and right decision based on the information, which is collected directly from the Electrical Power System. The protection system has few jobs to do it as below:

1. Getting information from the system each moment.
2. Comparing the information with the setting values.
3. Making a decision based on the information which is collected from the measurements.
4. If there is a fault, the protection system will isolate a small area and keep the rest works smoothly, but if there is no fault the protection system has to stay ready for any fault.

2.2 ANN for Fault Classification and Localization

Ravi Kumer, Ebha Koley, Anamika Yadav and A.S. Thoke [25], (2014) studied "Fault classification of phase to phase Fault in six phase transmission line using Haar Wavelet and ANN" and they found the Wavelet and ANN method are accurate to classify all fifteen types of line to line faults on the six phase transmission line and these two methods depend on the standard deviation of approximated coefficients of the voltage and the current, these were taking from one side only for all possible line to line fault in six phase transmission line. Also, they found these methods effective for all lines to line fault location, fault inception angle and fault resistance. So the changing of the inception angle or even the resistance fault will not effect on the classification result of these two methods.

G. Preston, Z. Radojevic and V. Trezija [26], studied "Novel Parameter-Free Fault Location Algorithm for Transmission Lines with Series Compensation". They were trying to avoid using the line parameters (R, XL and XC) for fault location with respect to all types of fault. Avoiding line parameters due to changing of the impedance based on the achieving of the stability and this will led to add a capacitor or inductor to reduce and eliminate the unbalance effect due to the changing of the load or any other parameters or conditions. They considered that any algorithm not depending on these parameters are robust algorithms and flexible. Furthermore, they used the data from both end sides to achieve their algorithm, which has a fast response and accurate, but they found it can be affected when from between the capacitors and the bus bars. The fact shows this error can be increased as the compensation increased. Thus their algorithm depending on the position of the capacitor regarding to fault if it is located before either after the compensation system.

Ali H. Al-Mohammed and M. A. Abido [27], (2014), they studied “A Fully Adaptive PMU-Based Fault Location Algorithm for Series-Compensated Lines”. They approved their algorithm to work with any type of series compensation. Their proposal applied through the PMU synchronized measurements only. Also each phase has an individual PMU measurements. All possible changing in the transmission line parameters (fault location, fault resistance, fault inception angle and pre-fault load) were tested. They built the system using PSCAD/EMTDC and the Matlab with 400KV transmission line.

Mohamed M Ismail and M. A. Moustafa Hassan [28], (2013) studied “Distance Relay Protection for Short and Long Transmission line” and they tried to find three things. First, detecting the fault in the transmission line and disconnecting the faulty system by a very short time. Second, classify the type of the fault and finally getting the location of this fault. They were trying these three steps for both long and short transmission line and they used different types of load. Also, they used a general technique to get the result depending on the ANN especially for the location of the fault. They got 8% error when they used ANFIS method, but still less than the error when they used the ANN which was 10% under the same conditions: different load, type of fault and different fault inception in both long and short transmission line.

J. A. C. B. Silva, K. M. Silva, W.L.A. Neves [29], B. A. Souza and F. B. Costa, (2012) studied “Sampling Frequency Influence at Fault Locations using Algorithms Based on Artificial Neural Networks”, they used Alternative transient program (ATP) software to build the system using ANN for the fault localization they got all the information of the fault depending on the digital recorders that should record all the normal and abnormal changes in the system. They used three elements to achieve their result. First, the phase quantities. Second, the zero sequence for the voltage and finally the current waveform data with 230 KV transmission line and finally. So they divided the transmission line into eight zones with several numbers of ANN were training for each type of fault. In the result they found the ANN is more efficient if the sampling lying in the perfect range. Therefore, more information of each fault means more error, long time to train the ANN and low efficiency.

Kapildev Lout and Raj K. Aggarwal [30], (2012) studied “A Feed forward Artificial Neural Network Approach to Fault Classification and Location on a 132kV Transmission Line Using Current Signals Only” they were working to get the fast, reliable and accurate method for the fault classification and localization algorithm that should has a high efficiency. They used the currents signals only through the Fast Fourier Transform (FFT) to get the information of the fault in transmission line which later will be input to the ANN. They were trying to change the parameters in their investigation for the fault resistance, fault inception angle and the length of the transmission line to reach the goal of this investigation. So they found this method is strong in fault classification against the changing of the parameters that may happen through the fault impedance, line length and increase in source capacity. So the fault classification was accurate but the effect will be presenting in the fault location and may cause a percentage error.

Jianyi Chen and R.K. Aggarwal [31], (2012) studied “A New Approach to EHV Transmission Line Fault Classification and Fault Detection Based on the Wavelet Transform and Artificial Intelligence”. They were analyzed the data (phase currents) that were collected from one end only. Using the wavelet transform to decompose the currents waves and get the significant frequencies by using the number of wavelet coefficients through the short time moving window. Hence the output of the wavelet transform stage will be input to the feature extraction stage before transfer it to the Neural Network for fault classification. According to the results this method has a very small error but it is robust to the changing of fault inception angle, fault location and the type of fault. While the results show different story. They used to approximate the results all the time.

A.P. Vaidya and Prasad A. Venikar [32], (2012). They studied “ANN Based Distance Protection of Long Transmission Lines by Considering the Effect of Fault Resistance”. They applied the ANN based distance method on the long transmission line and counted the effect of the fault resistance. Therefore, it has to be presented the effect of the fault resistance on the calculation, and because of the ANN is an algorithm that is treated with the linear and nonlinear behavior. So it is more efficient to use it. Also they used a filter to remove the DC and the harmonics components. Thus in their training they found the ANN as a way to improve the efficiency of distance relay through the pattern recognition, but it takes more time for training. Also it cannot adapt the changing of the network conditions.

3. ELECTRICAL POWER SYSTEM

3.1 Introduction

It is a network of Electrical devices and equipment these are used to produce, transmit and deliver the Electrical power to the load. An example, of an Electrical Power System is the network that provides (supplies) the industry or a town of homes with Electricity. This Power System is called the grid and in general it consists of Generator (Electric Power Supply) which produces the Electrical Power, Transmission Line System, which is working to transfer the Electrical Power from the source to the load through substations, and finally Distribution System that provides the power to the consumers that could be home, industrial, commercial [33]. The similar Power System can be found in hospital, industry, commercial, buildings …etc [33].

The Electrical Energy is popular energy more than other energies because all the people used to do everything through it and that because it can be generated by the source and transported by the conductors then delivered to the load with a high efficiency and acceptable cost [34].

Thomas Edison was the first one who was making the Electrical Power System in 1882 in the United States of America at Pearl Street Station in New York City. The Electricity was a Direct Current (DC) source, this Power System designed to turn on the light, and it was a low voltage. So, it designed to deliver the Power with only a small area and no long distance from the generator station because of the power losses is

$$\boldsymbol{Power\ losses} = (\boldsymbol{Current})^{\mathbf{2}} * \boldsymbol{Resistror} \tag{3-1}$$

When the transformer was inventing by (William Stanly 1885) the Alternative Current (AC) voltage for both of transmission and distribution was increased, while the Induction Motor was invented (Nikola Tesla 1888) and used it instead of the DC motors; Therefore, the AC system became more reliable and efficient to use instead of the DC systems. Also, that opened this field to produce the high power at higher voltage [34]. The Power should deliver to the load, but due to the distance between the generation source and the load it has to be delivered through the transmission line. Also, for the economical way the AC voltage was converted from the Extra High Voltage AC to Extra High Voltage DC and returns it to the AC before delivered to the load [34].

The Electrical Power Systems are growing very fast due to the requirements of the life and became a very wide. So, it connected together. Therefore; it began to design the protection systems to keep the power efficient and continuously all the time. As a result, the Electrical Power System should be stable. So, it has to be protected from the outer and the inner effects which may lead to disconnecting the Electricity or burn the equipment then of course shutdown the systems[34]. Also, the Electrical Power System under the control and the protection will be more efficient than other because when any fault happen both systems control and protection has to work and diminish the fault's effect to the smallest possible area and keep the Electrical Power system Provides the power to the load even the fault still on the system because the protection system recognize it and the control system disconnected it.

In general, the Electrical Power System consists of numbers of systems which in the aggregate constitute this system and each one considered as a system.

3.2 Power System Equipment

3.2.1 Generator

It is a very important component in the Electrical Power System, because it is the unit that is using to produce the power or three phase AC power. So, it called Synchronous Generator or Alternator [34]. The synchronous Generators have two rotating fields. One has gotten to be the Rotor when it is reached to the synchronous speed and excited by DC current, and the other field has gotten from the windings of the Stator by the Armature current [34]. The DC excitement to the Rotor comes from the DC generator that was placed on the same Rotor stuff this was the old way, but now it used the AC generators with rotating rectifiers and it is called Brushless Excitement System.

3.2.2 Transformer

It is another important component On the Electrical Power System, Which is working to transfer the Power from one form to another depends on the requirements. So, it means if the power needs to transport it has to be Step-Up Transformer or (Step-Up Voltage), but when it used to distribute the power it has to be Step-Down Transformer or (Step-Down Voltage) [34]. Also, the first one used to reduce the losses on the power when it is transported it and the second used when it is supported the load. The names of the two transformers (Step-Up and Step-down) belong to the behavior of this transformer if the input voltage greater than the output voltage it will be called Step-Down Voltage, but if the input voltage less than the output voltage it will be called Step-Up Voltage. In both of these transformers the Power should be equaled if it is an ideal Transformer, but if it not ideal then the Power input equal to the Power output added to the losses. Both currents and voltages (input and output) can be calculated by the equations below:

Reactive Power (primary) = Reactive Power (secondary)

$$\boldsymbol{V_{primary} * I_{primary} = V_{secondary} * I_{secondary}} \tag{3-2}$$

But if the number of turns is different between the primary side and the secondary side then the ratio of N1/N2, which is called the turn’s ratio, can be founded by the equations below.

$$\boldsymbol{\frac{V_{primary}}{V_{secondary}} = \frac{N1}{N2} = a} \tag{3-3}$$

So, from (1)

$$\boldsymbol{\frac{V_{primary}}{V_{secondary}} = \frac{I_{secondary}}{I_{primary}}} \tag{3-4}$$

Substitute (3) in (2)

$$\boldsymbol{\frac{I_{secondary}}{I_{primary}} = \frac{N1}{N2} = a} \tag{3-5}$$

3.2.3 Transmission Line

It the system that used to transfer the Electric power from the place to place that will be used it, and it can be divided in to two steps [34]:

- From the Generation area to the substation area.
- From the substation to the load.

In general, the Transmission line has chosen depending on many factors like (Voltage, Current, Temperature, Weather… etc), but the main thing that should take care of it is the Power that should deliver to the load [34].

3.2.4 Distribution

The Distribution system is the stage before delivering the Power to the load, that is coming from the Generator, and this system should design according to many conditions, like (the space between the substation and the load should be closed to the load, capacity… etc) [34].

3.2.5 Load

The last component of the Electrical Power System is the load, which is receiving the power from the distribution system to spend it as needed to do. The load can be divided in to three types [34]:

a. Industrial
b. Commercial
c. Residential

And these three types of load receive the power and transformation it into many types (Heat, Voice, Mechanical movement …etc) [34].

The largest Energy consuming during 24 hours of the day called the maximum demand or the peak [34].

3.3 Power System Protection

3.3.1 Introduction

Power System Protection is the system that should place to protect the Electrical Power System from the faults that may happen and make the system under the critical situation. This system has to keep the Electrical Power System stable, continuous and efficient by reducing the effect of the faults to the lowest property. So, there are several conditions (as below) to adopt or build this system to reduce the fault's effects (inner and outer) to the lower possible limit and keep the Electrical Power System works properly under and after the fault occurs [35]:

a. Speed: It is the time that will spend to make the decision if there is a fault or not.
b. Accuracy: It is the ability to recognize the behavior of the equipment in the Electrical Power System.
c. Simplicity: The simplicity of the installation of relay protection is an essential factor in the efficiency and reliability of the relay and the speed of installation and maintenance.
d. Reliability: It is the ability of the system to work when it should work, that means the system will work when the equipment became abnormal due to the fault.
e. Sensitivity: It is defined as the ability of the system to find the abnormal behavioral of the Electrical Power System, when it is exceeding the normal operation, and it considers the Efficient of this system.

f. Security: It is the ability of the system to prevent unnecessary operation when the Electrical Power System works normal.

g. Economics: The economy is one of the most important principles of the design and operation of any system.

And there are many conditions to adopt and build the Protection System, due to the requirements for the system that wants to be protected. The circumstance played the basic role in these equations [35].

3.3.2 Generator Protection

The protection of the generator is the system that is controlled to protect the Generator from the abnormal operation and diminish (minimize) the faults if it happens from going to the other system and this system build to protect the Generator's equipment from each other if the fault happens in one of them [35].

Some types of protection for the Generator:

a. Over/Under speed protection

b. Over/Under frequency protection

c. Directional power protection

d. Loss of field protection

e. Field ground protection … etc.

3.3.3 Transformer Protection

The Transformer protection is applied to keep this expensive item from burning due to the fault (inner or outer). So, this should be protected very well. Furthermore, it has to be protected from the two sides before and after the transformer because it is located between systems (Generator and Transmission line) or even (Distribution and the Load) [35].

Some types of protection for the Generator:

a. Low Oil level protection
b. Low isolation protection
c. High temperature protection
d. Over current protection
e. Over/Under voltage protection
f. Differential protection
g. Earth fault protection
h. Current balance protection
i. Lightning protection … etc.

3.3.4 Bus-Bar Protection

It is protected by deferential protection.

3.3.5 Transmission Line Protection

Transmission line protection is required because it can be affected by the changing of the environment. So, in the design of the transmission line must take into account all possible changes that may cause any abnormal behavior [35].

There are many types of protection applied to the transmission line as below:

a. Differential protection
b. Distance protection
c. Directional protection

d. Over current protection

e. Lightning protection

f. Earth fault protection

3.3.6 Transmission Line Faults

3.3.6.1 Introduction

As the other Electrical System works it has many types of faults depending on the causative of the fault and many of these types are out of control. So, these types of faults can be considered as natural faults, but it should be taken in to consideration to protect the transmission line from these faults and the other is the faults due to design flaws [35].

3.3.7 Causes of Electrical Faults in Transmission Line

There are many reasons to cause the faults in the transmission line as below.

3.3.7.1 Natural Faults

3.3.7.1.1 Fires

There are many types of faults occurring on the transmission lines caused by the Fire, and this is why the power outage in many countries. The fire leads to cause a fault on the transmission line due to line to line fault or single line to ground fault according to the voltage value and the characteristics of the transmission line. The fire may be happened because of the trees in the bottom of the transmission line. So, the fire will effect on the efficiency of the transmission line because the Conductivity is inversely proportional to the Heat. Also, the isolation will be decreased [36]. That means the transmission line will not be able to carry and transfer the same power as before when it becomes hot because the transmission line designed according to the specific parameters that took it from the specific area. Also, the temperature will make the transmission line to be extended. As a result of this increasing in temperature the sag becomes increasing and the distance between the ground and the line will decrease to be small. So, the gap now less than before, and it can be considered that the probability of fault to be happened on the system will increase depending on the current situation. The other problems as a result of the fire, dust and soot. So, these lead to reduce the isolation. Therefore, it is very important to keep the transmission line away from the area that the possibility of the fire to be happened is higher. Also, decreasing of the outage of transmission line it needs to increase the distance between the lines with the ground in the places that have trees and clean the area from it [36].

3.3.7.1.2 Lightning

In Japan a lot of faults happen, but more than 50% of the faults on transmission line happen because of the lightning and from 20% to 30% of the faults extended to be double circuit, these faults have a direct effect on the Electrical Power System, and the fault current will pass through the tower to the ground [37]. This current will pass through the resistance which called (Footing Resistance). Footing Resistance is the resistance found between the tower and the earth and it can be measured from the base of the tower with the earth [38]. High Footing resistance has the influence effect on the insulator strings because it has to discharge the current in a very small time. So, it should be small to keep the equipment from the fault's effect if the lightning fault happened [37] [38].

3.3.7.1.3 Pollution

The demand on the Electricity has increased dramatically in the last years. So, this leads companies to offer the high efficiency of the Electricity to the customers, and this quality comes from the continuity of the Electrical power by avoiding the faults on the Electrical Power System. So, the effect on the transmission line may be happened because of the Pollution. It is affected on the insulator of the transmission line system, the pollution causes flashover on the insulator because the dust and the soot which is the result of the pollution is going to stay on the surface of the insulator then if the weather has humidity, fog, rain or dew the dust and the soot will be mixed. As a result, this New Composite works as a conductor, and this layer works as a way to the current to pass through it. So, increasing the conductivity of the insulator leads to decrease the efficiency of the transmission line to transfer the Electricity and the chance of flashover will increase. Also, in this case the current that may pass through the insulator can be considered a fault current [39].

3.3.7.1.4 Other Natural Faults

a. Wind: it has the significant impact on the transmission line. In general, the wind causes many effects on the system by:
    1. Wind load: which is causing the transmission line to be heavy and not stable, and it can break the tower, which the transmission line hung on it.
    2. Swinging: It is affecting on the transmission line by increasing the displacement between two lines or even three lines, and it could make the

lines in touch with the tower, which is already grounded that means the probability of the line to ground fault increasing even the line to line fault.

b. Ice or Snow: It is affected on the transmission line because it is falling on it. So, the weight of the transmission line should increase due to the Ice or even the Snow.
c. Birds: In transmission line it is very common the line to ground faults or the line to line faults caused because when these birds come to landing or taking off will open their wings and this will fill the space between the lines or even the line to line [40].
d. Trees: Also the trees become as a source to make the transmission line system fault because it grew more enough to work as a conductor [40].

And there are many things cause the fault on the transmission line system.

3.3.7.2 Faults Due to Design Flaws

These faults happen when there is defect on the equipment like (tower design, inaccurate calculation… etc). Therefore, choosing of the suitable insulation, size of conductor, tower, and other thing related to the transmission line system with the safety values that should be applied to get a perfect system and prevent the faults on the transmission line that is caused by any reason due to the defect or wrong calculation. So, the transmission line will work with high efficient and more stable. So, the transmission line should be designed according many things like temperature, current, voltage, distance, type of conductor… etc.

3.3.7.2.1 Transmission Lines Requirements

The transmission line system is very important to transfer the power and it must be able to carry this power in a high efficiency. So, there are several requirements to design it and it based on which transmission line is proper to do that [41].

a. Type and magnitude of the voltage.
b. Type and magnitude of the current.
c. The distance that the transmission line will carry the power.
d. The climate change.
e. Mechanical load.
f. The possibility of corona that may happen.
g. The type of conductor.

Because of the Electricity must be continuous and stable when it transfers by the transmission line. Therefore, transmission line has to complete all requirements before it is going to install it. So, there are no chances for the mechanical faults or any entire faults due to the wrong design.

3.4 Types of Faults in Transmission Line and Fault Indices Calculation

3.4.1 Series Fault

Also it can be called open conductor fault and it comes from either outer or inner effects and the problem that will make it on the transmission line is the unbalance on this system. So, the system has to be sensitive for this problem and make a decision to open the circuit breaker until solving this problem. Also, the series fault can be divided in to three types of the series fault.

a. One line open

b. Two lines open

c. Three lines open

All of these faults are caused by many reasons like storm, blown fuse, circuit breaker failing to contact, falling of tree, or any other reason [42]. As a result of this fault the symmetrical current will pass through this circuit. So, it can be used the equations and the formulas for the symmetrical component and sequence networks analysis [42].

3.4.1.1 One Line Open

Consider this fault occur on the line (a), then the symmetrical component could be applied on it to get all information for this fault; therefore, the positive, negative and zero sequences could be explained as below figure (3-1) (a and b).

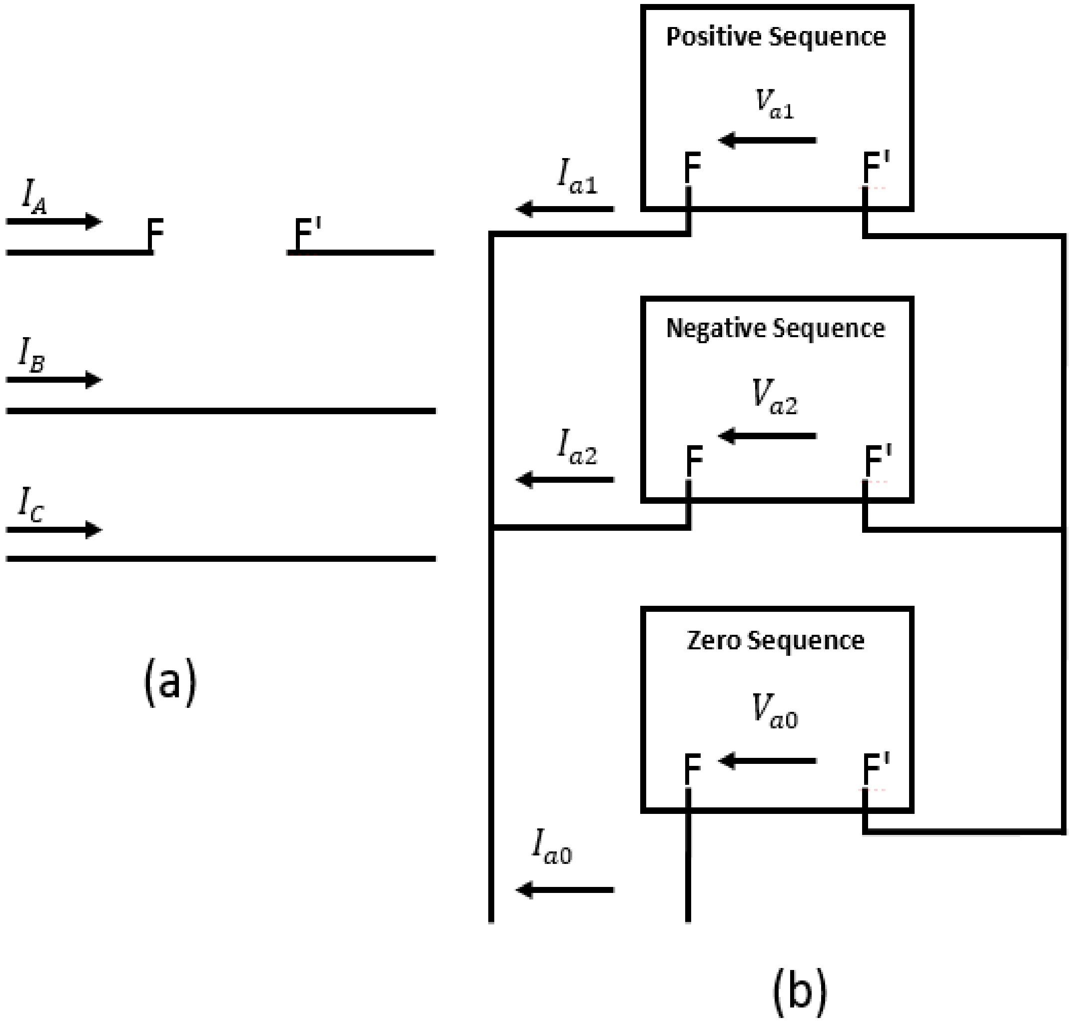

Figure 3-1: (a) One-Conductor Open Series Fault; (b) Connection of Sequence Networks.

From figure (5-1) (a)

$$\boldsymbol{I_A = 0} \tag{3-6}$$

And

$$\boldsymbol{V_B = V_C} \quad . \tag{3-7}$$

So,

$$\boldsymbol{Z_{eq0}} = (\boldsymbol{Z_F} + \boldsymbol{Z_0}) \tag{3-8}$$

$$\boldsymbol{Z_{eq1}} = (\boldsymbol{Z_F} + \boldsymbol{Z_1}) \tag{3-9}$$

$$\boldsymbol{Z_{eq2}} = (\boldsymbol{Z_F} + \boldsymbol{Z_2}) \tag{3-10}$$

And the total impedance will be:

$$\boldsymbol{Z_{eq\,Total}} = \left(\boldsymbol{Z_{eq}} + (\boldsymbol{Z_{eq1}} // \boldsymbol{Z_{eq2}})\right) \tag{3-11}$$

So

$$\boldsymbol{I_{a1}} = \frac{\boldsymbol{V_f}}{\boldsymbol{Z_{eq\,Total}}} \tag{3-12}$$

Also

$$\boldsymbol{I_{a2}} = \frac{\boldsymbol{Z_{eqo}}}{\boldsymbol{Z_{eq0}} + \boldsymbol{Z_{eq2}}} \times \boldsymbol{I_{a1}} \tag{3-13}$$

And

$$\boldsymbol{I_{a0}} = \frac{\boldsymbol{Z_{eq2}}}{\boldsymbol{Z_{eq0}} + \boldsymbol{Z_{eq2}}} \times \boldsymbol{I_{a1}} \tag{3-14}$$

And

$$\boldsymbol{I_{a2}} + \boldsymbol{I_{a1}} + \boldsymbol{I_{a0}} = \boldsymbol{0} \tag{3-15}$$

Also

$$\boldsymbol{V_{a2}} = \boldsymbol{V_{a1}} = \boldsymbol{V_{a0}} = \frac{\boldsymbol{1}}{\boldsymbol{3}} \boldsymbol{V_A} \tag{3-16}$$

So

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \times \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} \tag{3-17}$$

3.4.1.2 Two Line Open

This fault could be happened when two of three phases are broken or disconnected in any place of the transmission line. Also, it could be presented by the equations below according to the figure (3-2) (a and b).

$$V_a = 0 \tag{3-18}$$

And

$$I_a = I_C = 0 \tag{3-19}$$

Also

$$V_{a2} + V_{a1} + V_{a0} = 0 \tag{3-20}$$

Furthermore,

$$I_{a2} = I_{a1} = I_{a0} = \frac{1}{3} I_a \tag{3-21}$$

Mjjjjjjjkj,gmmklk;,nmt;;hjgfhjkflg..,..

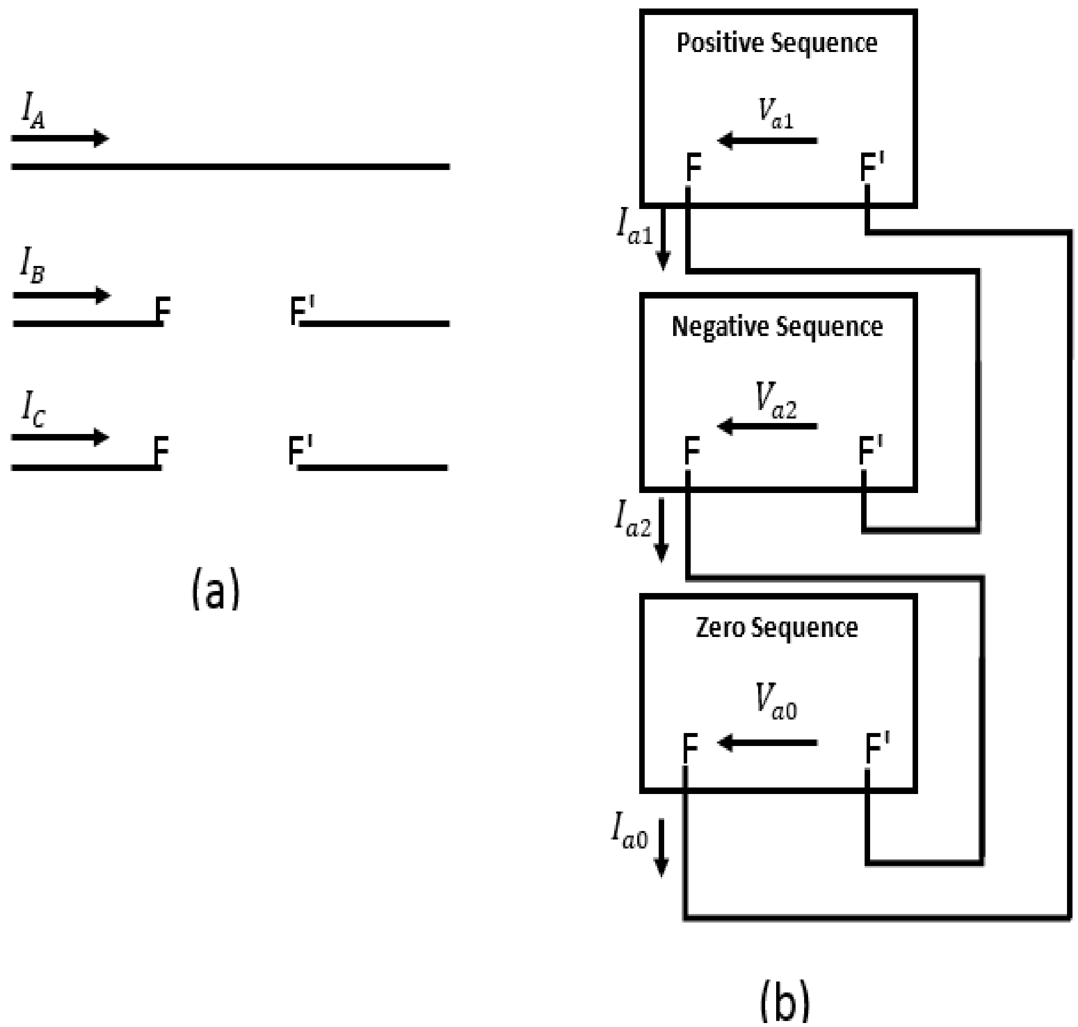

Figure 3-2: (a) Two-Conductor Open Series Fault; (b) Connection of Sequence Networks.

3.4.1.3 Three Line Open

It is not very dangerous as one or two lines open because it is like open circuit and there is no fault. So, in this case the fault already disconnected if this one caused by fault [43].

3.4.2 Shunt Fault

It is the second type of the fault in transmission line [44]. The shunt faults are very popular in the transmission line. Shunt faults are very wide in the transmission line [44]. Also, it becomes to be more effective than the series type because it is affected on the stability, continuity and the equipment, which connected directly to this system. So, there are many factors that are working to make the shunt fault and the result is making the transmission line outage and these factors are like (wind, storm defect on the equipment … etc). As a result it can be classified in to four types.

3.4.2.1 Single Line to Ground (SLG)

It is very common one. It can be defined that one line of three phase transmission line contact with the ground as a result of lightning, external or internal cause. So, this one could be represented as the figure 3. Also, it can be happened in any phase the three phase of transmission line. Let's take the phase A has a (SLG) fault. So the computation could be explained by the equations below.

$$\boldsymbol{I_{FB} = 0} \tag{3-22}$$

$$\boldsymbol{I_{FC} = 0} \tag{3-23}$$

Because there is no current pass through phase B or phase C to ground.

So,

$$\boldsymbol{I_{FA}} = \frac{\boldsymbol{V_{FA}}}{\boldsymbol{Z_F}} \tag{3-24}$$

When I_{FA} is the current that pass from phase A to ground, V_{FA} is the voltage at the point of fault on phase A, and Z_F represents the fault impedance.

The symmetrical components will be expressed as a positive, negative and zero sequence. So, each one could represent as a circuit. Also, each one has Thévenin-equivalent impedance as shown in figure 3b. Furthermore, the positive sequence consists of impedance in addition to voltage source, which is called (Thévenin-equivalent voltage source). So, the equivalent circuit will be formed from all the Thévenin-equivalent impedances of all (positive, negative and zero) [45], as shown in figure (6-3).

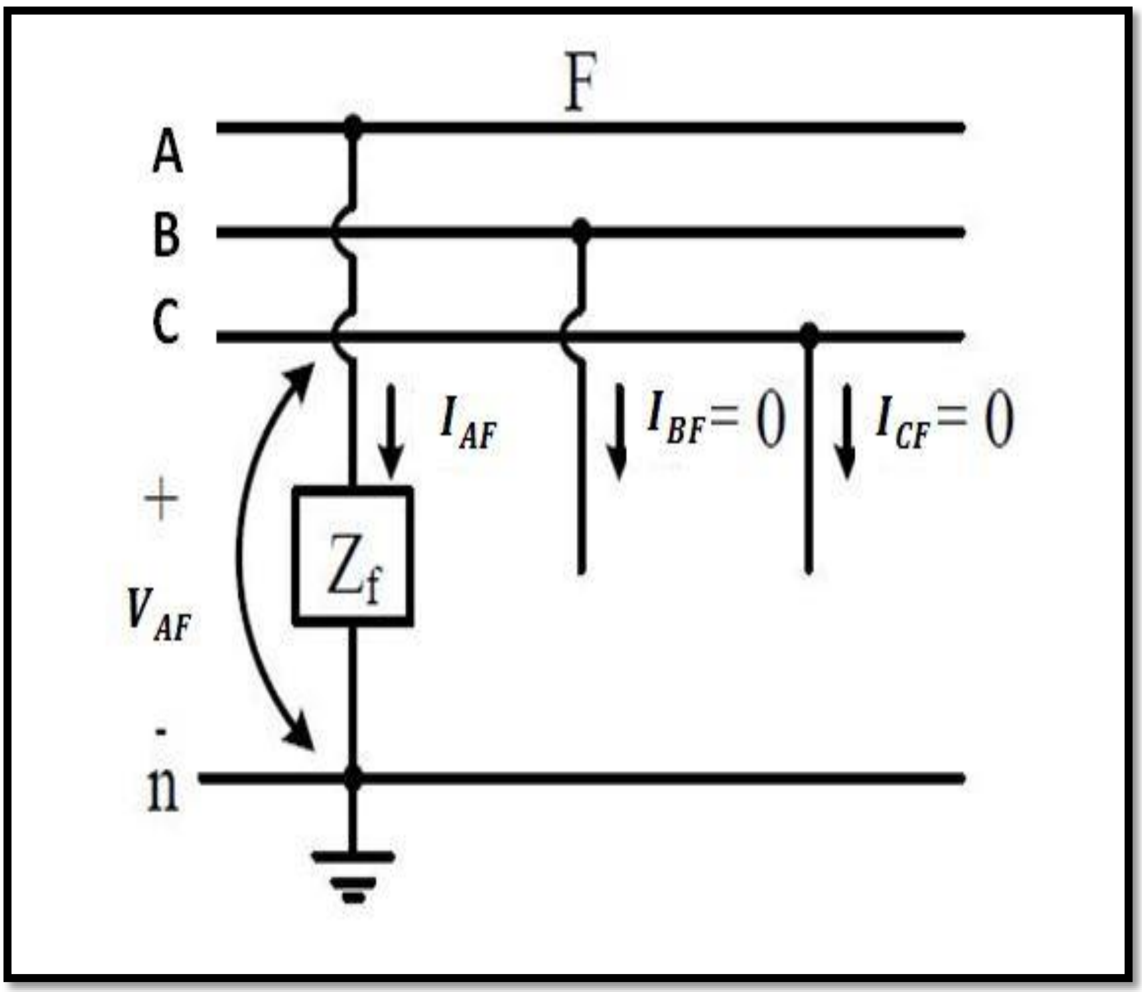

Figure 3-3: General Representation of a Single Line-to-Ground Fault.

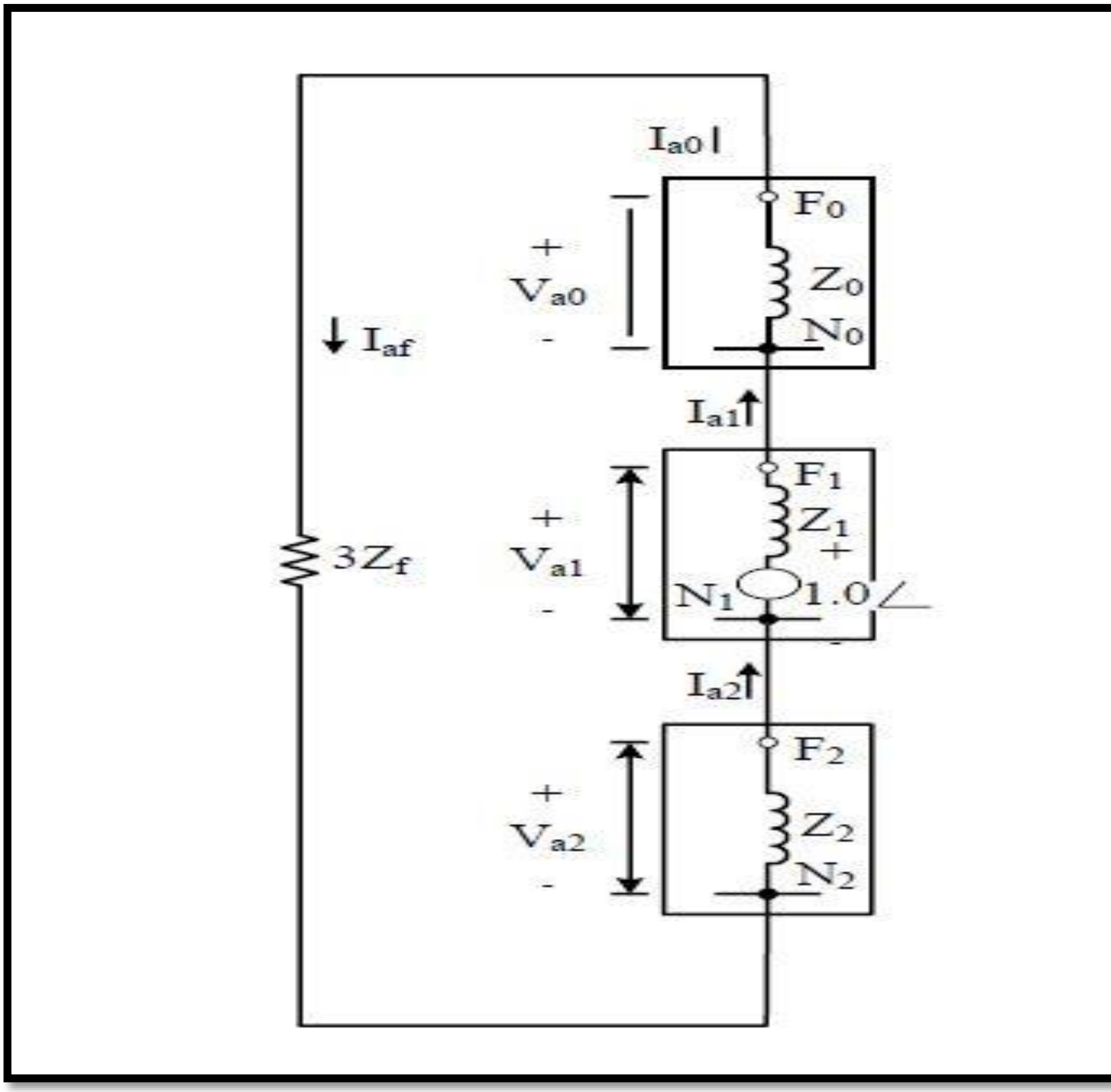

Figure 3-4: Inter Connection of Network Sequence for Single Line to Ground Fault.

$$I_A = I_{a0} + I_{a1} + I_{a2} \tag{3-25}$$

According to the equivalent circuit in figure (6-4). The current is the same for all sequences positive, negative and zero because the series connection.

$$I_{a0} = I_{a1} = I_{a2} \tag{3-26}$$

So,

$$I_A = 3I_{a0} \quad (3\text{-}27)$$

Or

$$I_{a0} = I_{a1} = I_{a2} = \frac{1}{3} I_A \quad (3\text{-}28)$$

Also,

$$I_B = I_{b0} + I_{b1} + I_{b2} = 0 \quad (3\text{-}29)$$

And,

$$I_C = I_{c0} + I_{c1} + I_{c2} = 0 \quad (3\text{-}30)$$

And it can be solved as below:

$$\begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \times \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} \quad (3\text{-}31)$$

When

$$a = 1\angle 120^\circ \quad (3\text{-}32)$$

$$a^2 = 1\angle 240^\circ \quad (3\text{-}33)$$

And for the voltages

$$V_A = I_A \times Z_F = 3I_{a0} \times Z_F \quad (3\text{-}34)$$

$$V_A = 0 = V_{a0} + V_{a1} + V_{a2} = 3I_{a0} \times Z_F \quad (3\text{-}35)$$

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ V_F \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 + Z_F & 0 & 0 \\ 0 & Z_1 + Z_F & 0 \\ 0 & 0 & Z_2 + Z_F \end{bmatrix} \times \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} \tag{3-36}$$

So,

$$I_{FA} = \frac{3 \times V_F}{Z_0 + Z_1 + Z_2 + 3Z_F} \tag{3-37}$$

3.4.2.2 Line to Line (L-L)

This fault comes in the second order of the shunt faults by the probability of shunt fault occurs [43]. So it can be represented as in figure (6-5) below consider phase B connected to phase C, then the calculation will be expressed by the equations below [46].

$$I_A = 0 \tag{3-38}$$

$$I_B = -I_C \tag{3-39}$$

In this type of fault ($I_{a0} = 0$) because the Thévenin-equivalent of zero impedance will not connect on the circuit as in figure (6-5) below [45].

So,

$$I_{a0} + I_{a1} + I_{a2} = 0 \tag{3-40}$$

But,

$$I_{a0} = 0 \tag{3-41}$$

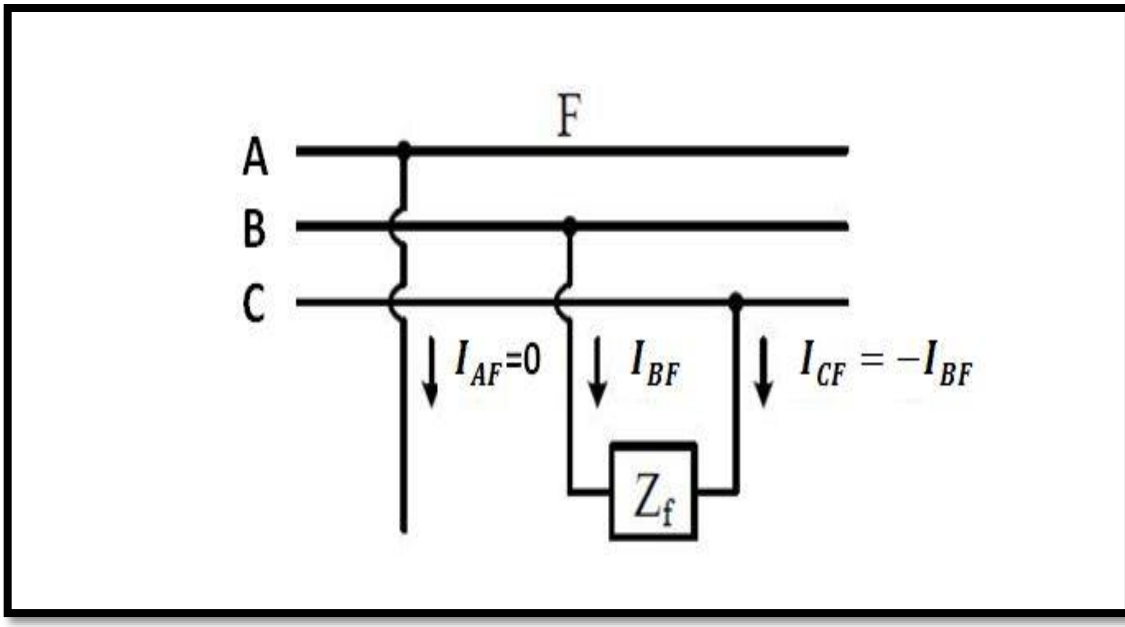

Figure 3-5: General Representation of Double Line Fault.

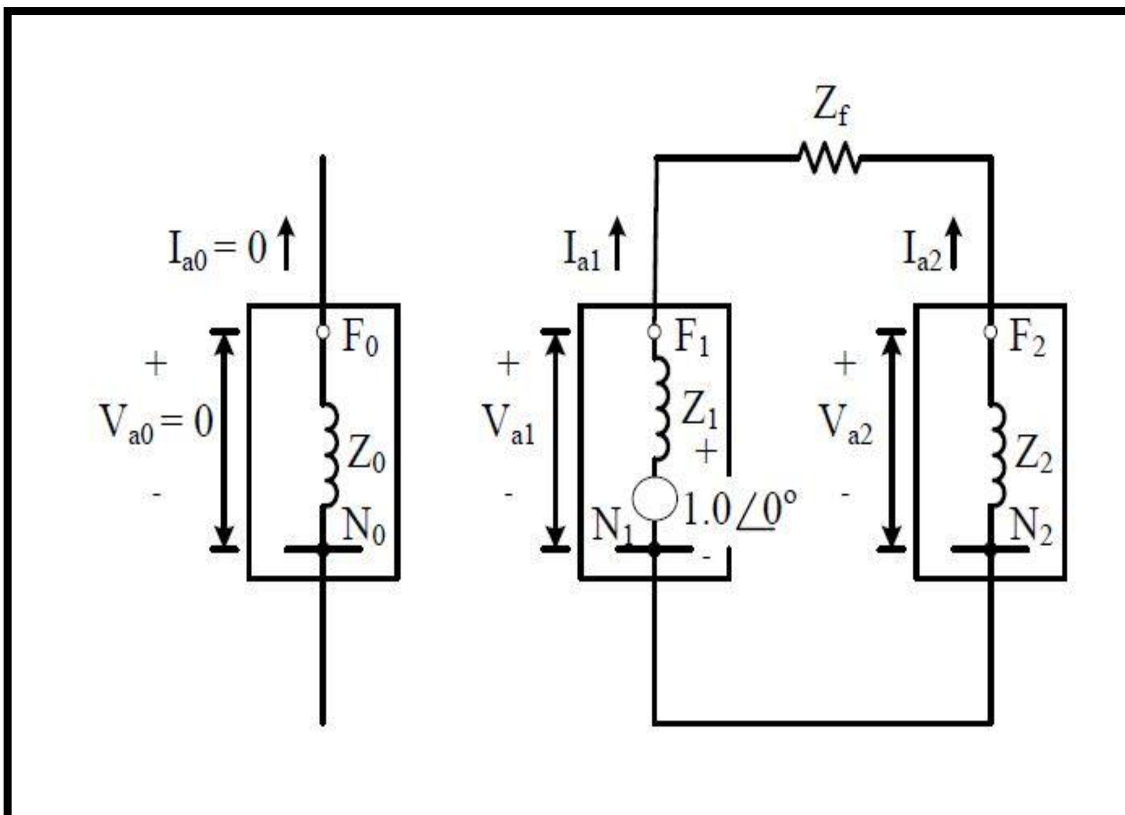

Figure 3-6: Inter Connection of Network Sequence for Double Line Fault.

Then

$$(\boldsymbol{I_{a1}} + \boldsymbol{I_{a2}} = \boldsymbol{0}) \tag{3-42}$$

Or

$$(\boldsymbol{I_{a1}} = -\boldsymbol{I_{a2}}) \tag{3-43}$$

Also,

$$\begin{bmatrix} \boldsymbol{I_{a0}} \\ \boldsymbol{I_{a1}} \\ \boldsymbol{I_{a2}} \end{bmatrix} = \frac{1}{3} \times \begin{bmatrix} \boldsymbol{1} & \boldsymbol{1} & \boldsymbol{1} \\ \boldsymbol{1} & \boldsymbol{a} & \boldsymbol{a^2} \\ \boldsymbol{1} & \boldsymbol{a^2} & \boldsymbol{a} \end{bmatrix} \times \begin{bmatrix} \boldsymbol{I_A} \\ \boldsymbol{I_B} \\ \boldsymbol{I_C} \end{bmatrix} \tag{3-44}$$

So, in the same way of the currents it can be calculated from the matrix below.

$$\boldsymbol{V_B} - \boldsymbol{V_C} = \boldsymbol{I_B Z_F} \tag{3-45}$$

Also,

$$\begin{bmatrix} \boldsymbol{I_{a0}} \\ \boldsymbol{I_{a1}} \\ \boldsymbol{I_{a2}} \end{bmatrix} = \frac{1}{3} \times \begin{bmatrix} \boldsymbol{1} & \boldsymbol{1} & \boldsymbol{1} \\ \boldsymbol{1} & \boldsymbol{a} & \boldsymbol{a^2} \\ \boldsymbol{1} & \boldsymbol{a^2} & \boldsymbol{a} \end{bmatrix} \times \begin{bmatrix} \boldsymbol{0} \\ \boldsymbol{I_B} \\ -\boldsymbol{I_B} \end{bmatrix} = \frac{1}{3} \times \begin{bmatrix} \boldsymbol{0} \\ (\boldsymbol{a} - \boldsymbol{a^2})\boldsymbol{I_B} \\ (\boldsymbol{a^2} - \boldsymbol{a})\boldsymbol{I_B} \end{bmatrix} \tag{3-46}$$

So,

$$(\boldsymbol{V_{a0}} + \boldsymbol{a^2 V_{a1}} + \boldsymbol{a V_{a2}}) - (\boldsymbol{V_{a0}} + \boldsymbol{a V_{a1}} + \boldsymbol{a^2 V_{a2}}) = \boldsymbol{Z_F}(\boldsymbol{I_{a0}} + \boldsymbol{a^2 I_{a1}} + \boldsymbol{a I_{a2}}) \tag{3-47}$$

But

$$(\boldsymbol{V_{a0}} = \boldsymbol{0}) \tag{3-48}$$

$$(\boldsymbol{V_{a0}} = \boldsymbol{0}) \tag{3-49}$$

$$(\boldsymbol{I_{a1}} = -\boldsymbol{I_{a2}}) \tag{3-50}$$

Then

$$(\boldsymbol{a^2} - \boldsymbol{a})\boldsymbol{V_{a1}} - (\boldsymbol{a^2} - \boldsymbol{a})\boldsymbol{V_{a2}} = \boldsymbol{Z_F} \times (\boldsymbol{a^2} - \boldsymbol{a})\boldsymbol{I_{a1}} \tag{3-51}$$

Divided by $(a^2 - a)$

$$\boldsymbol{V_{a1}} - \boldsymbol{V_{a2}} = \boldsymbol{Z_F} \times \boldsymbol{I_{a1}} \tag{3-52}$$

And

$$\boldsymbol{I_{a1}} = -\boldsymbol{I_{a2}} = \frac{\boldsymbol{V_F}}{\boldsymbol{Z_1} + \boldsymbol{Z_2} + \boldsymbol{Z_F}} \tag{3-53}$$

For the current in phase B

$$\boldsymbol{I_B} = \boldsymbol{I_{a0}} + \boldsymbol{a^2}\boldsymbol{I_{a1}} + \boldsymbol{a}\boldsymbol{I_{a2}} \tag{3-54}$$

Then

$$\boldsymbol{I_B} = (\boldsymbol{a^2} - \boldsymbol{a})\boldsymbol{I_{a1}} \tag{3-55}$$

But

$$(\boldsymbol{a^2} - \boldsymbol{a}) = -\boldsymbol{j}\sqrt{\boldsymbol{3}} = \sqrt{\boldsymbol{3}}\angle - \boldsymbol{90}^{\circ} \tag{3-56}$$

The final equation for the current in phase B

$$\boldsymbol{I_B = \frac{-j\sqrt{3}V_F}{Z_1+Z_2+Z_F} = \frac{(\sqrt{3}\angle -90^{\circ})\times V_F}{Z_1+Z_2+Z_F}} \tag{3-57}$$

Also,

$$\boldsymbol{I_C = -I_B = \frac{j\sqrt{3}V_F}{Z_1+Z_2+Z_F} = \frac{(\sqrt{3}\angle 90^{\circ})\times V_F}{Z_1+Z_2+Z_F}} \tag{3-58}$$

In the same way to find the voltages from the matrix below

$$\boldsymbol{\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \times \begin{bmatrix} 0 \\ V_{a1} \\ V_{a2} \end{bmatrix}} \tag{3-59}$$

And the line to line voltages are

$$\boldsymbol{V_{AB} = V_A - V_B} \tag{3-60}$$

$$\boldsymbol{V_{BC} = V_B - V_C} \tag{3-61}$$

$$\boldsymbol{V_{CA} = V_C - V_A} \tag{3-62}$$

3.4.2.3 Double Line to Ground (DLG)

It is the third type of the shunt fault and the probability of this fault is less than the two types above. It happens when line of three phase contact the other line of the two phase remaining to the ground [47]. So, the main changes in this type of fault are two things. The magnitude of the impedance with the ground Z_g and the assumption of the impedance fault Z_F. Also, this fault in it is not cleared in the shortest possible time it may expand to become a three phase fault [44] [47]. In figure (6-7) below explains the DLG fault through the fault impedance with the ground impedance fault. Assuming phase B and Phase C are the DLG faulted.

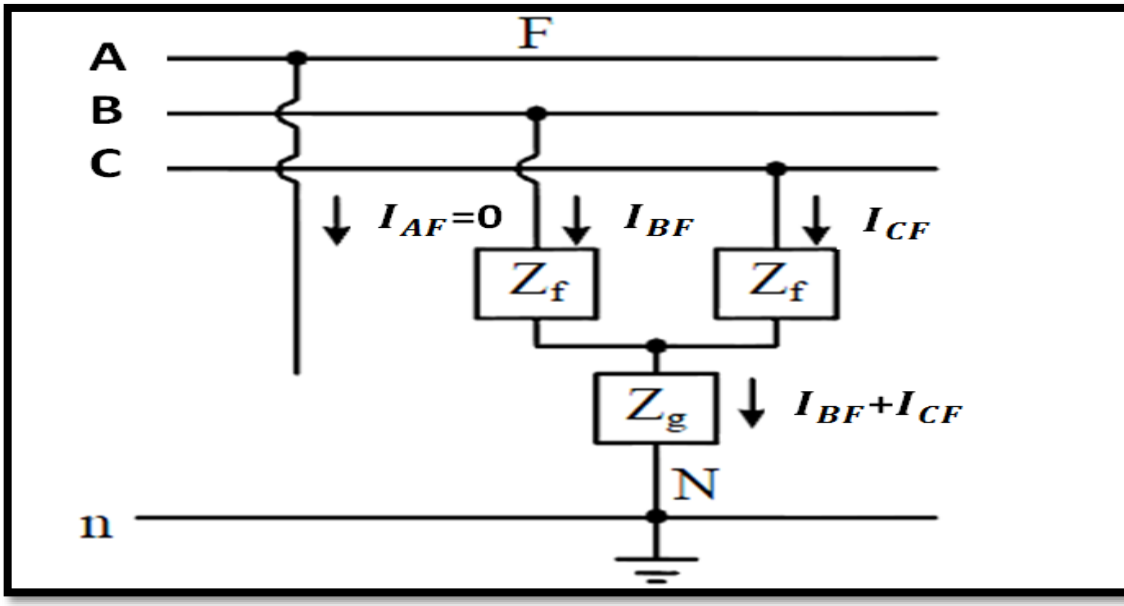

Figure 3-7: General Representation of Double Line-to-Ground Fault.

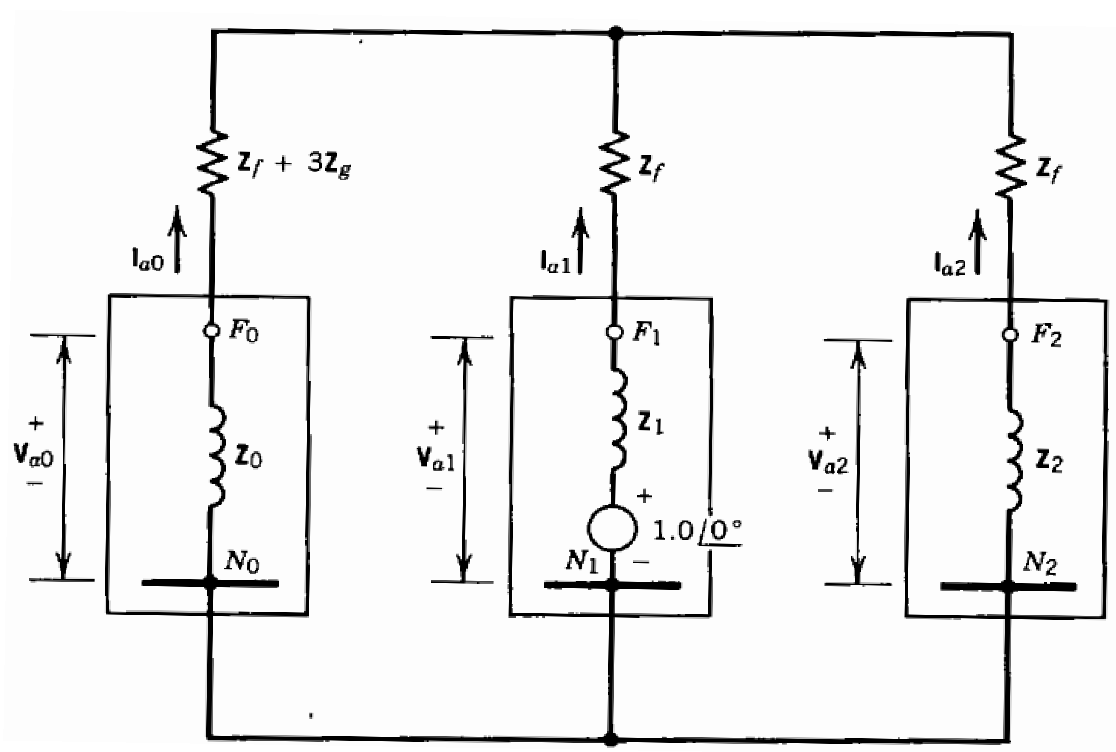

Figure 3-8: Inter Connection of Network Sequence for Double Line-to-Ground Fault.

$$\boldsymbol{I_A = 0} \tag{3-63}$$

And

$$\boldsymbol{I_{a0} + I_{a1} + I_{a2} = 0} \tag{3-64}$$

Also,

$$\boldsymbol{V_B = \left(Z_F + Z_g\right)I_B + Z_g I_C} \tag{3-65}$$

In the same way for V_C

$$\boldsymbol{V_C = \left(Z_F + Z_g\right)I_C + Z_g I_B} \tag{3-66}$$

So,

$$\boldsymbol{I_{a1} = \frac{V_F}{(Z_1+Z_F)+\left(\frac{(Z_2+Z_F)(Z_0+Z_F+3Z_g)}{Z_0+Z_2+2Z_F+3Z_g}\right)}} \tag{3-67}$$

By current divider

$$\boldsymbol{I_{a2} = -\left(\frac{(Z_0+Z_F+3Z_g)}{(Z_2+Z_F)(Z_0+Z_F+3Z_g)}\right) \times I_{a1}} \tag{3-68}$$

And

$$\boldsymbol{I_{a0} = -\left(\frac{(Z_2+Z_F)}{(Z_2+Z_F)(Z_0+Z_F+3Z_g)}\right) \times I_{a1}} \tag{3-69}$$

In the case of $Z_g = 0$

$$I_{a1} = \frac{V_F}{(Z_1) + \left(\frac{(Z_2)(Z_0+3Z_F)}{Z_0+Z_2+3Z_F}\right)} \tag{3-70}$$

By current divider

$$I_{a2} = -\left(\frac{Z_0+3Z_F}{Z_2+Z_0+3Z_F}\right) \times I_{a1} \tag{3-71}$$

And

$$I_a = -\left(\frac{Z_2}{Z_2+Z_0+3Z_F}\right) \times I_{a1} \tag{3-72}$$

In the case of $Z_F = 0$, and $Z_g = 0$ the positive negative and zero sequence can be explained in figure (6-9). Below

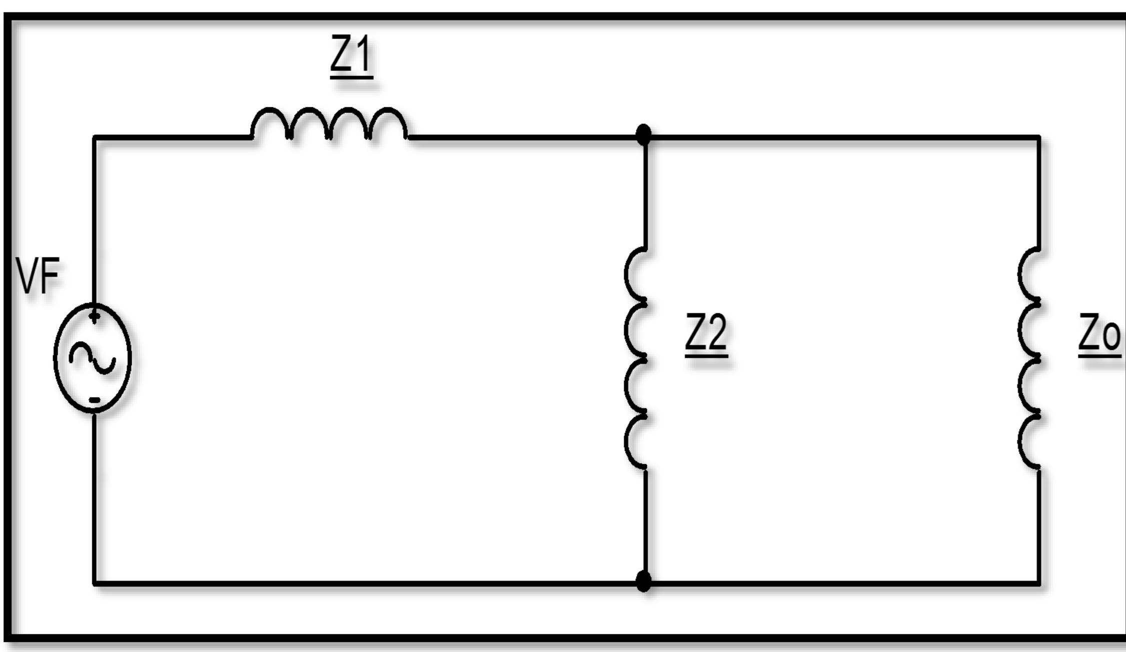

Figure 3-9: Double Line to Ground Fault without $\mathbf{Z_F}$ and $\mathbf{Z_g}$.

$$\boldsymbol{I_{a1}} = \frac{\boldsymbol{V_F}}{\boldsymbol{Z_1} + \left(\frac{\boldsymbol{Z_2} \times \boldsymbol{Z_0}}{\boldsymbol{Z_0} + \boldsymbol{Z_2}}\right)} \tag{3-73}$$

And by current divider

$$\boldsymbol{I_{a2}} = -\left(\frac{\boldsymbol{Z_0}}{\boldsymbol{Z_2} + \boldsymbol{Z_0}}\right) \times \boldsymbol{I_{a1}} \tag{3-74}$$

And

$$\boldsymbol{I_{a2}} = -\left(\frac{\boldsymbol{Z_2}}{\boldsymbol{Z_0} + \boldsymbol{Z_2}}\right) \times \boldsymbol{I_{a1}} \tag{3-75}$$

Also,

$$\begin{bmatrix} \boldsymbol{0} \\ \boldsymbol{I_B} \\ \boldsymbol{I_C} \end{bmatrix} = \begin{bmatrix} \boldsymbol{1} & \boldsymbol{1} & \boldsymbol{1} \\ \boldsymbol{1} & \boldsymbol{a^2} & \boldsymbol{a} \\ \boldsymbol{1} & \boldsymbol{a} & \boldsymbol{a^2} \end{bmatrix} \times \begin{bmatrix} \boldsymbol{I_{a0}} \\ \boldsymbol{I_{a1}} \\ \boldsymbol{I_{a2}} \end{bmatrix} \tag{3-76}$$

The total fault current passing through the neutral is [44]

$$\boldsymbol{I_n} = \boldsymbol{3I_{a0}} = \boldsymbol{I_B} + \boldsymbol{I_C} \tag{3-77}$$

So, it is easy to calculate the voltages

$$\begin{bmatrix} \boldsymbol{V_{a0}} \\ \boldsymbol{V_{a1}} \\ \boldsymbol{V_{a2}} \end{bmatrix} = \begin{bmatrix} \boldsymbol{0} \\ \boldsymbol{V_F} \\ \boldsymbol{0} \end{bmatrix} - \begin{bmatrix} \boldsymbol{Z_0} + \boldsymbol{Z_F} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{Z_1} + \boldsymbol{Z_F} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{Z_2} + \boldsymbol{Z_F} \end{bmatrix} \times \begin{bmatrix} \boldsymbol{I_{a0}} \\ \boldsymbol{I_{a1}} \\ \boldsymbol{I_{a2}} \end{bmatrix} \tag{3-78}$$

The phase voltages will be

$$\begin{bmatrix} \boldsymbol{V_a} \\ \boldsymbol{V_b} \\ \boldsymbol{V_c} \end{bmatrix} = \begin{bmatrix} \boldsymbol{1} & \boldsymbol{1} & \boldsymbol{1} \\ \boldsymbol{1} & \boldsymbol{a^2} & \boldsymbol{a} \\ \boldsymbol{1} & \boldsymbol{a} & \boldsymbol{a^2} \end{bmatrix} \times \begin{bmatrix} \boldsymbol{V_{a0}} \\ \boldsymbol{V_{a1}} \\ \boldsymbol{V_{a2}} \end{bmatrix} \tag{3-79}$$

For $Z_F = 0$, and $Z_g = 0$ then

$$\boldsymbol{V_{a0} = V_{a1} = V_{a2} = V_F - (I_{a1} \times Z_1)} \tag{3-80}$$

So,

$$\boldsymbol{V_A = V_{a0} + V_{a1} + V_{a2} = 3V_{a1}} \tag{3-81}$$

Also,

$$\boldsymbol{V_B = V_C = 0} \tag{3-82}$$

And the line to line voltages

$$\boldsymbol{V_{AB} = V_A - V_B = V_A} \tag{3-83}$$

$$\boldsymbol{V_{BC} = V_B - V_C = 0} \tag{3-84}$$

$$\boldsymbol{V_{CA} = V_C - V_A = -V_A} \tag{3-85}$$

3.4.2.4 Balanced or Symmetrical Three Phase Faults

It is the last type of the shunt faults on the transmission line system. Also, it can use the symmetrical components to calculate all voltages and other values, which is needed [47]. In this type there is no zero and negative sequences connected with the voltage sequence. So, the positive sequence is only the circuit that will represent this fault. Also, it can refer from above there is no current pass through the ground impedance even the value is equal zero or infinite [48]. Figure (6-10) and Figure (6-11) represent the three phase fault in transmission line and the equivalent circuit for the symmetrical components respectively.

Also, the fault voltage is very important and it completes the information about this type of fault. Most of the time V_F is unknown and in general it has taken from ($1.0\angle 0^{\circ} V$–$1.1\angle 0^{\circ} V$) p.u. mostly it is taken ($1.05\angle 0^{\circ} V$). Also, it is considered a reference for the computation [48].

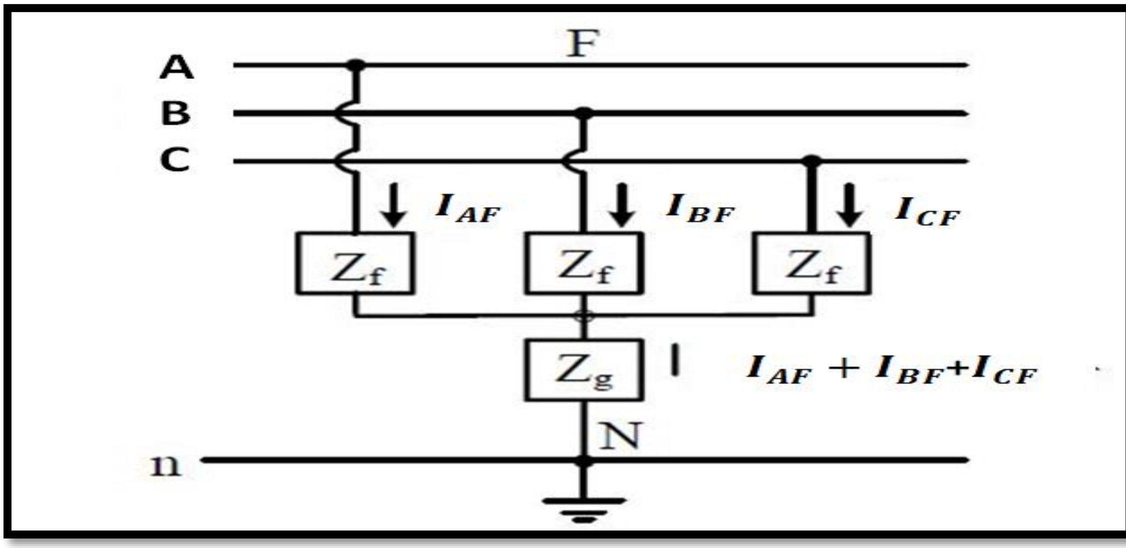

Figure 3-10: General Representation of a Three Phase-to-Ground Fault.

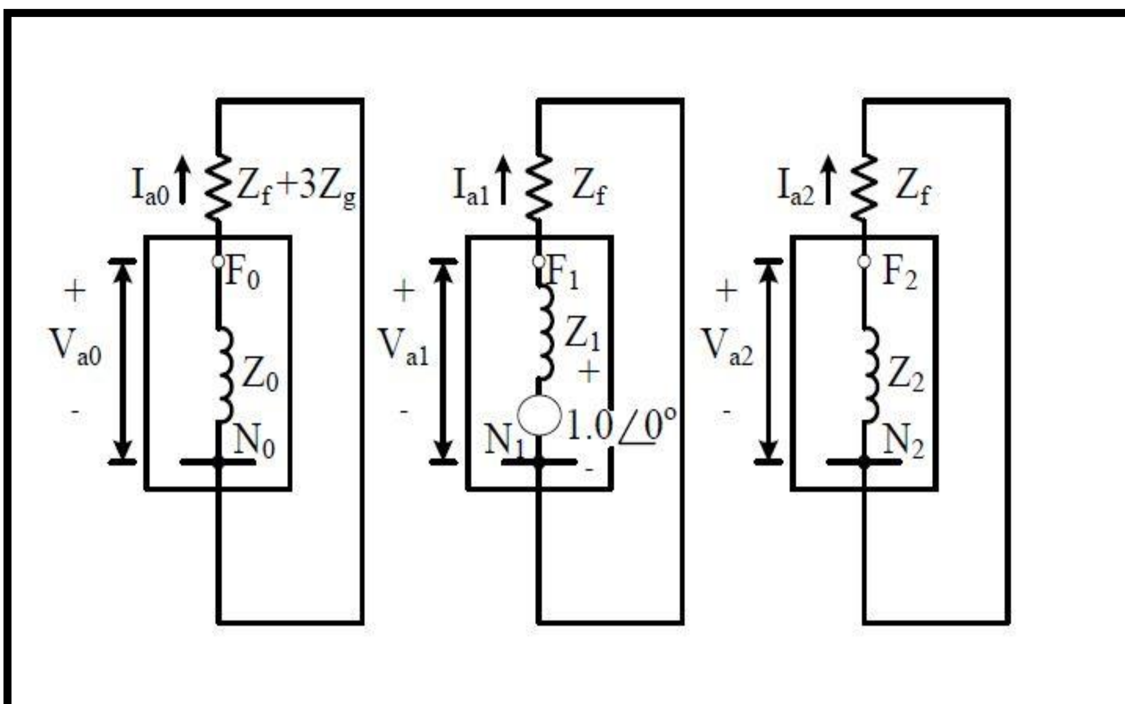

Figure 3-11: Inter Connection of Network Sequence for Three Phase-to-Ground Fault.

$$I_A = I_{a1} = \frac{V_F}{Z_1 + Z_F} \quad (3\text{-}86)$$

And

$$V_{a1} = \frac{1}{3}(V_a + aV_b + a^2V_c) = \frac{1}{3}(I_A + a^2I_B + aI_C)Z_F \quad (3\text{-}87)$$

For the phase current

$$I_B = a^2 I_{a1} \quad (3\text{-}88)$$

And

$$I_C = aI_{a1} \quad (3\text{-}89)$$

Then the positive sequence voltage will be

$$V_{a1} = \frac{1}{3}(I_{a1} + I_{a1} + I_{a1})Z_F \quad (3\text{-}90)$$

So,

$$V_{a1} = I_{a1}Z_F \quad (3\text{-}91)$$

Also,

$$V_A = I_A Z_F = V_{a1} \quad (3\text{-}92)$$

$$V_B = a^2 V_{a1} \quad (3\text{-}93)$$

$$V_C = aV_{a1} \quad (3\text{-}94)$$

And the currents for the other sequences are

$$\boldsymbol{I_{a0} = I_{a2} = 0} \tag{3-95}$$

So, it is easy to calculate the voltages

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ V_F \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix} \times \begin{bmatrix} 0 \\ I_{a1} \\ 0 \end{bmatrix} \tag{3-96}$$

Furthermore, the line to line voltages can be founded from the formulas below.

$$V_{AB} = V_A - V_B = (1 - a^2)V_A = \sqrt{3} I_{a1} Z_F \angle 30^{\circ} \tag{3-97}$$

$$V_{BC} = V_B - V_C = (a^2 - a)V_A = \sqrt{3} I_{a1} Z_F \angle -90^{\circ} \tag{3-98}$$

$$V_{CA} = V_C - V_A = (a - 1)V_A = \sqrt{3} I_{a1} Z_F \angle 150^{\circ} \tag{3-99}$$

3.5 Types of Protection Methods Used in Transmission Line

3.5.1 Introduction

There are many types of methods of protection that applied to protect the transmission line, and each one has advantages and disadvantages. Thus these methods are affecting on the behavior of the transmission line when the fault occurs. Also, these methods affected by the external and internal factors depending on the situation of the transmission line before the fault [49].

3.5.2 Distance Method

The distance method his operation depends on the two important things. First, applied voltage. Second, the current passes through this transmission line. Thus, the ratio of the applied voltage to the current that flows in the transmission line will represent the impedance; therefore, the distance relay is measuring the effectiveness of the impedance of the transmission line to be protected. So, this method works if the fault happens. Hence, the parameters will be counted according to the measurements and these instruments were installed to measure the voltage and the current all the time. As a result, under the fault condition the voltage will drop or fall very fast, and the current will increase and become very large in the same time. According to the ohm's law the impedance will decrease based on the current data that collected from the VT and CT. This method is used to protect the transmission line. It works depending on the impedance measurement [50]. Also, the transmission line has to be divided into zones to calculate the impedance in each zone, put the proper time delay for each zone and to make the protection more effective because if the transmission line is considered a one zone the distance relay protection will be not be accurate due to the impedance per distance, the drop voltage and the phase shift due to the line inductance. Thus, the number of zones depends on the length of the transmission line [50]. While the impedance proportional to the length of the transmission line; Therefore, the relay used in this method called distance relay.

$$\boldsymbol{Z_m = \frac{V_f}{I_f}} \tag{3-100}$$

Where Z_m is the total magnitude of the fault impedance with the line impedance from the source to the fault point$(Z_f + Z_s)$, V_f is the fault voltage and I_f is the fault current.

In general, the impedance distance relay calculates the value of the complex impedance. Also, it can be represented by the figure (7-1) below.

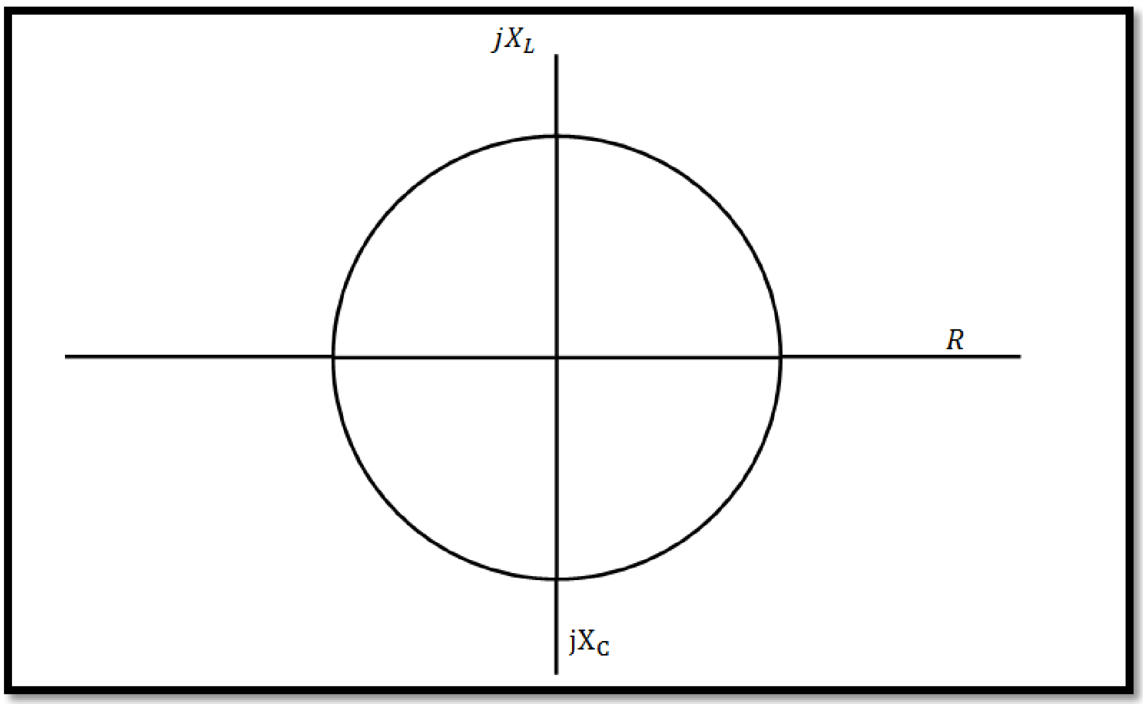

Figure 3-12: R-X Diagram for the Generic Impedance Relay.

So, the X-axis represents the resistor (real part) and the Y-axis represents the inductor or the capacitor (imaginary part).

According to the figure the relay will consider each point with or within the circle as a fault. Also, the radius of this circle will be

$$\boldsymbol{r_d} = \sqrt{(\boldsymbol{R^2} + \boldsymbol{X^2}} \quad (3\text{-}101)$$

For example: let the setting impedance is

$$\boldsymbol{Relay\ setting\ impedance = R_a + X_a} \quad (3\text{-}102)$$

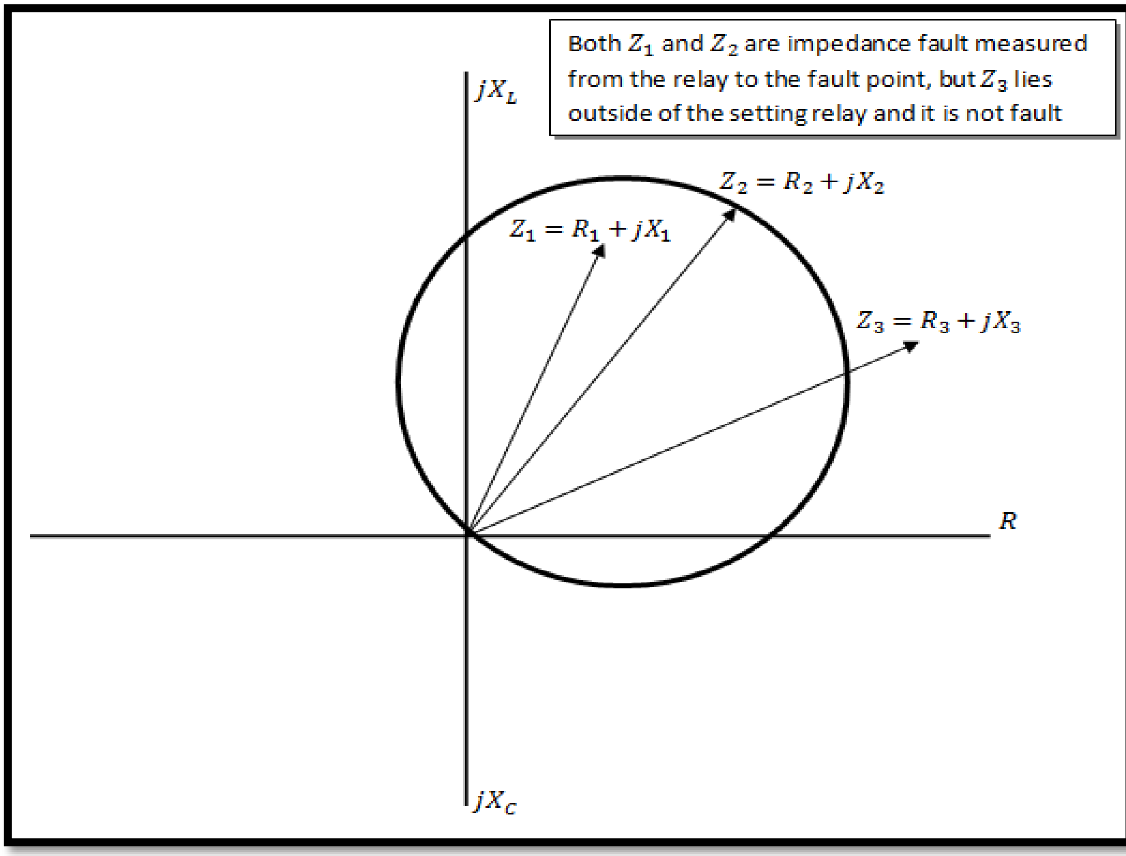

Figure 3-13: R-X Diagram for mho Relay.

For all types of the fault the table below shows the equation of each type of fault:

Table 3-1: Impedance Calculation for any Type of Fault.

Fault type	Formula
AG, BG or CG	$V_A/(I_A+KI_o)$, $V_B/(I_B+KI_o)$ and $V_C/(I_C+KI_o)$ Respectively
AB/ABG	$(V_A - V_B)/(I_A - (-I_B))$
AC/ACG	$(V_B - V_C)/(I_B - (-I_C))$
BC/BCG	$(V_C - V_A)/(I_C - (-I_A))$
ABC/ABCG	$V_A/(I_A)$, $V_B/(I_B)$ OR $V_B/(I_B)$

Where:

A, B, C indicates faulty phase, G indicates Ground.

I_A, I_B and I_C indicates Phase Currents.

V_A, V_B and V_C Indicates Phase Voltages.

$K = (Z_o - Z_1)/3Z_1$, Residual compensation factor.

Z_o and Z_1 are the zero-sequence impedance , positive-sequence impedance respectively

$I_o = \frac{1}{3}(I_A + I_B + I_C)$, I_o is the zero-sequence current

So, if the impedance that the relay measured it is equal or less than $(R_a + X_a)$ the relay will send a trip signal to disconnect the circuit breaker due to the fault. Otherwise, the relay should not response and it will stay idle. For the directional impedance relay it is used to limit the distance relay reach from the reverse direction. So, the mho relay measures the admittance as in figure (9).

Also, it is considered a directional impedance relay as in figure (10) according to the characteristics of this relay which is mostly lies in the first quadrant of the (R and X) diagram. Furthermore, it can be moved to any position according to the purpose of using this relay.

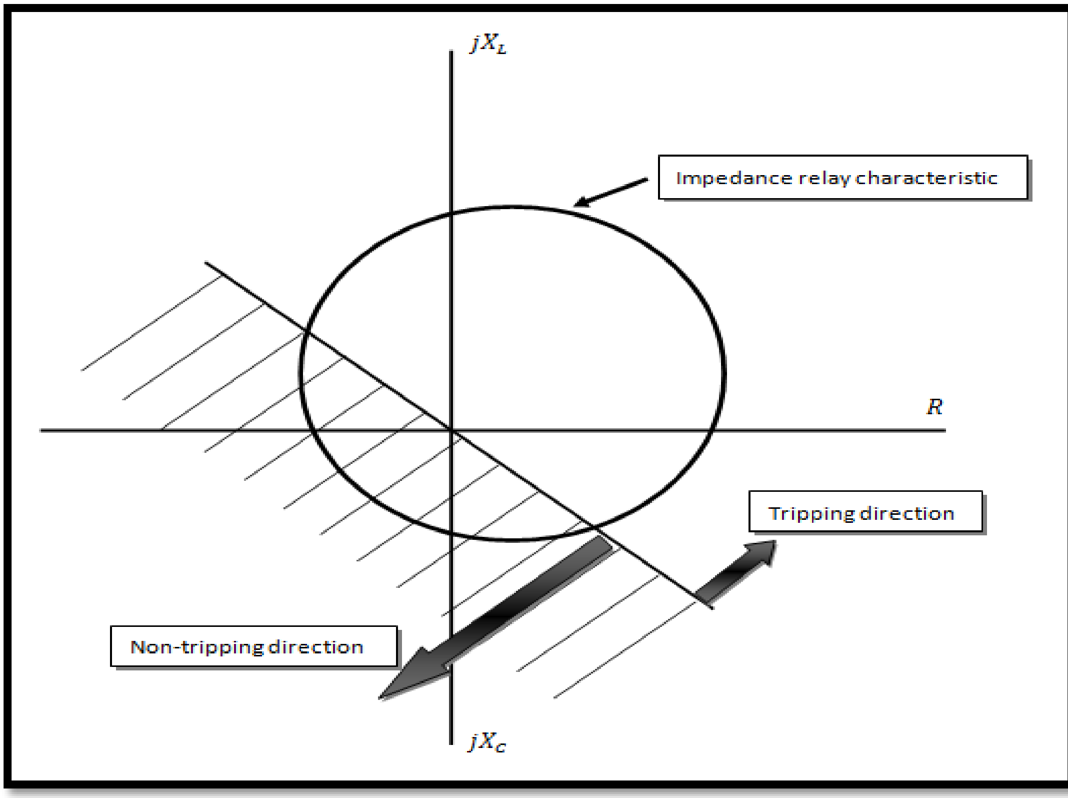

Figure 3-14: R-X Diagram for a Directional Impedance Relay.

3.5.3 Directional Method

This method is commonly used and has many types like (directional current, directional voltage and directional power), But the directional over current is the most popular one in transmission line protection [51] [52]. The fault current may be passing through the transmission line towards the load or passing in the opposite direction of the normal current. Thus, under no fault the current normally going from the source to the load this method can be used to detect the direction fault current with a specific voltage angle, which has chosen to define the other parameters according to this reference voltage.

As other methods has a requirement to operate. So, it needs the voltage with phase shift and current with phase shift to detect the fault. Such, the displacement phase shift of the current from the voltage reference, which previously identified has to determine and recognize the fault current [53]. For example, if the direction method used to check the direction of the current as a protection, then the pre fault current will be known according to the reference voltage with the line impedance. According to Kirchhoff's law the equation will be

$$\boldsymbol{I_{prefault}} = \frac{\boldsymbol{V_{reference}}}{\boldsymbol{Z_{line}}} \tag{3-103}$$

Also, the line impedance has two parts real part and imaginary part (R + jX) and most of the time the imaginary part is an inductive. Thus, the pre fault current will be lagging that means the current angle will be negative, then if fault happen at any point in the transmission line the fault current will have a new angle. Hence, the current will have new angle it is easy to recognize the changing in the current angle and make a decision if that fault according to the setting and the permittivity. In figure below, the reverse current will be detected by the directional relay due to the current angle, which is different as compare with the pre fault current.

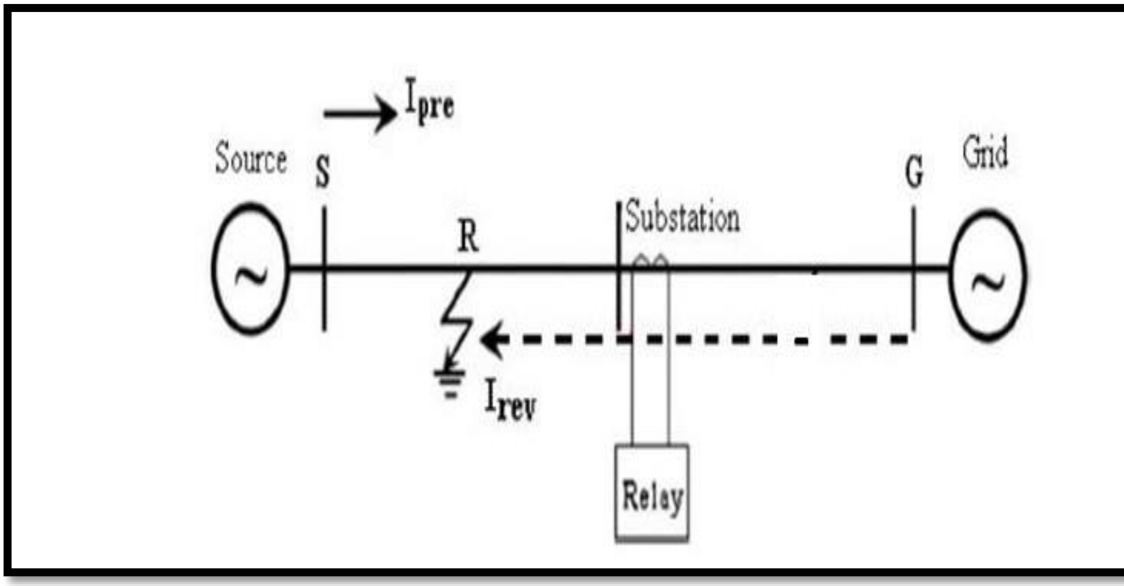

Figure 3-15: Directional Over Current Relay.

3.5.4 Over Current Method

This method depends on the increasing of the current in the system due to abnormal behavior. It is widely used in the medium voltage in the transmission line, which is used in the distribution system more than the grid, ring or two sources because of the best protection for these systems is the Directional Over Current. There are many types of this method such as (inverse time, very inverse time, extremely inverse time, etc) [54]. Also, it is classified in to two types instantaneous and time delay according to the response. Over current method operates when the current exceeds the current limitation [54]. Thus, it is used as a main protection even a buck up protection. Therefore, the time delay has a time delay to send a trip signal, but the instantaneous one is made to operate directly (no time delay). So, the time that will spend to clear the fault is limited and known according to the design. Over current relays have many current ranges and tap setting. See the table below [54].

Table 3-2: Relays Tap Range and Tap Setting.

TAP RANGE	TAP SETTING
0.5-2.5 Or (0.5-2)	0.5,0.6,0.8,1.0,1.2,1.5,2.0,2.5
0.5-4	0.5,0.6,0.7,0.8,1.0,1.2,1.5,2.0,2.5,3.0,4.0
1.5-6 Or (2-6)	1.5,2.0,2.5,3.0,3.5,4,5,6
4-16 Or (4-12)	4,5,6,7,8,10,12,16
1-12	1.0,1.2,1.5,2.0,2.5,3.0,3.5,4,5,6,7,8,10,12

3.5.5 Differential Method

This method is depending on the theory that the input value of any variable should be equaled to the output value of the same variable like the output current has to be same value of the input current, which delivered to the load under the normal operation[55]. It has to be same in the zone to be protected, but when the fault or any abnormal behavior happen in specific zone some of this current will pass through the fault point. So, the current out of the zone will be less than the current into the zone. Thus, the summation of both currents (taking into consideration the direction of both currents) gives a value (it means no zero), this magnitude will make the relay to operate and make a decision if there is a fault or not depending on the pre-set value. As a result, the sensitivity of the relay to the fault can be adjusted due to many factors. So, the accuracy of the equipment and the method that is used to transfer the information from the end side to the send side, which will compare and make a decision will play an important role in this process. Therefore, these factors effect on the sensitivity of the relay. Above all, this method is used to detect the fault immediately and sensitive for the sudden rising in the current and the out of the zone faults [55].

There are many types of differential relays as below:

a. Over current differential relay

b. Pilot wire differential relay

c. High impedance differential relay

d. Percentage differential relay

    1. Fixed percentage (restraint) differential

    2. Variable percentage (restraint) differential

    3. Harmonic-current percentage differential

The differential method provides the high-speed protection, high sensitivity and inherently selective protection. On the other hand, the main problem with his method is the error of the equipment that are used in sending and receiving ends. However, this problem of the relay which has error due to the manufacturing differences even both C.T's are the same (in typing and rating) by using the relay which has two windings that called operating restraining windings that are designed one opposite the other, as in figure (12) below. The current on the operating coil responsible for the tripping signal. While the restraining will operate to prevent this process to be happened.

This type called Percentage differential relay. Furthermore, these types are called percentage because the current on the operating winding is small value as compare with the C.T current (restraining coil). So, the characteristics will be presented as a straight line as in figure below [48].

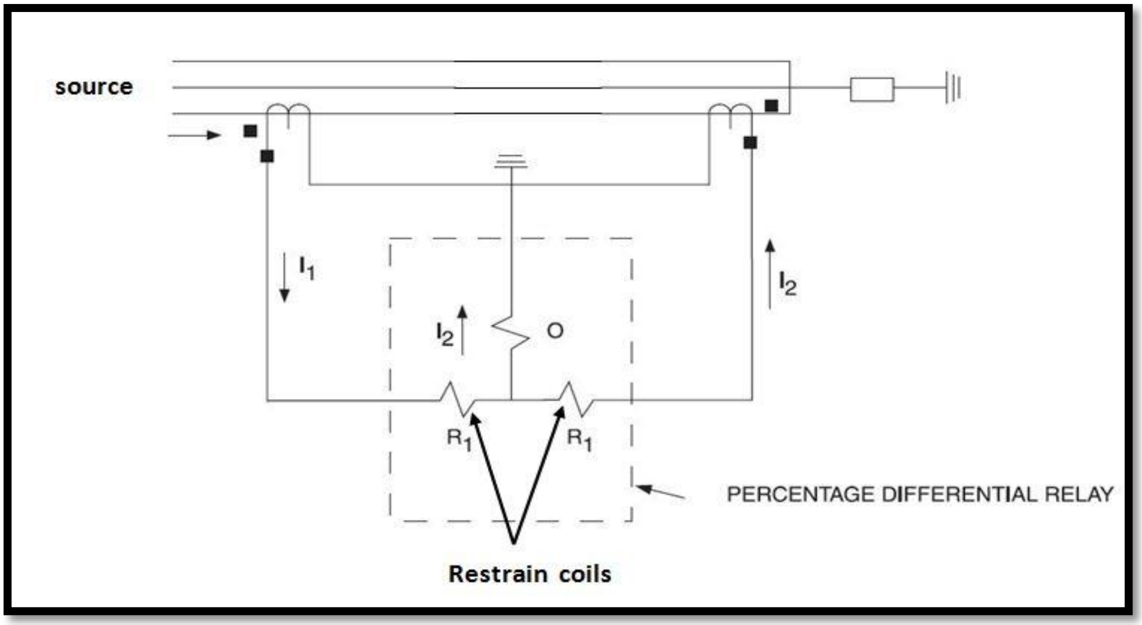

Figure 3-16: Differential Relay with Restrain Coils.

3.6 Coordination of Protection in Transmission Line

The main idea from using the coordination in transmission line protection is to know the steps of projection and each point setting according to schemes and the information of the system. Therefore, it will be easy to apply a perfect protection and back up protection. Moreover, it gives a guidance to coordinate every zone with the other zone and each system with the other system these need to connect directly with these zones and systems. Also, the coordination makes the systems more efficient due to the protection sequences and the time. So, the purpose of using this technique is to minimize the fault effect, control the system and prevent the other systems or zones that are working under the normal status from unnecessary trip through the abnormal behavior of the faulted system unless the other systems or zones lies in the same area of the fault [56].

The backup protection is very important if the system fails to disconnect the fault by the main protection for any reason. Thus, the backup protection has to clear the fault immediately. On the other hand, the backup protection has a delay time after the main protection [57]. According to the previous definition the transmission line protection has two things:

a. The main protection, which is the nearest one to the fault.
b. The backup protection that is the nearest one to the main protection.

Also, it can be defined that the main protection when a fault lies on the same zone of the protection relay, and the backup protection for the faults lies outside the zone of the protection relay.

All the method above has one zone accept the distance method which divides the transmission line into many zones depends on the length of the transmission line, and each one has many tap setting for main and back up protection as shown in figure (13) below.

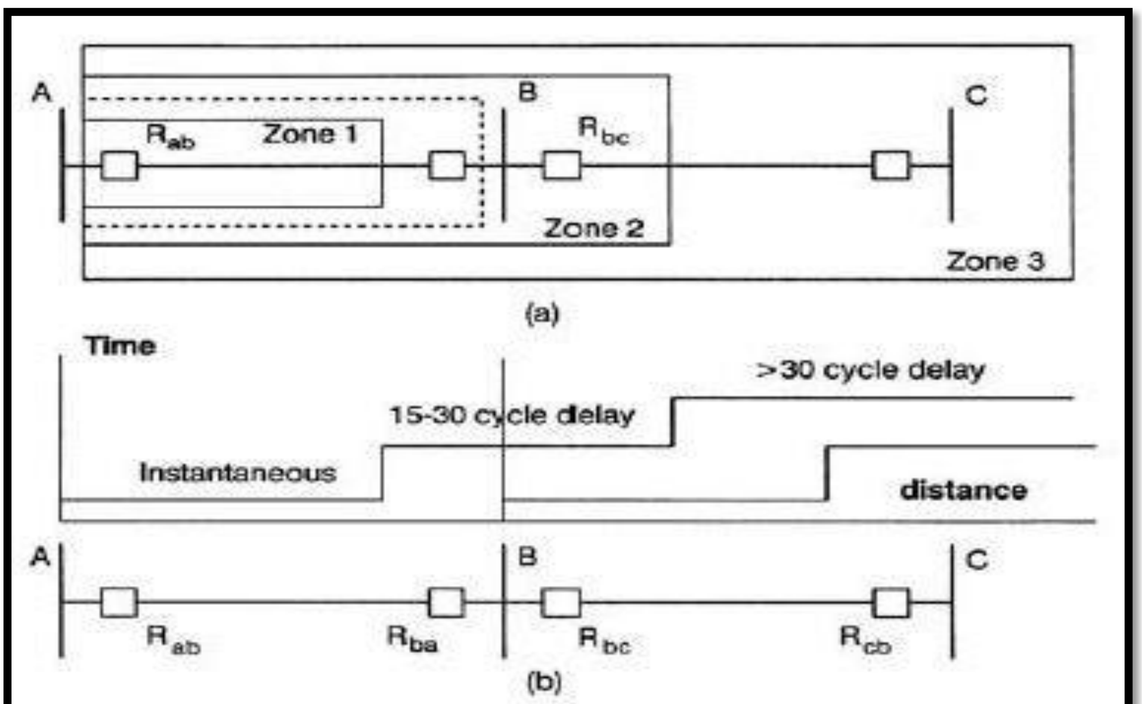

Figure 3-17: Coordination of Distance Relay.

The table below shows the most popular relays and each one has an identifying relay function number and taking in consideration the letters when it is essentially. All of these numbers are listed in IEEE Std C37.2-1996 [58].

Table 3-3: Abbreviated List of Commonly Used Relay Device Function Numbers.

Protection function type	**Function Number**
Distance	21
Synchronizing	25
Under-voltage	27
Directional power	32
Loss of excitation (field)	40
Phase balance (current balance, negative-sequence current)	46
Phase-sequence voltage (reverse phase voltage)	47
Thermal (generally thermal overload)	49
Instantaneous Over-current	50
Time-Over-current	51
Overvoltage	59
Voltage balance (between two circuits)	60
Directional Over-current	67
Frequency (Under and Over-frequency)	81
Lockout	86
Differential	87

4. MODELING AND SIMULATION OF A NEW COMPOSITE RELAY AND THE MODIFIED ANN WITH THREE-PHASE COMPENSATED NETWORK

4.1 The Power System Network Parameters Description

A three-phase, 60 Hz, 735 kV power system transmitting power from a power plant consisting of six 350 MVA generators to an equivalent network through a 600 km transmission line. The transmission line is split in two 300 km lines connected between buses B1, B2, and B3. In order to increase the transmission capacity, each line is series compensated by capacitors representing 40% of the line reactance. The series compensation equipment are located at the B2 substation where a 300 MVA 735/230 kV transformer with a 25 kV tertiary winding feeds a 230 kV, 250 MW load. The series compensation subsystems are identical for the two lines. For each line, each phase of the series compensation module contains the series capacitor, a metal oxide varistor (MOV) protecting the capacitor, and a parallel gap protecting the MOV. When the energy dissipated in the MOV exceeds a threshold level of 30 MJ, the gap simulated by a circuit breaker is fired. CB1 and CB2 are the two line circuit breakers [59].

The generators are simulated with a Simplified Synchronous Machine block. Universal transformer blocks (two-windings and three-windings) are used to model the two transformers [59].

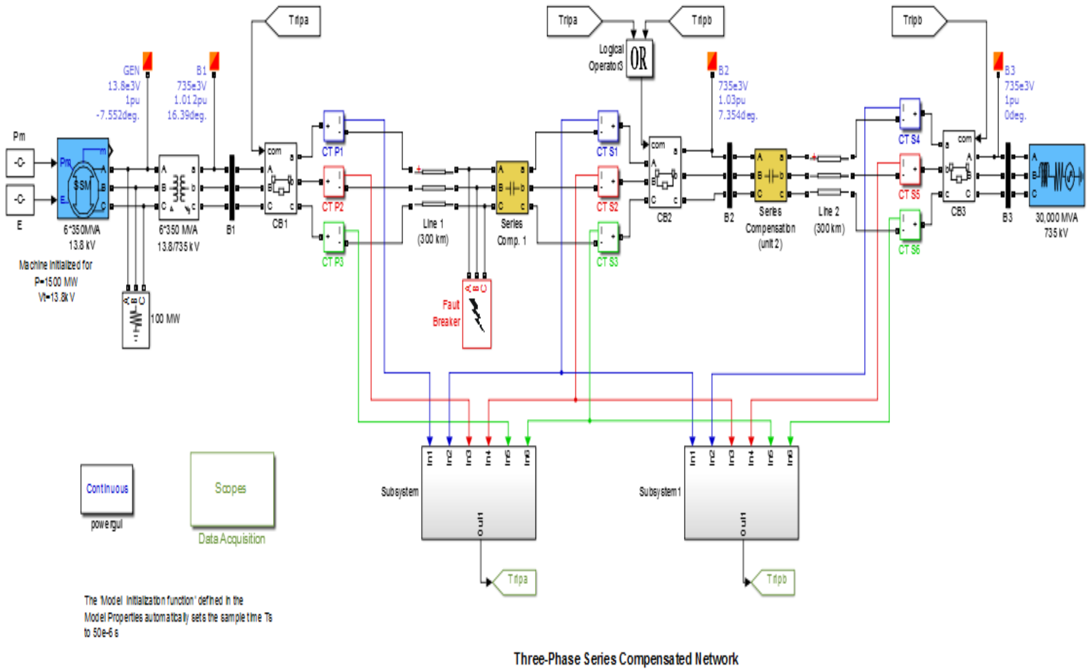

Figure 4-1: Power System Network with Series Compensators in MATLAB/SIMULINK with the New Composite Relay.

4.2 Transmission Line Fault Detection

The fault detection in the transmission line was calculated and demonstrated by the New Composite relay. Therefore, the New Composite relay was employed to detect all types of fault on the transmission line like the series faults (One Line Open OLO and Two Line Open TLO) and the shunt faults like (Single Line to Ground SLG, Double Line DL or L-L, Double Line to Ground DLG or L-L-G, Three-Phase 3PH, and Three-Phase to Ground 3PH-G). Designing of the New Composite relay through the digital component using the Matlab/Simulink. Figure (4-2) below is the flow chart for the process how to detect the fault in the transmission line:

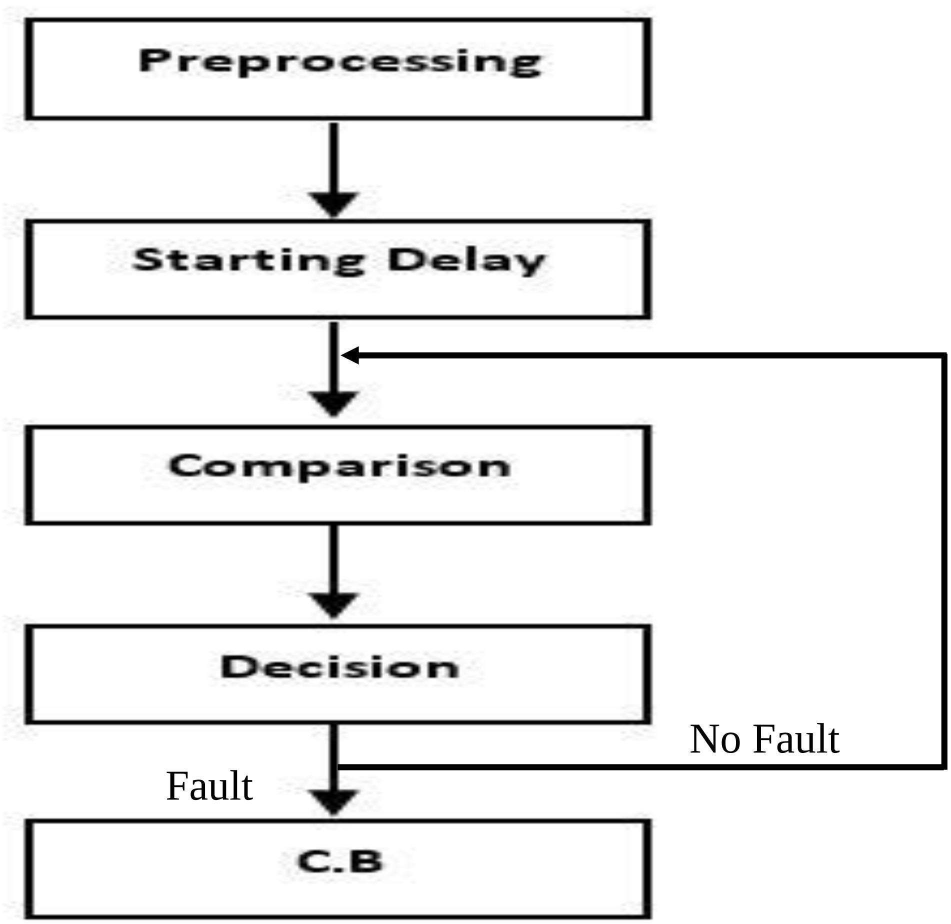

Figure 4-2: Transmission Line Fault Detection Flow Chart.

The New Composite relay works through few steps as below:

1. Processing: The process is the pre-fault process to collect the data from the Current Transformers (CT) from both sides of the transmission line that is want to protect and this data has to be in the same time.
2. Delay: This unit is used to unify the beginning of the two currents signals of the same phase to compare between them because the input current phase A to the transmission line and the output current from the transmission line of the same phase due delayed due to the inductance of the transmission line and this impedance depending on the material, length and cross-section area of the transmission line.
3. Comparison: After unifying the input and the output current of the same phase then the comparison will compare between them and substitute between them and if there is any different will send it to the next step.
4. Decision: This unit is responsible for the decision of the system if there is a fault or not. The signal will send to the circuit breaker according to the setting and the limit of the system.
5. Circuit Breaker (C.B): The C.B is the connection that the Power will pass through it to the transmission line. Also, it works according to the situation of the system with the condition signal when the system works normal the signal will be one but if the system works abnormal then the signal will be zero.

To model the New Composite relay the three types of methods are formed to represent it.

1. Differentiation method.
2. Over current method.
3. Distance method.

Mixing the differentiation method with the over current method it can called differential over current method (D.O.C) and this one is widely used in the high voltage transmission line, and the third method is how to connect the (D.O.C) to protect the high voltage transmission line. Therefore, the transmission line protection is facing a big challenge due to the length of it. So, instead of installing two ends of the (D.O.C) relay for the whole transmission line it can be divided into few parts according to the length of the transmission line. Thus, it is clearly that the advantage of this new technique is to detect the fault as fast as possible. Also, for the far away fault it is not easy to detect it. So, by this algorithm the fault will be detected and cleared faster than the distance or even the differential methods each one alone. The new idea of the transmission line protection can be coordinated as an advantage of this method because the D.O.C protect the whole transmission line and cannot coordinate.

There are few advantages of designing the New Composite relay as comparing with the other methods as in the table (4-1) below:

Table 4-1: Comparison among the Protection Methods.

New Composite method	**Differentiation method**	**Over current method**	**Distance method**
Detecting the fault fast	Detecting the fault slowly	Detecting the fault fast	Detecting the fault slowly
Can be coordinated	Cannot coordinate	Cannot coordinate	Can be coordinated
Can isolate the small area	Isolate the whole system	Isolate the whole system	Can isolate the small area
Not effected by the changing of the parameters	Not effected by the changing of the parameters	Not effected by the changing of the parameters	effected by the changing of the parameters
Depending on the current signal only	Depending on the current signal only	Depending on the current signal only	Depending on current and voltage signals
Reading both ends for accuracy	Reading both ends	Reading one side only	Reading one side only
Compare between input and output currents	Compare between input and output currents	Compare with setting value of current	Compare with setting value of impedance

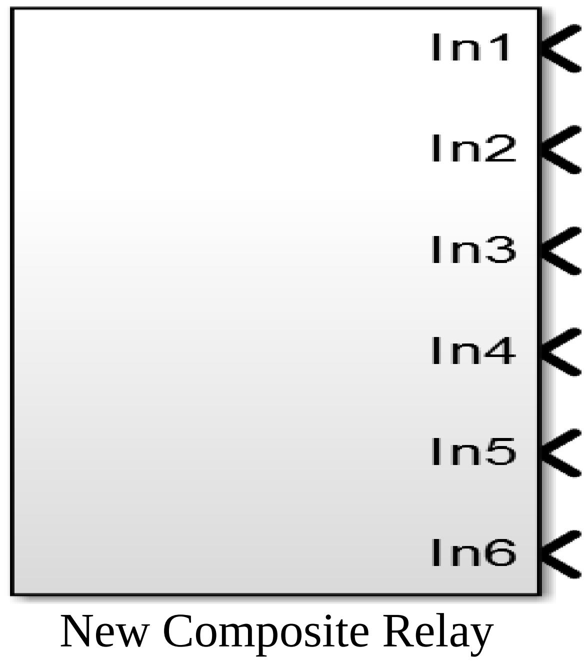

Figure 4-3: The New Composite Relay Model with Six Inputs.

In1, In3 and In5 will be connected to the three phases of the input currents to the transmission line coming from the source (IA, IB and IC respectively) through the Current Transformers (CT's). Also, In2, In4 and In6 will be connected to the output currents from the transmission line going towards the load (IA', IB' and IC' respectively) through the (CT's) too. The inside of the mask is the analog and the digital process which gives the result as one when there is no fault to keep the Circuit Breaker (C.B) on all the time, but if the output of the New Composite relay is zero then the trip signal has to send to the (C.B) to disconnect the system and keep the rest or the unfaulty system works smoothly. Figure (4-4) below shows the inside of the New Composite relay for zone (a) of the transmission line. The delay is putting in the input. Also, the output will send to the C.B (trip signal).

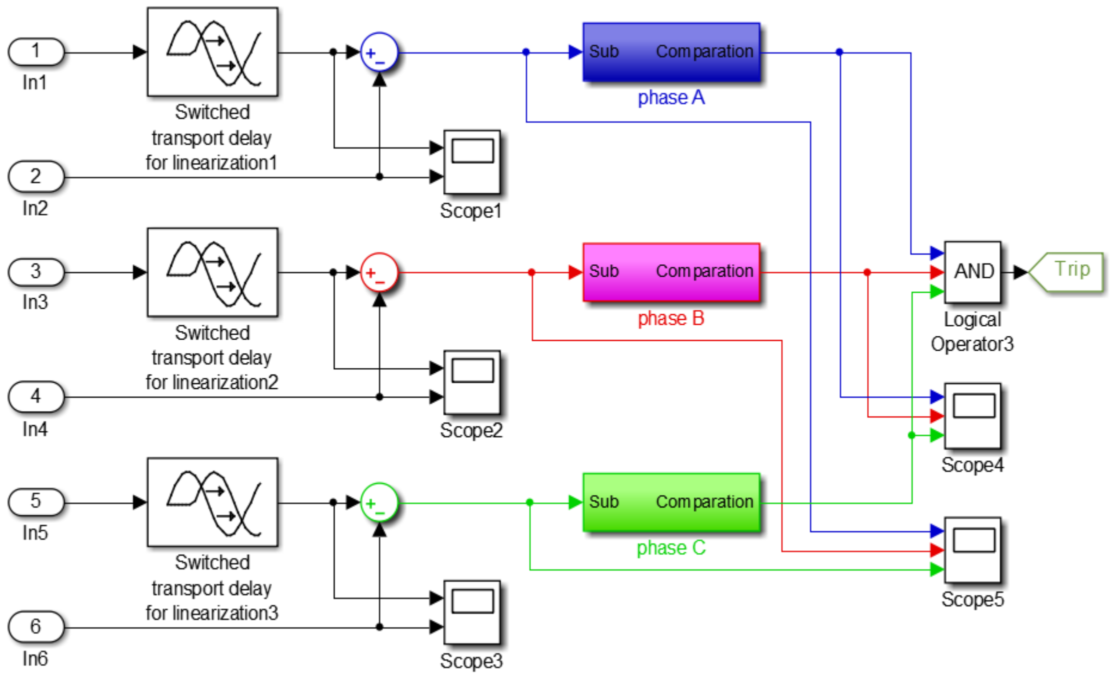

Figure 4-4: Three Phase New Composite Relay with Six Inputs Three of the Input to the Transmission Line and the Second Three Inputs are the Output Currents from the Transmission Line.

Figure 4-5: The Delay Process to the Input Current and Unify it with the Output Current to Prepare them for the Comparison.

Figure (4-6) below shows the process of the New Composite relay after receiving the data from the substitution. So the two current signals will be unified then subtract one from the other then the output from the Subtractor will be input to the process of the New Composite relay.

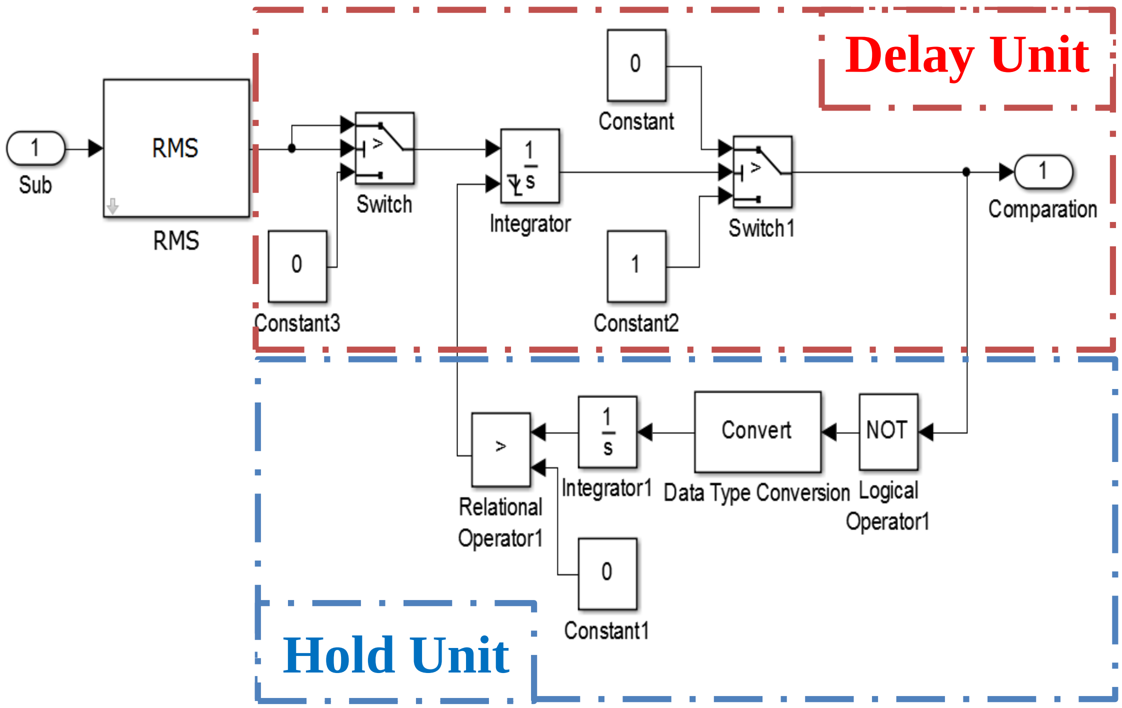

Figure 4-6: The New Composite Relay (Delay Unit and Hold Unit).

The main parts of the process are two and as below:

1. Delay unit: It works to cutoff the transient or the abnormal behavior of the system for a short time because the transient may be seeing in time of turning on the Electrical Power System and the abnormal behavior due to the changing of the load or even the short time short circuit. So, if one or both of the previous situations occur and continued for more than the setting time the process will take the fault case and start the disconnect process. Therefore, after subtracting the input from the output current that is passing through the transmission line the RMS (root mean square) will work to get the effective value, after that switch1 will give the RMS value if the input equal or exceed the limitation and zero if it is less. The output will be the input to the integrator. Thus if there is any magnitude the integrator will start to increase this value. The last part of the delay is the normalizing switch2 that should

give the decision for the system, in case of the integrator output is a magnitude and exceeding the reference, the output will be (0) meaning fault, and (1) meaning no fault. Figure 2 top shows the delay process.

$$\boldsymbol{Output} = \begin{cases} \mathbf{0} & , \ \boldsymbol{input} \ < \boldsymbol{Set\ value}(\boldsymbol{NF}) \\ \boldsymbol{I}_{\boldsymbol{A}_{\boldsymbol{in}}} - \boldsymbol{I}_{\boldsymbol{A}_{\boldsymbol{out}}}, & \boldsymbol{input} \geq \boldsymbol{Set\ value}\ (\boldsymbol{F}) \end{cases} \tag{4-1}$$

2. Hold unit: It is important to save the (EPS) during the fault. Thus, it is very necessary to keep the faulty system off when the fault happened. Therefore, it had to be keeping the trip signal active and send it to the C.B. So, the purpose of using the hold block is to keep the trip signal working till fixing the faulted system. The reason of this process due to the behavior of the system during the fault. Detecting of the fault is depending on the variable signal (currents signals) which is the RMS of this variable and based on the signals behavior it can be divided in to three regions as in the table (4-2) below:

Table 4-2: Transmission Line Fault Steps.

	Pre-Fault	**Fault Time**		**Past fault**
Situation	Normal	Abnormal	Normal	No signals
Trip signal	Off	On	Off	On

It is clearly from the table above the variable behaves as normal and abnormal in time of the fault. Therefore, the system will see normal condition and forcing on signal to the circuit breaker. As shown in figure (4-6), the bottom is the hold block, if the output of the delay is one then there is no trip. Thus, the comparator will give zero and reset the integration process, but when it is zero the output of the comparator is one, in this case the integrator will keep count till it exceeds the limit of switch2 and send a trip signal.

The figure (4-7 and 8) below explains the flow chart of the delay and hold units:

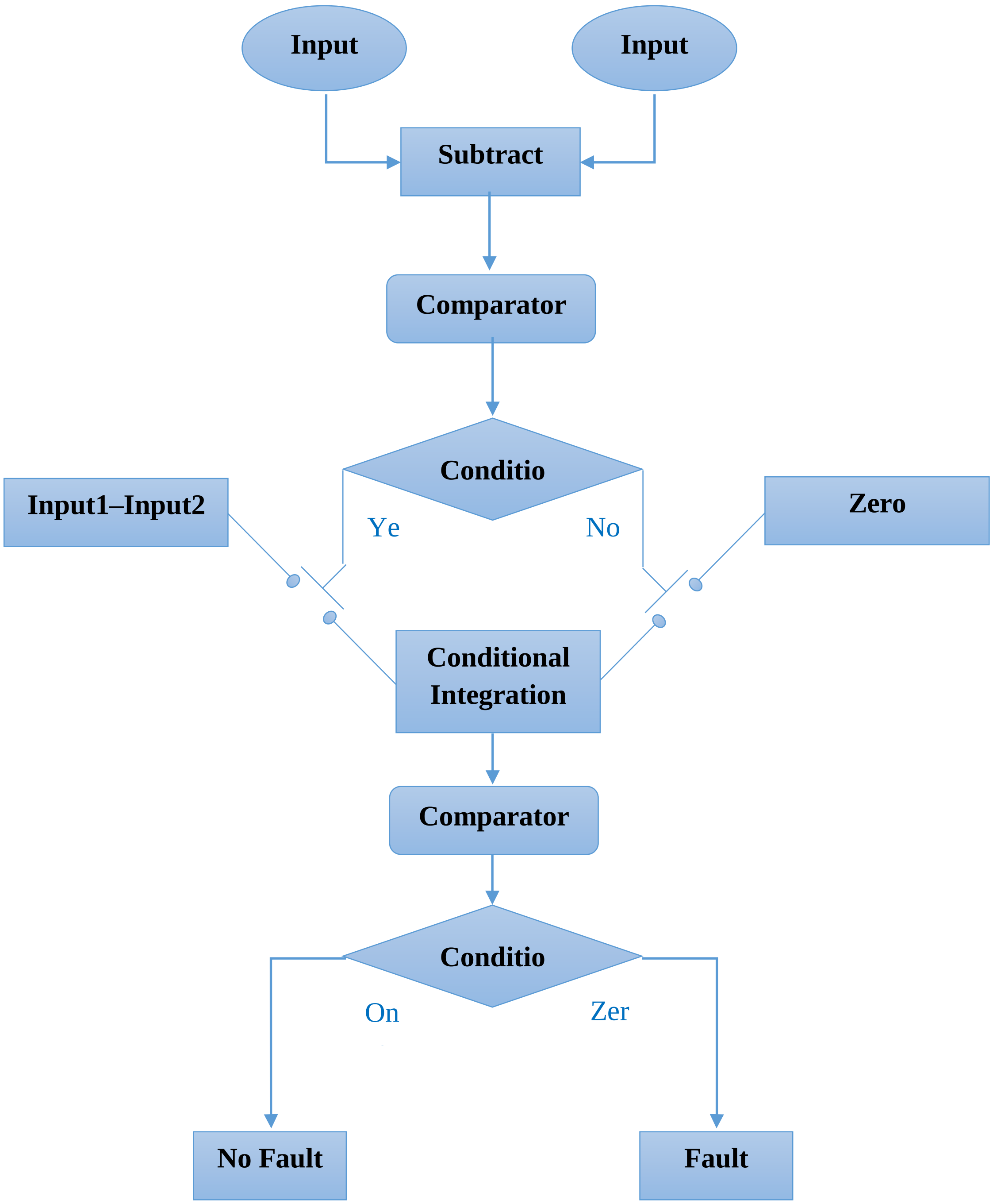

Figure 4-7: Flow Chart of the Delay Process in the New Composite Relay.

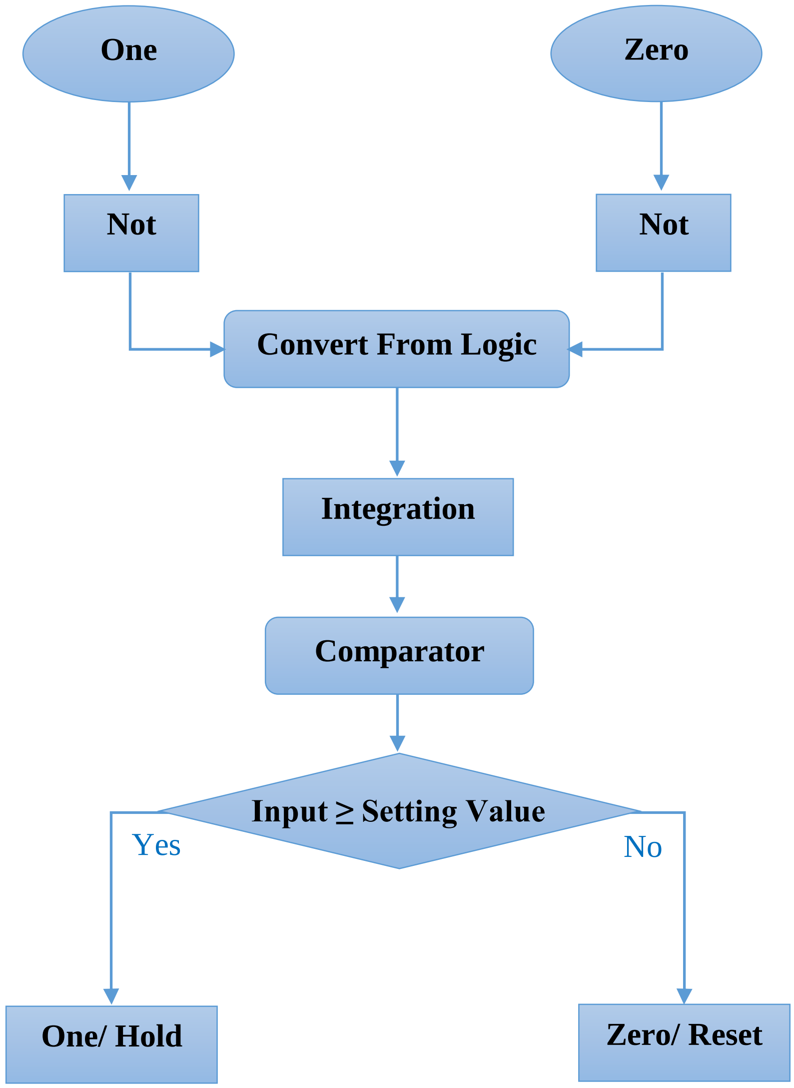

Figure 4-8: Flow Chart of the Hold Process in the New Composite Relay.

4.3 Transmission Line Fault Classification and Localization

The Artificial Neural Network (ANN) is considered as a machine like the brain of the human and one of the famous classifier used in the Electrical Power Systems especially for the fault (Detection, classification and localization). Moreover, there are different types of this network like (Feed Forward (FF), Cascade Forward Back-Prop. (CFB), Radial basis (RB)…etc.). It has the properties of learning, training, capability and generalization [60]. Also, it can be defined as a set of artificial neurons that is depending on a series of a specific mathematical model for information processing on the basis of relational approach for the computation [32]. The most significant property for this algorithm is the ability to understand and learn the behavior of the model with a lot of data training which give satisfy and desirable results because this algorithm deal with the linear and non-linear systems. Therefore the Feed Forward Artificial Neural Network (FFANN) algorithm was adopted to classify and localize the fault. The ANN can be responded to the changes, but with the small changes, the ANN may not investigate the minor changes of the input signals which might come from the noise or even the distortion to the signal that is lying in this pattern [61]. Therefore the signal that has a small distortion or noise, the ANN will not be taken into consideration the small differences [61]. In the other hand, this algorithm expects the behavior of the system or the model even without the prior knowledge of this situation or even the behavior because it had been trained for different behaviors before and therefore this algorithm will imply the way that will or want to follow, and all these acquis belong to a lot of training. In case of learning more about each changing might effect on the efficiency of the algorithm particularly when there is an overlapping with the information of the different situation or variables with different behavior. Figure (4-9) shows the general representation of the ANN. The ANN system given by the equation below, the inputs are $P_1, P_2, \dots \dots, P_n$ the weight of each input is $W_1, W_2, \dots \dots, W_n$. Also the bias is represented by b and the output represented by a. So, to determine the output by the equation below, it should consider the value of each input with its current activation state [32]. Using of the Feed Forward Artificial Neural Network (FFANN) is one of the best classifiers to define the behavior of the system.

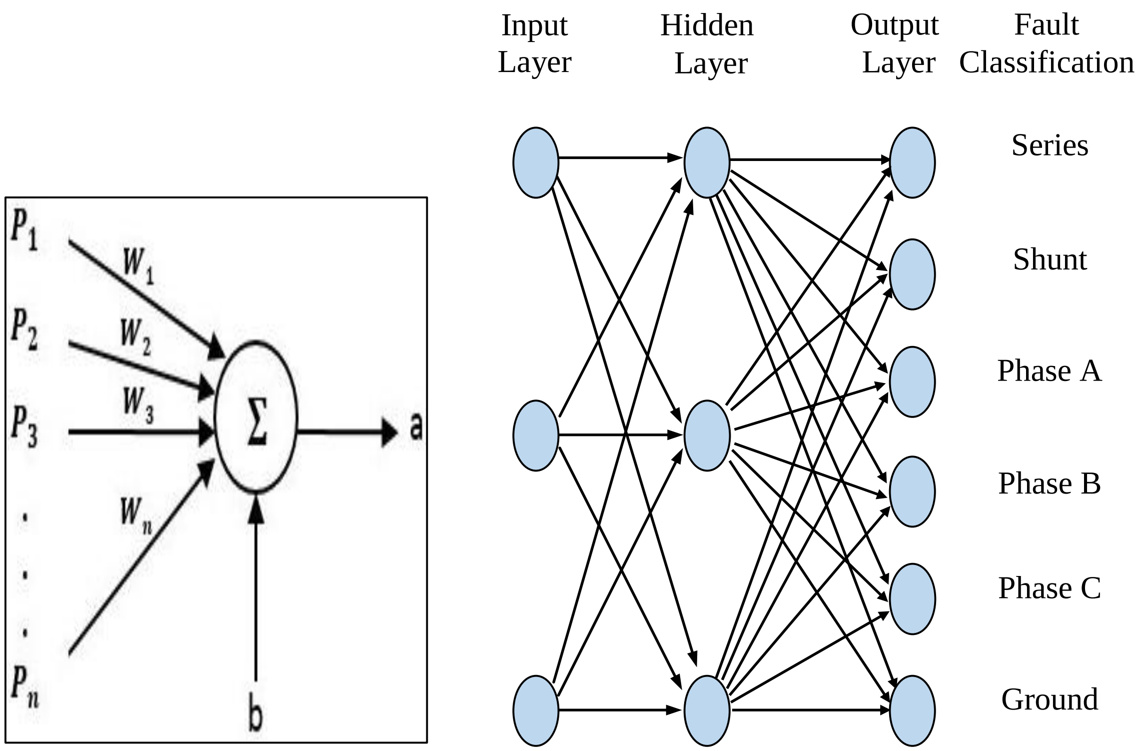

Figure 4-9: Perceptron Representation and Neural Network for Fault Classification.

$$\boldsymbol{a} = \sum_{\boldsymbol{k}=1}^{\boldsymbol{n}} \boldsymbol{W_k P_k} + \boldsymbol{b} \qquad (4\text{-}2)$$

To make the ANN's system works duly it has to be trained. All inputs have to be assigned to an output [32], there is no problem if the number of input less or greater than the number of output. The output is a result of a set of processes that occur on the input, which means the output should be close as possible as to the desire response or by another way the output can be defined as it needs to define by a numerical only that may explain later for any situation or behavior. The main goal of using the ANN with all systems because of the efficiency of this algorithm to reach the require point with all systems if its output is linear or nonlinear.

4.3.1 Fault Classification

There are three ideas were built the NN system for training and comparing among them according to the errors, accuracy and efficiency of the result or even to improve the NN system. Classifying of the fault is the second part, and studying this section is very important and the reason of classifying the fault in the transmission line can be summarized as below:

1. Avoiding the same fault in the next time because the fault can be caused by the same factor or the same reason that was leading to this fault in the previous time for the same fault.
2. For the fast maintenance, because the knowing of the fault type will decrease the time to fix this problem.
3. Low cost, due to less number of team for fixing the problem without spending time for the wrong classification.

The ANN adopted to classify the T.L faults as shown in figure (4-10).

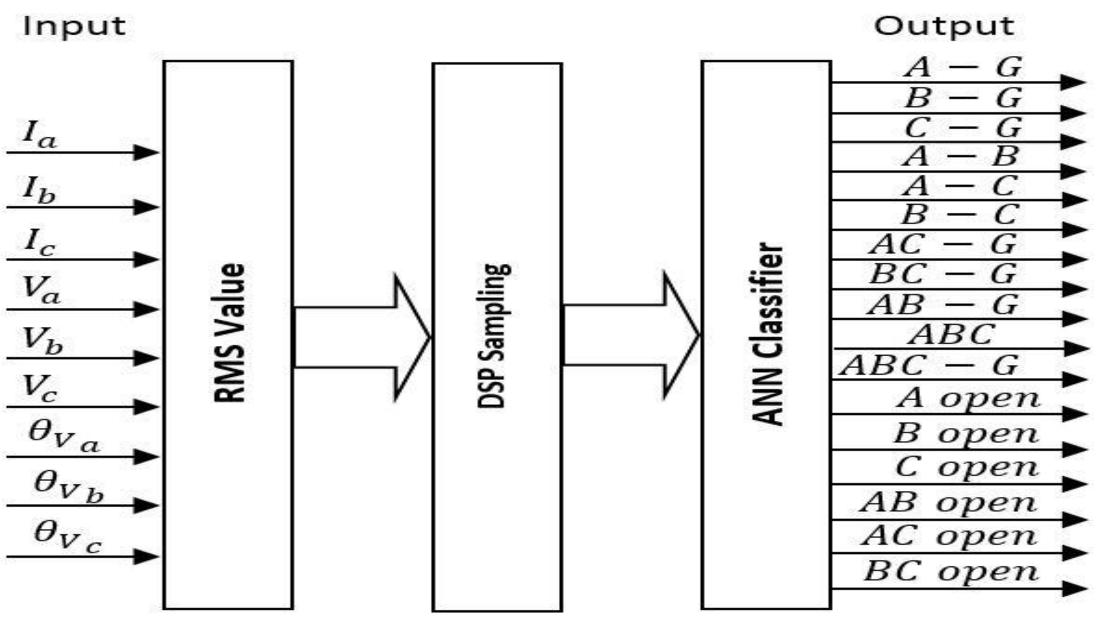

Figure 4-10: Fault Classification Block Diagram.

Figure (4-11) below shows the flow chart for the classification process.

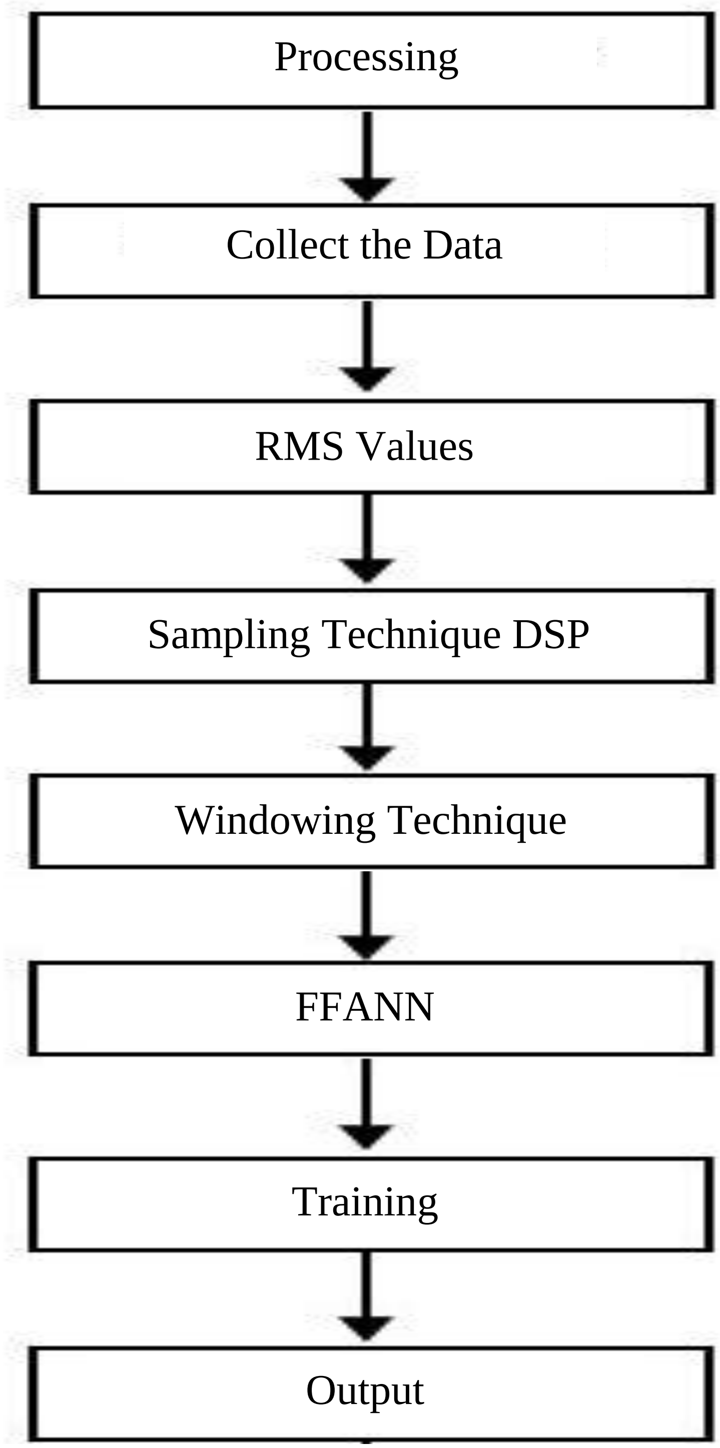

Figure 4-11: Flow Chart of the Transmission Line Fault Classification.

For the final fault classification system, the signals was taking from one side only with three variables that is used to find the best classifier in case of fault happen in the transmission line. It is necessary for the classifier to be generalized and designed to carry out all the type of the fault, which means this system has the ability to adapt with the changing in the parameters, position of the fault, the value of the fault resistance over and above the type of the fault which is the big challenge due to the overlapping of the signals during the fault. According to the Digital Signal Processing (DSP) the sampling technique was applied on the data that had been collected from the recorders. The faults in this system were sampled with 20000 samples/sec (333.333 samples/cycle) and trained with 2000, 500, 200, 100 and 50 samples for each type of fault. The total data trained was 34000 samples.

The ANN algorithm is built in the Matlab/ Simulink using Feed Forward ANN through three types of methods; each trained through one hidden layer. Then, it was improved to get the best, accurate and minimize the mean square error (mse) by taking the best number of layers and the percentage of validation and training. Every type of these methods has three inputs and six targets. The training data have to include all of the needful information of the input in different cases.

According to the previous information that collected from the recorders the three phase voltages ($V_a, V_b \ and \ V_c$), currents ($I_a, I_b \ and \ I_c$) and phase voltages angle ($\theta_{V_a}, \theta_{V_b} and \ \theta_{V_c}$), the ANN system now ready to define each type of fault these are already defined on the transmission line and send it to the output. Therefore, in this work, the name and the type of the fault will be indicated by giving the name of the exact phase, for example the single line to ground may be happened between (A-G, B-G or C-

G), for double line (A-B, A-C or B-C), for double line to ground (AB-G, AC-G or BC-G) and for three line to ground (ABC-G), all of these faults are called shunt faults [45], but in the other types which are called series faults, for example the open line (A-open, B-open and C-open), for two line open (AB-open, AC-open and BC-open) and three line open it is considered as a non-effective fault and it needs just for reclosing relay [48]. Figure (4-12) shows the final circuit of the fault classification.

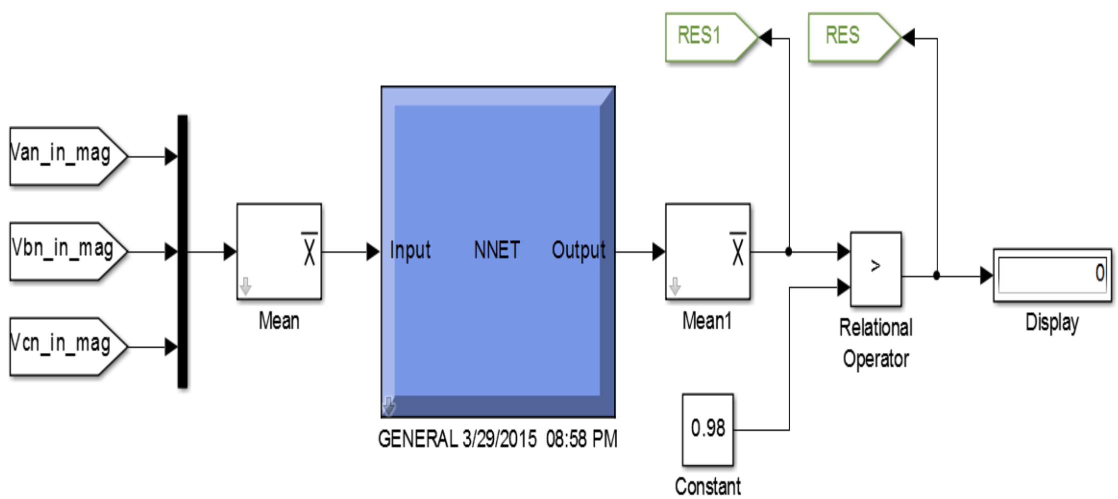

Figure 4-12: The ANN Network System for the Fault Classification Using MATLAB/SIMULINK.

The input goes through the mean block to get the average magnitude of the variables. Here is the variable is the phase voltages and the other variables were trained by the same way separately, after the mean the output will be input to the Neural Network (NN). The second mean is to get the average of the NN's output because the NN response to the input. So any changing in the input the output will be changed by the same way of the changing in the input. The final stage is the comparator (normalizing) and the purpose is to get the result as (one and zero only). Therefore, one means this option is active and the zero means deactivate.

4.3.2 Fault Localization

The fault localization is important to find the problem and fix it as fast as possible. The fault localization is the third part and the researches on this section are very important and the reason of localizing the fault in the transmission line can be summarized as below:

1. Less time spend to fix the problem because the checking for the position of the fault may take few days based on the length of the transmission line.
2. With the fast maintenance leads to low cost for fixing the problem.
3. Figure out the reasons that lead to this fault in this area and support the data information for the research for best calculation of the transmission line parameters and better isolation.

The flow chart in the classification is the same process to explain the process of the fault localization.

For the final fault localization system, the signals was taking from one side only for both phase voltages and phase currents that is used to find the accurate result of the fault localization in case of fault happen in the transmission line. It is necessary for the localization to be generalized and designed to localize the fault in the transmission line as the fault classification without depending on the type of the fault, which means this system has the ability to localize any type of fault, any changing in the transmission line parameters and weather it has a compensation or even a load. Localizing the fault in all systematic built in two ways. First, by the equations. Second by using individual NN for each type of fault (SLG, DL, DLG and Three phase). But in this work will define a new way how to design the general system to carry out all the types without having to rely on the transmission line parameters or even the fault type. According to the Digital Signal Processing (DSP) the sampling technique was applied on the data that had been collected from the recorders. The faults in this system were sampled with 10000 samples/sec (166.667 samples/cycle) and trained using the FFANN.

The ANN algorithm is built in the Matlab/ Simulink using Feed Forward ANN as in the figure (4-13) below.

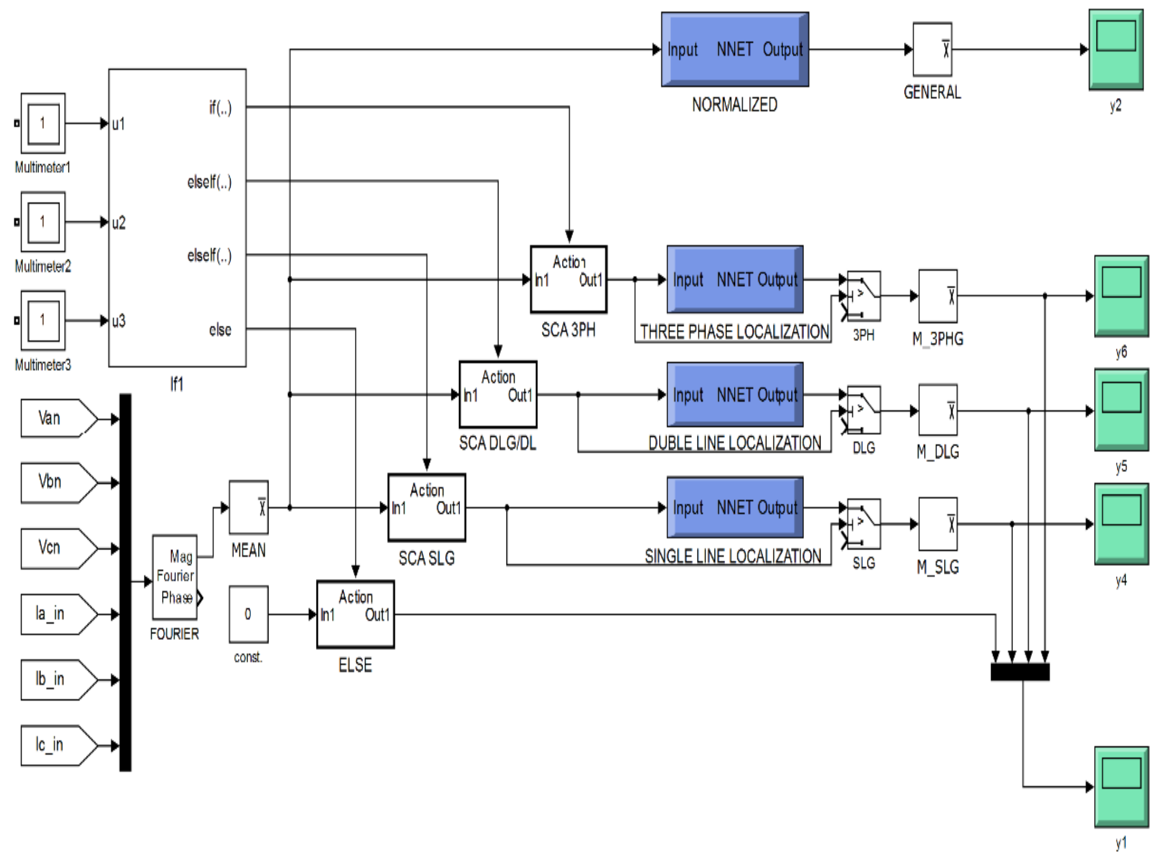

Figure 4-13: Fault Classification Using Two Types of ANN Individual and Generalized Blocks with the Generalize Control.

The input is the RMS values of the phase voltages and the phase currents then all of them will be input to the Fourier to separate the magnitude and the phase shift from the main signals. So, because of the small ripple will passes them through the mean block.

The control of the NN will be designed based on the fault type as the conditions in the table (4-3) below:

Table 4-3: Digital Representation of the ANN Generalizing Control.

Fault Type	Control Formula
Three Phase	((u1 & u2 & u3)>s), s=setting value
DL/ DLG	(((u1>s)&(u2>s)&(u3<s))|((u1>s)&(u3>s)&(u2<s))|((u2>s)&(u3>s) &(u1<s))), s=setting value
SLG	((((u1)>s)&((u2<s)&(u3<s)))|(((u2)>s)&((u1<s)&(u3<s)))|(((u3)>0)&((u1<s)&(u2<s)))), s=setting value
Else	N/A

Also it can be represented by the logical components as below:

Three phase 3PH:

(u1 and u2 and u3) > setting

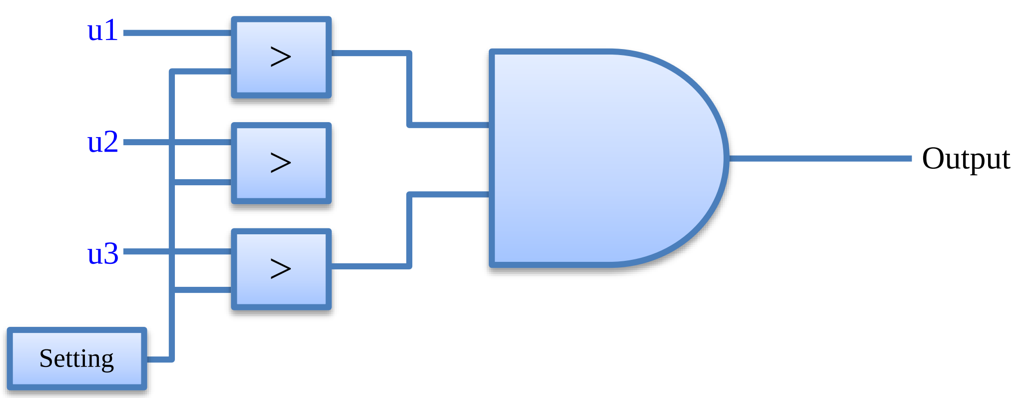

Figure 4-14: The Hardware Design of the Three Phase Gate Control for the Generalizing Classifier. The Inputs are the Phase Currents and the Output is the Pulse Signal Turn on the Gate to Start Classifying the Fault.

Double Line/ Double Line to Ground (DL/ DLG)

(((u1>s)&(u2>s)&(u3<s))|((u1>s)&(u3>s)&(u2<s))|((u2>s)&(u3>s)&(u1<s)))

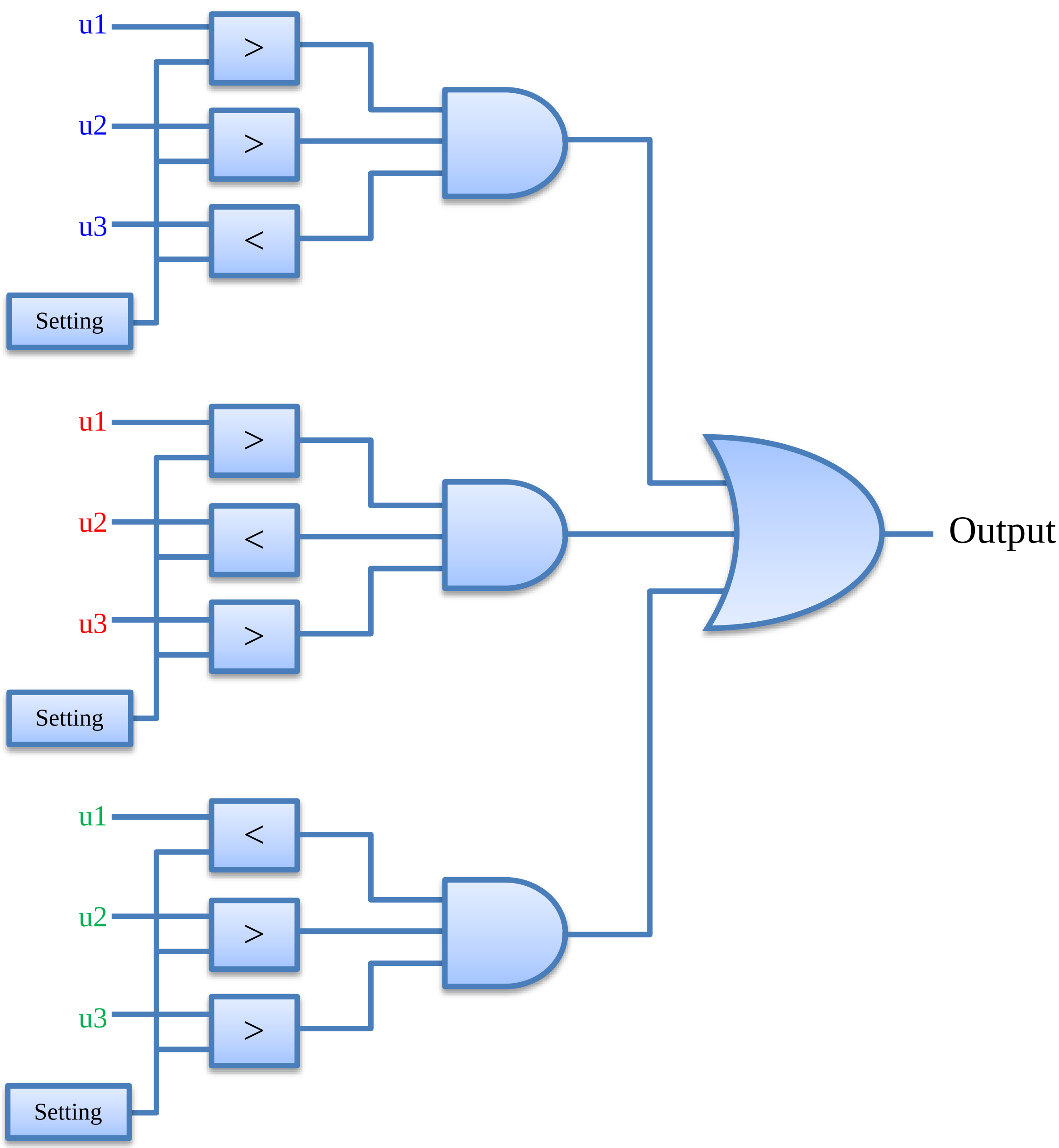

Figure 4-15: The Hardware Design of the Double Line and the Double Line to Ground Gate Control for the Generalizing Classifier. The Inputs are the Phase Currents and the Output is the Pulse Signal Turn on the Gate to Start Classifying the Fault.

Single line to ground SLG

((((u1)>0)&((u2=0)&(u3=0)))|(((u2)>0)&((u1=0)&(u3=0)))|(((u3)>0)&((u1=0)&(u2=0))))

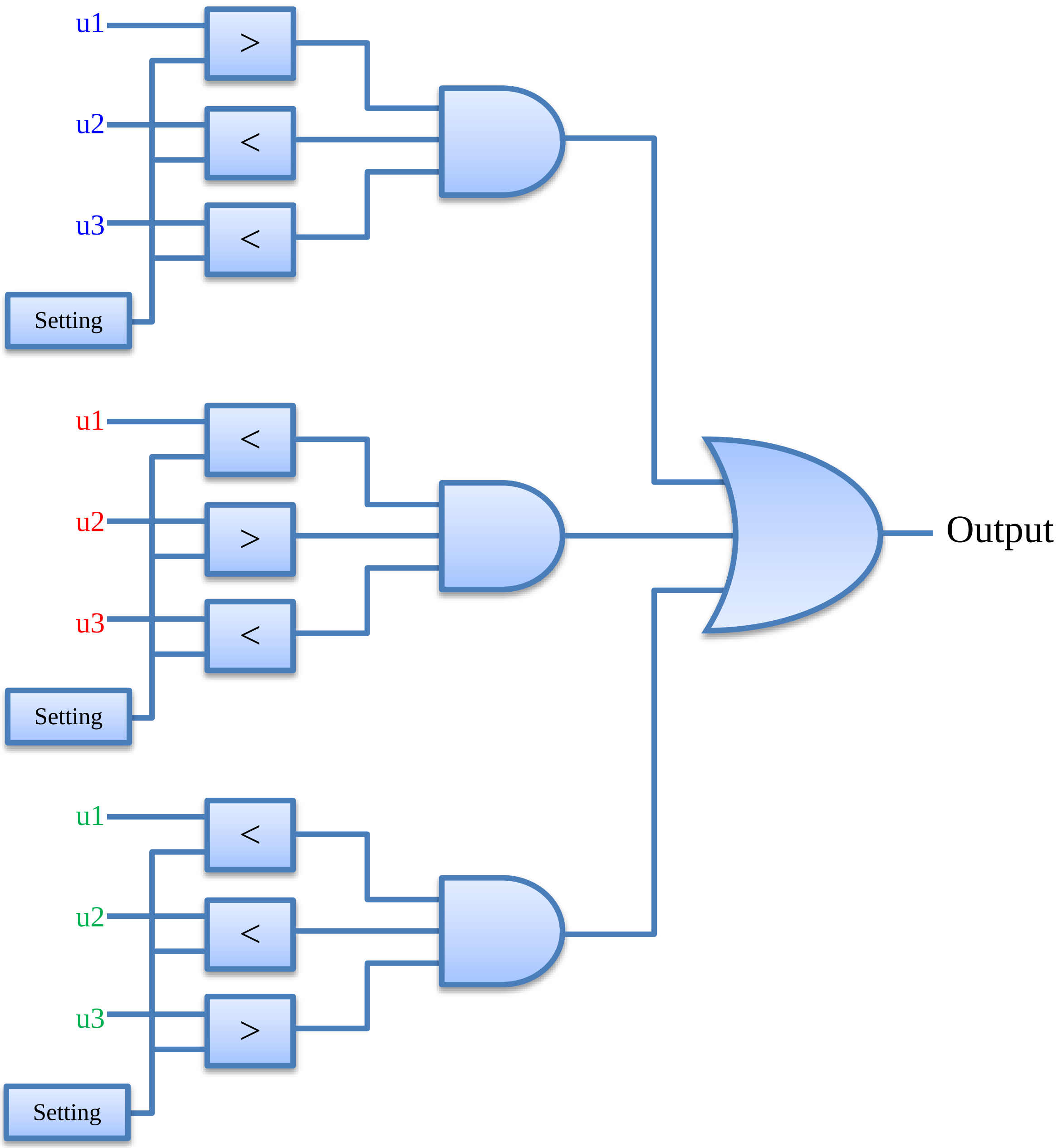

Figure 4-16: The Hardware Design of the Single Line to Ground Gate Control for the Generalizing Classifier, the Inputs are the Phase Currents and the Output is the Pulse Signal Turn on the Gate to Start Classifying the Fault.

5. RESULTS AND DISCUSSION

5.1 Fault Detection Results

All the types of the fault were considered, tested and checked regarding to design the fast and reliable fault detection digital relay, but will present on of each type.

5.1.1 Shunt Fault

5.1.1.1 Single Line To Ground Fault (SLG)

Figure (5-1) below explains behavior of the sending end voltages and currents with the trip signal. It spent approximately 9ms after the fault occurs at 0.1 sec to cut off the power.

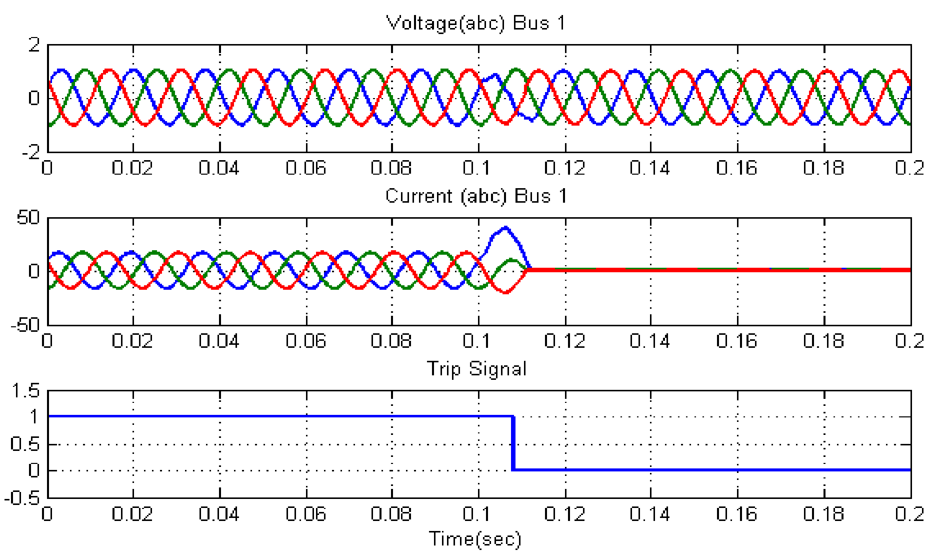

Figure 5-1: Single Line to Ground Fault, Three Phase Input Voltages, Three Phase Input Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

Figure (5-2) shows the receiving end.

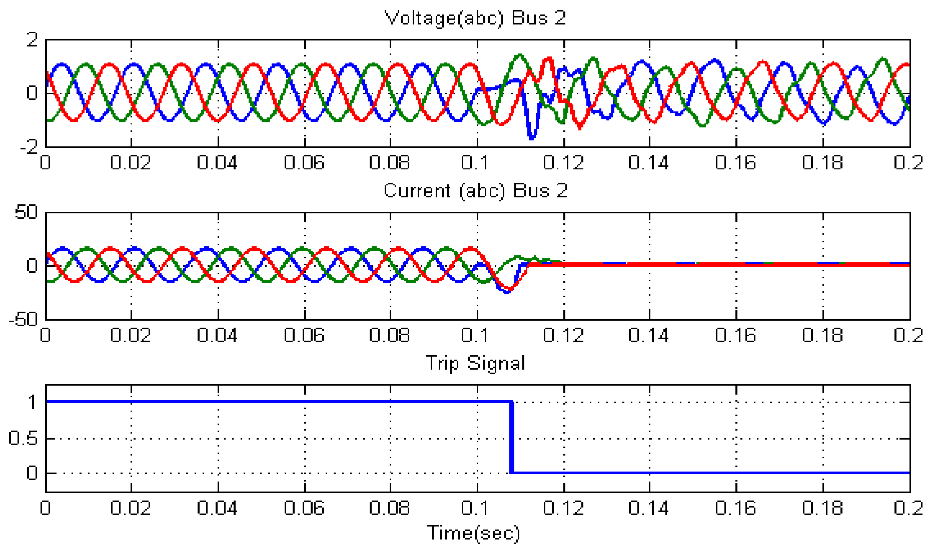

Figure 5-2: Single Line to Ground Fault, Three Phase Output Voltages, Three Phase Output Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

Figure (5-3) shows the fault currents.

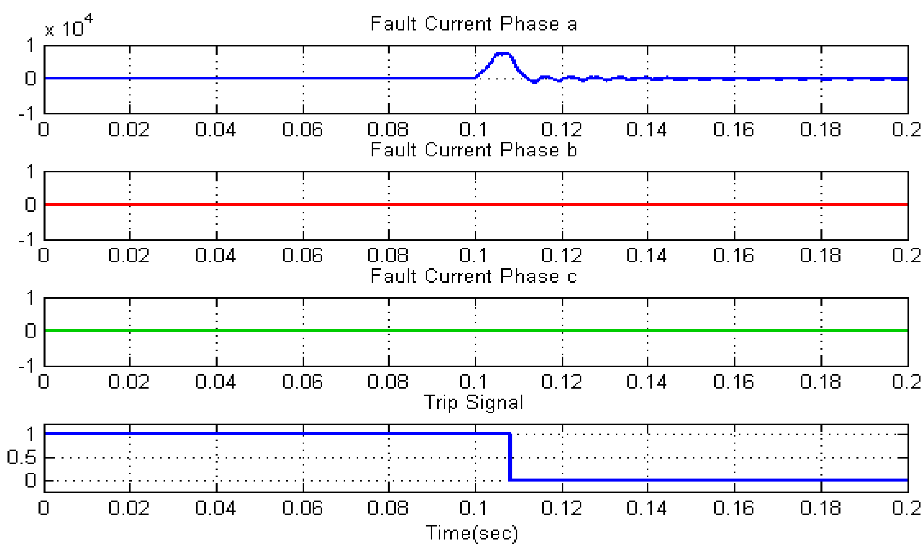

Figure 5-3: Single Line to Ground Fault, Three Phase input Fault Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

5.1.2 Double Line (DL or L-L)

The figure (5-4) below explains behavior of the sending end voltages and currents with the trip signal. It spent approximately 7ms after the fault occurs at 0.05 sec to cut off the power.

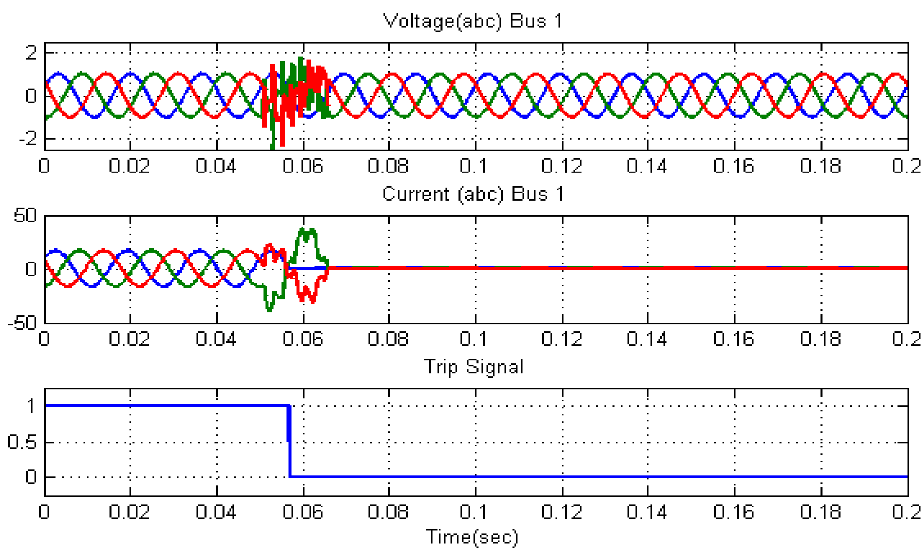

Figure 5-4: Double Line Fault, Three Phase Input Voltages, Three Phase Input Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

Figure (5-5) shows the receiving end.

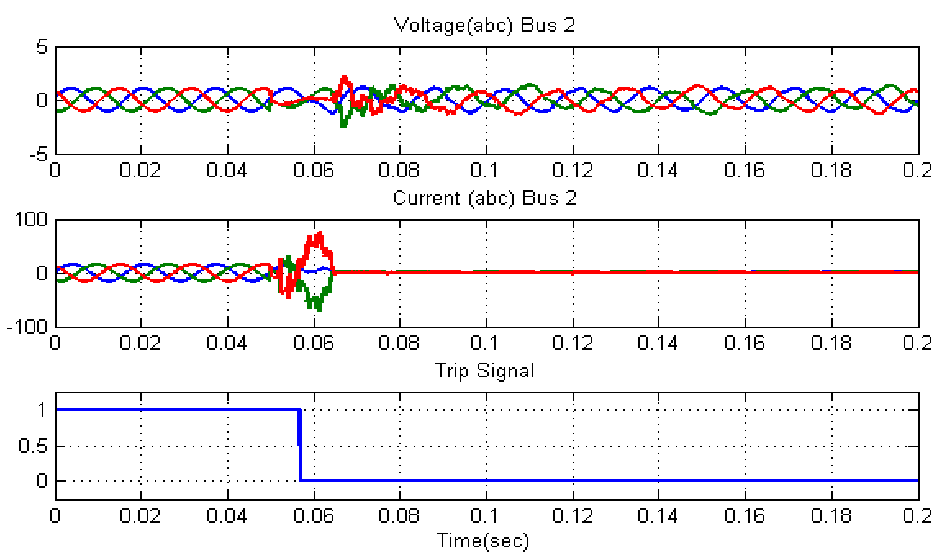

Figure 5-5: Double Line Fault, Three Phase Output Voltages, Three Phase Output Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

Figure (5-6) shows the fault currents.

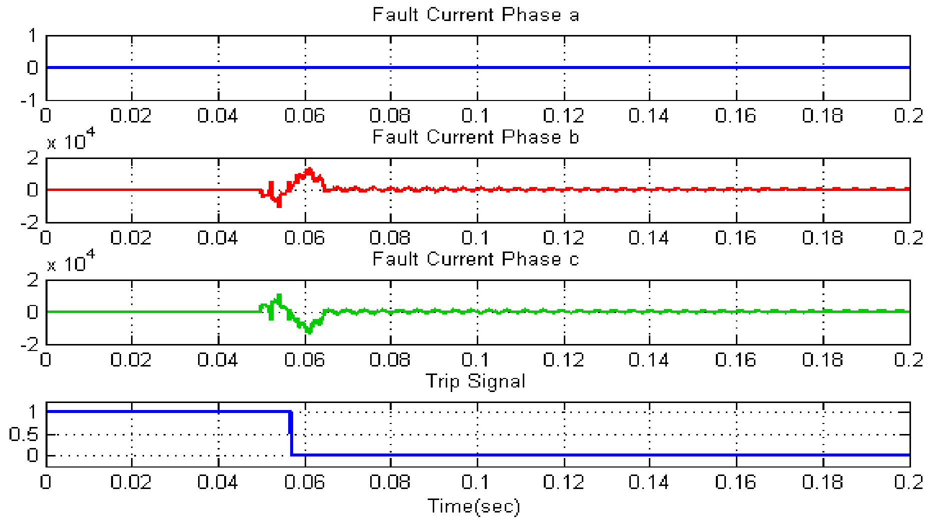

Figure 5-6: Double Line Fault, Three Phase Input Fault Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

5.1.3 Double Line to Ground Fault

The figure (5-7) below explains behavior of the sending end voltages and currents with the trip signal. It spent approximately 7ms after the fault occurs at 0.12 sec to cut off the power.

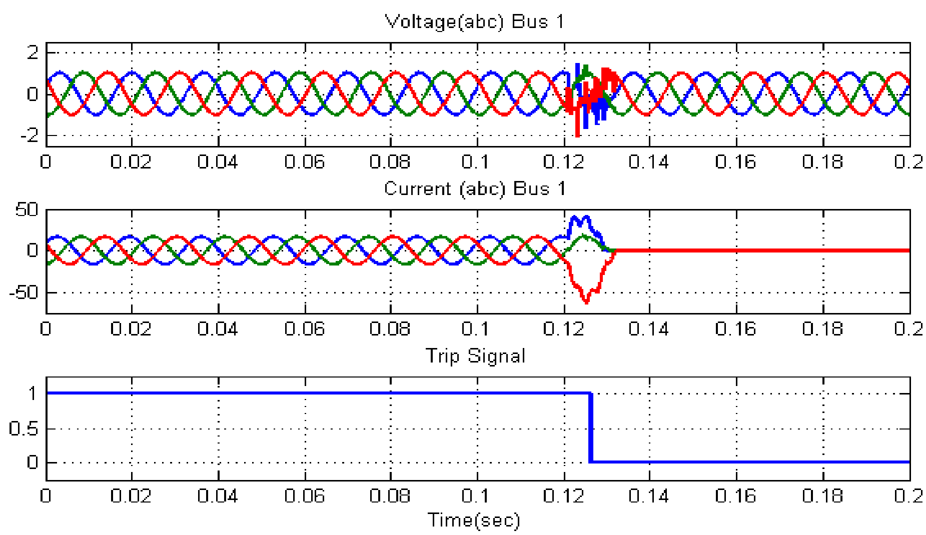

Figure 5-7: Double Line to Ground Fault, Three Phase Input Voltages, Three Phase Input Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

Figure (5-8) shows the receiving end.

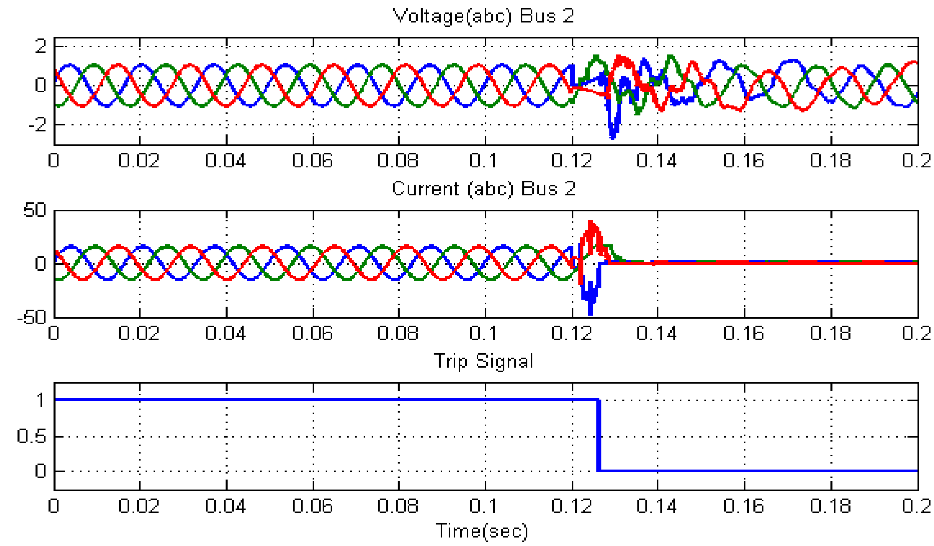

Figure 5-8: Double Line to Ground Fault, Three Phase Output Voltages, Three Phase Output Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

Figure (5-9) shows the fault currents.

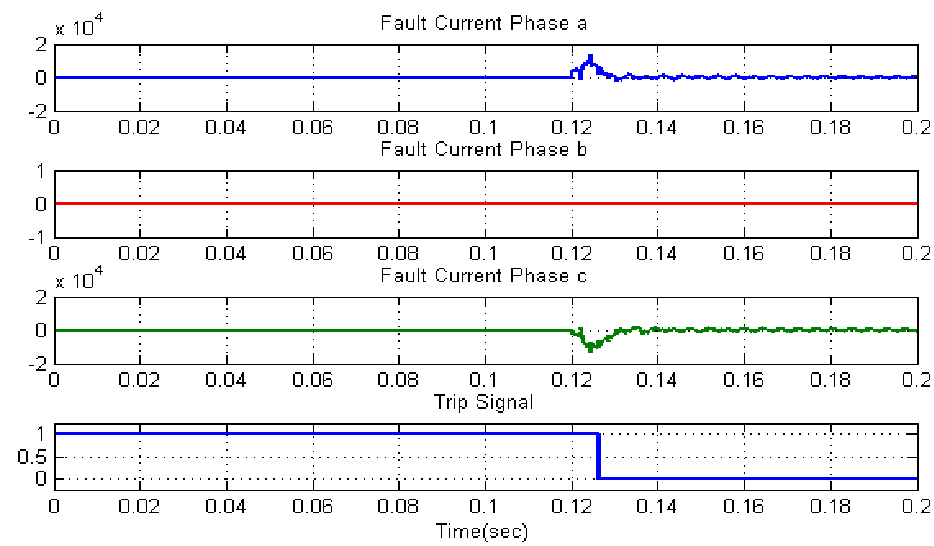

Figure 5-9: Single Line to Ground Fault, Three Phase Input Fault Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

5.1.4 Three Phase and Three Phase to Ground (3PH/ 3Ph-G)

The figure (5-10) below explains behavior of the sending end voltages and currents with the trip signal. It spent approximately 5ms after the fault occurs at 0.08 sec to cut off the power.

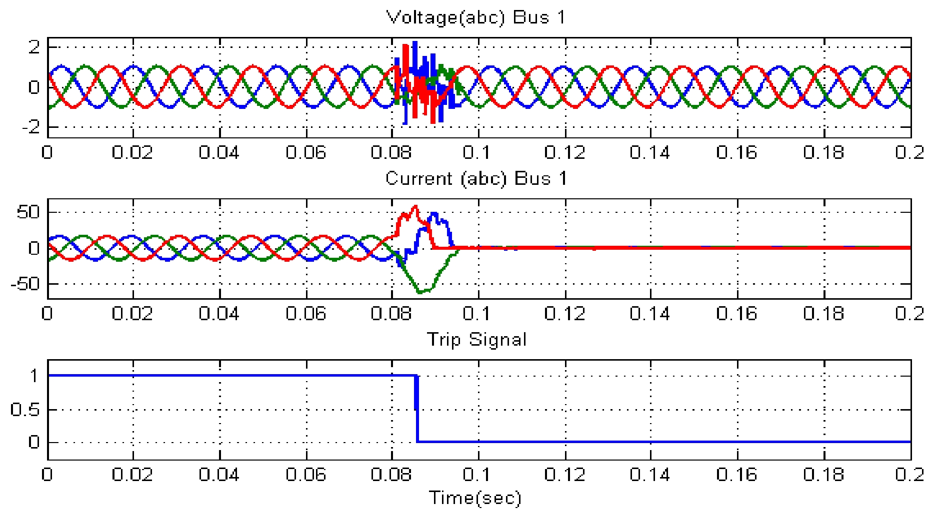

Figure 5-10: Three Phase/ Ground Fault, Three Phase Input Voltages, Three Phase Input Currents and the Trip Signal Send from the New Composite Relay to the Circuit Breaker.

Figure (5-11) shows the receiving end.

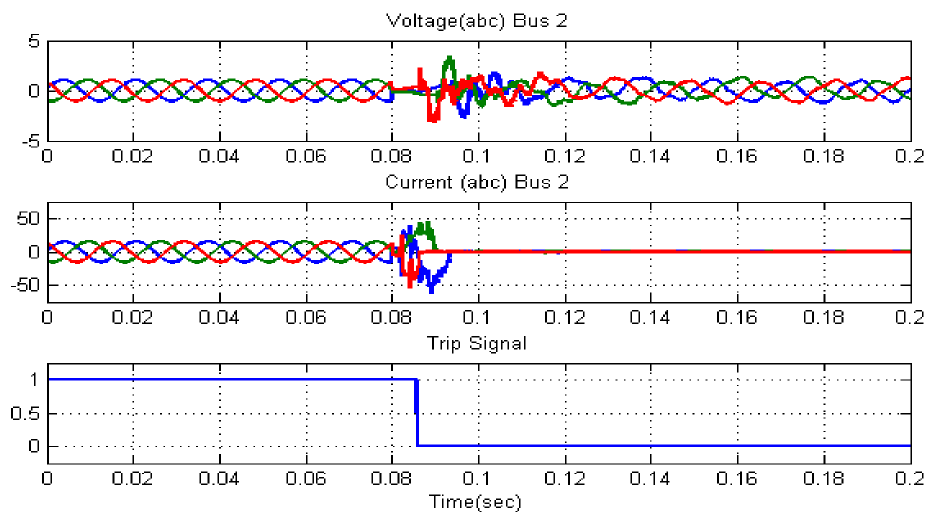

Figure 5-11: Three Phase/ Ground Fault, Three Phase Output Voltages, Three Phase Output Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

Figure (5-12) shows the fault currents.

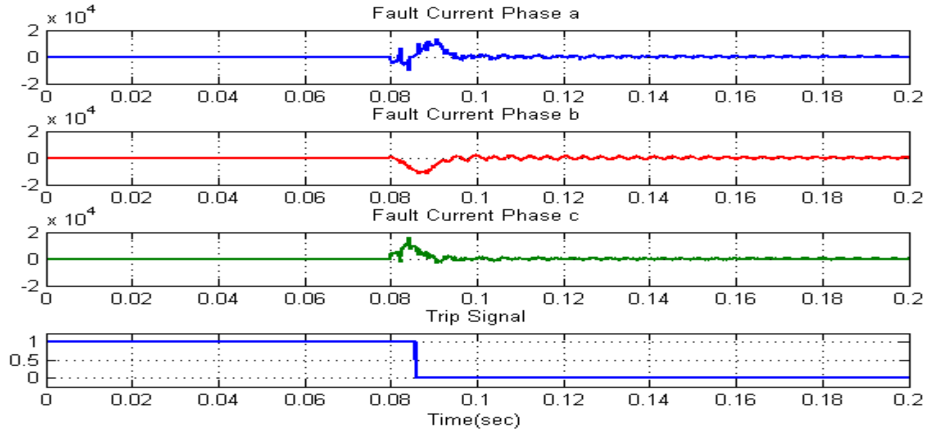

Figure 5-12: Three Phase/Three Phase to Ground Fault, Three Phase Input Fault Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

5.1.5 Series Fault

5.1.5.1 One Line Open (OLO)

It considered that the one line open will take more time to detect the fault as compare with the shunt faults due to the increasing in the current which will be increasing slowly. Figure (5-13) below explains behavior of the sending end voltages and currents with the trip signal. It spent approximately 25ms after the fault occurs at 0.1 sec to cut off the power.

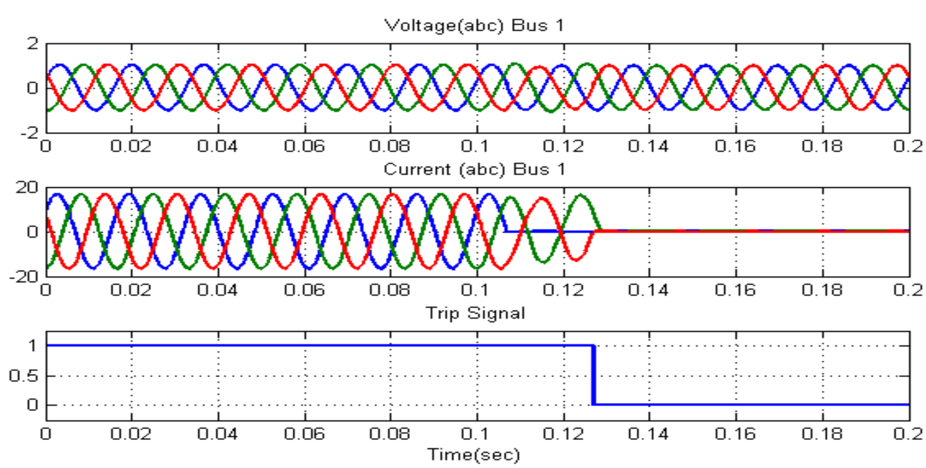

Figure 5-13: One Line Open Fault, Three Phase Input Voltages, Three Phase Input Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

Figure (5-14) shows the receiving end.

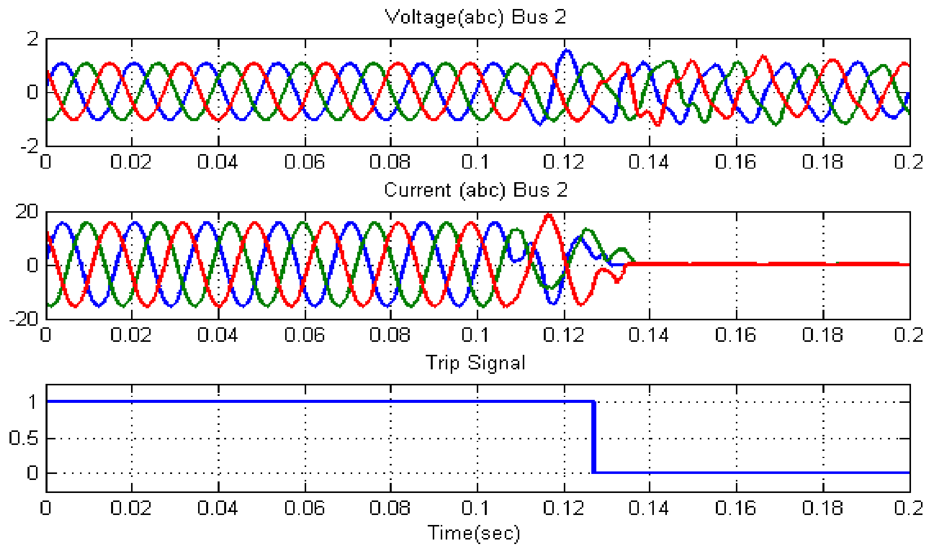

Figure 5-14: One Line Open Fault, Three Phase Output Voltages, Three Phase Output Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

Figure (5-15) shows the fault currents.

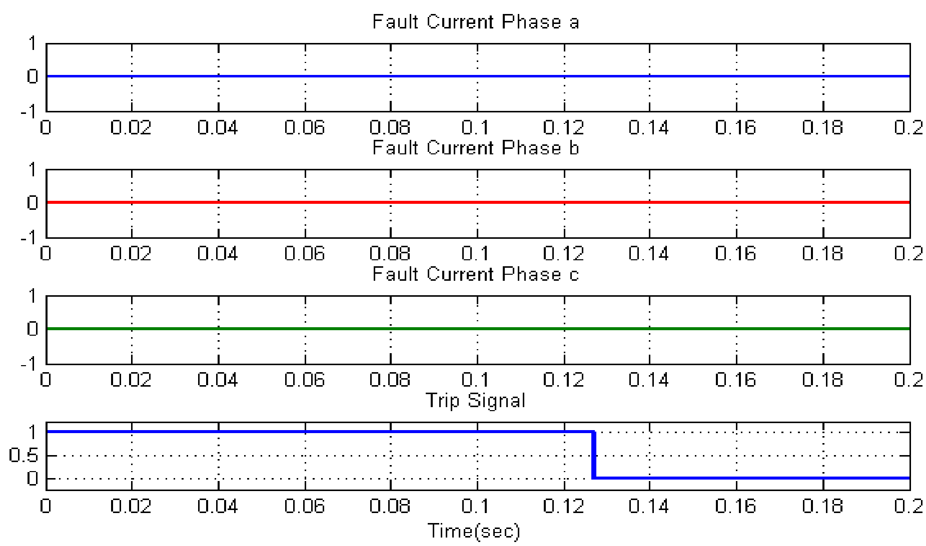

Figure 5-15: One Line Open Fault, Three Phase Input Fault Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

5.1.5.2 Two Line Open (TLO)

Also the two line open will take more time to detect the fault as compare with the shunt faults due to the increasing in the current, which will be increasing slowly but a little less than (OLO). Figure (5-16) below explains behavior of the sending end voltages and currents with the trip signal. It spent approximately 22ms after the fault occurs at 0.08 sec to cut off the power.

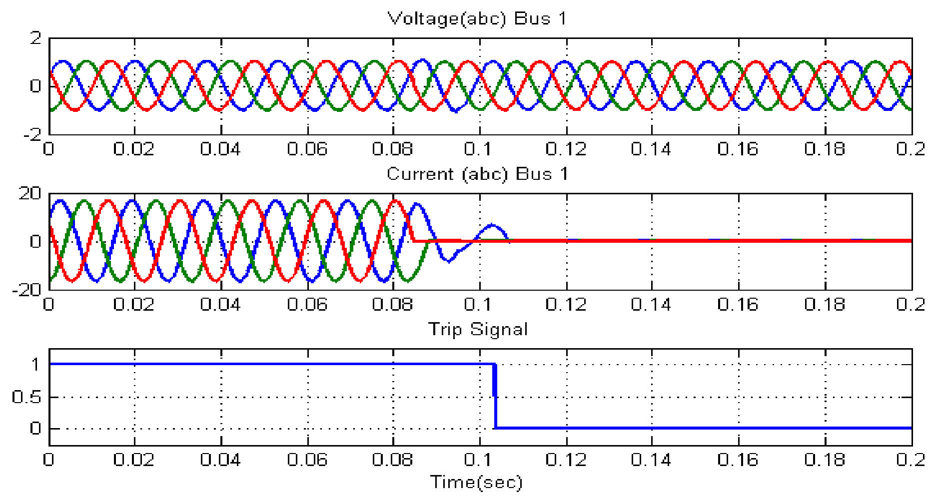

Figure 5-16: Two Line Open Fault, Three Phase Input Voltages, Three Phase Input Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

Figure (5-17) shows the receiving end.

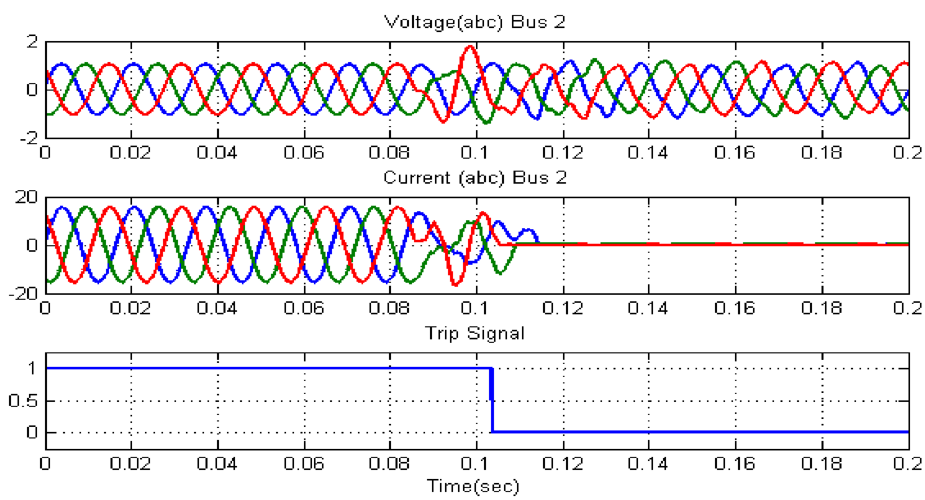

Figure 5-17: Two Line Open Fault, Three Phase Output Voltages, Three Phase Output Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

Figure (5-15) shows the fault currents.

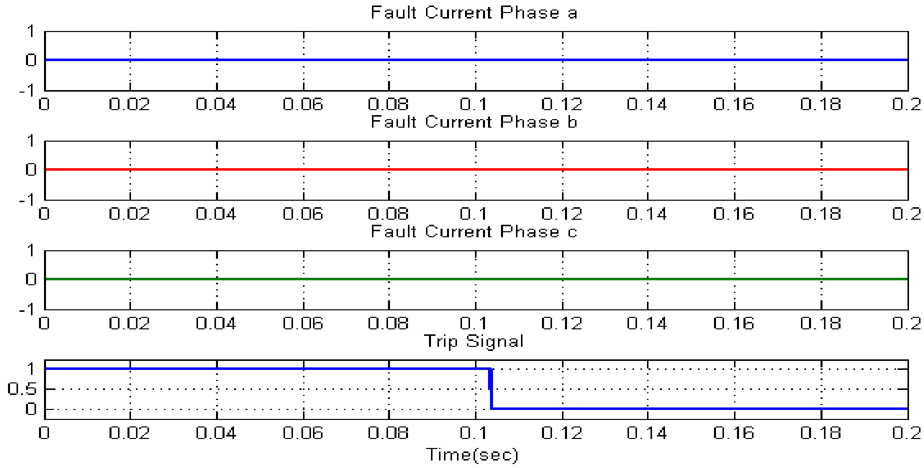

Figure 5-18: Two Line Open Fault, Three Phase Input Fault Currents and the Trip Signal Sent from the New Composite Relay to the Circuit Breaker.

5.2 Fault Classification Results

The classifier is considered one of the big challenge due to the behavior of the system through the fault because the classifier has to have the ability to read the present and predict the future. So there are many classifier to classify the fault in the transmission line. Thus, the classifier should have the ability to analyze and expect with the high accuracy the behavior of the system when the fault accord.

Each classifier will design according to the output required but even with the desirable output from the classifier it might has an error which can lead to wrong result. Moreover with the Neural Network classifier there are many factors (internal and external) effect on the Neural Network. The internal factors due to the flaw design like (number of layers, percentage of validation and training and the type of the NN) and the most significant external factors is choosing the over lapping features of the different cases. Thus, according to the effect of these factors, five types of sampling, two values of validation and testing, three types of variables, three number of layers and one algorithm were applied to get satisfying system that can be applied in different systems. Figure (5-19) is the result of the NN. It shows the internal and external effects with the least error (36.1 %).

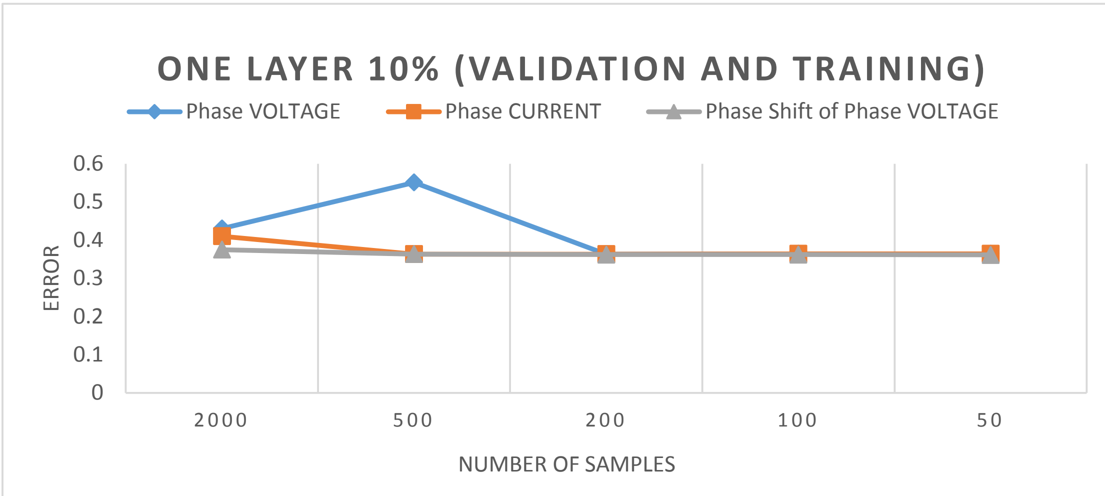

Figure 5-19: ANN Results for the Fault Classification with All Possible Type of Fault One Layer and 10% Validation and Training.

Figure (5-20) is the result of the NN by increasing the number of the hidden layers. The internal and external effects with the least error (6 %).

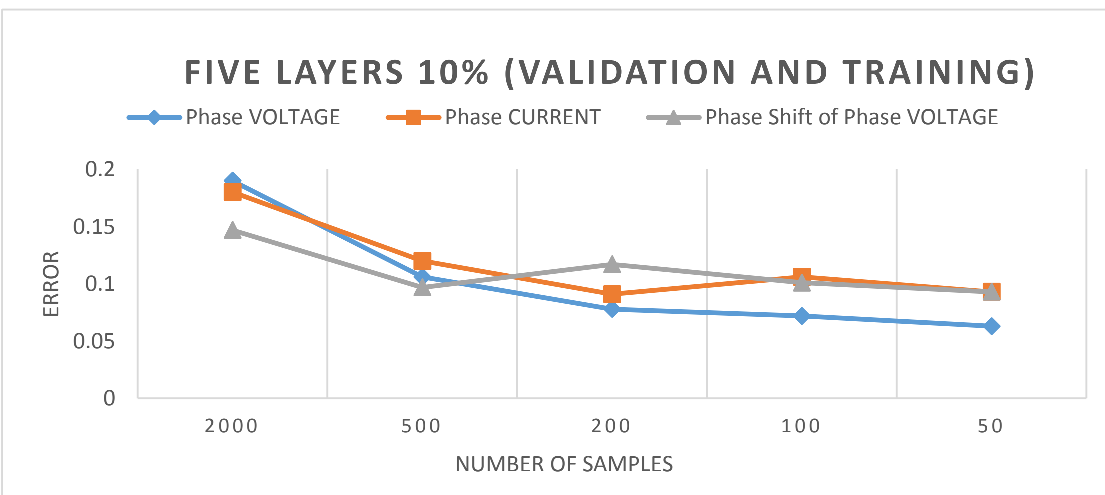

Figure 5-20: ANN Results for the Fault Classification with All Possible Type of Fault Five Layers and 10% Validation and Training.

Figure (5-21) is the result of the NN by increasing the number of the hidden layers. The internal and external effects with the least error (0.02%).

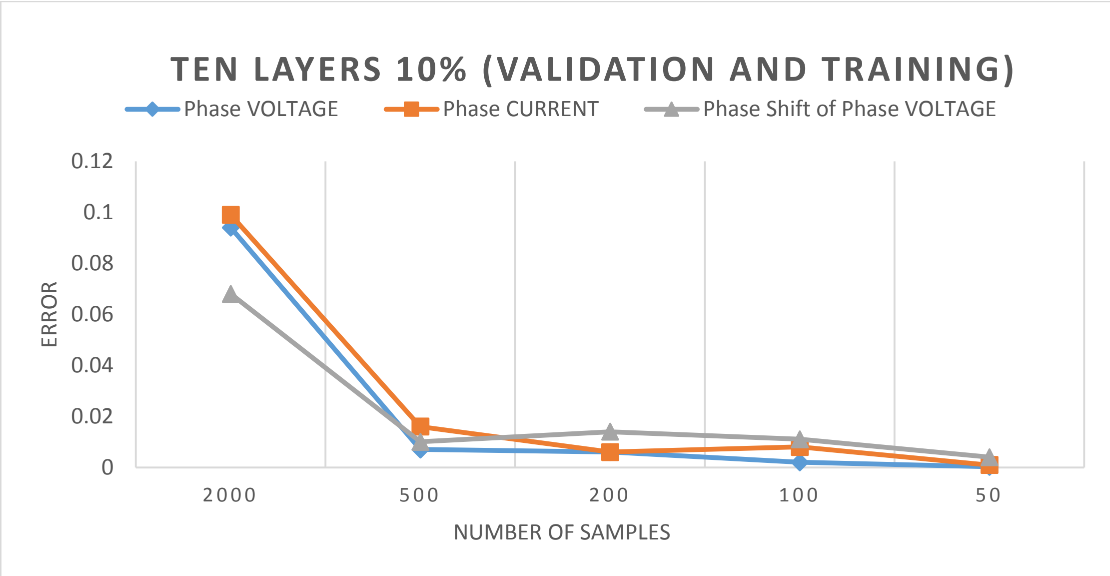

Figure 5-21: ANN Results for the Fault Classification with All Possible Type of Fault Ten Layers and 10% Validation and Training.

From the previous charts, despite the fact that the results were good, but it still needs to improve. Therefore, the next step is trying to get the best result through changing the classifier performance and features then apply it through the same number of sampling with the same variables by the same algorithm (NN) and figure out what is the best characteristics and features that may lead to the best results. Therefore it has to be searching for the system which can recognize each feature of the system behavior and classify the type of the fault accurately regarding to the ability of this classifier which can treat with the linear and nonlinear systems.

The next three charts will give the answer about the classifier if it can use it for with these type of systems or not.

Figure (5-22) is the result of the NN by increasing the number of the percentage of the validation and the training. The internal and external effects with the least error (36.1%).

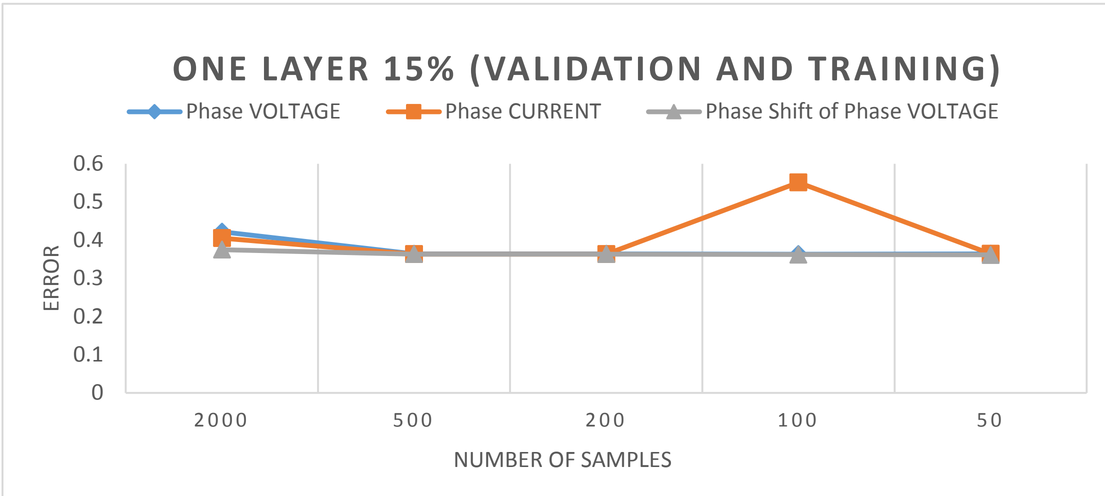

Figure 5-22: ANN Results for the Fault Classification with All Possible Type of Fault One Layer and 15% Validation and Training.

Figure (5-23) is the result of the NN by increasing the number of the hidden layers. The internal and external effects with the least error (6.4%).

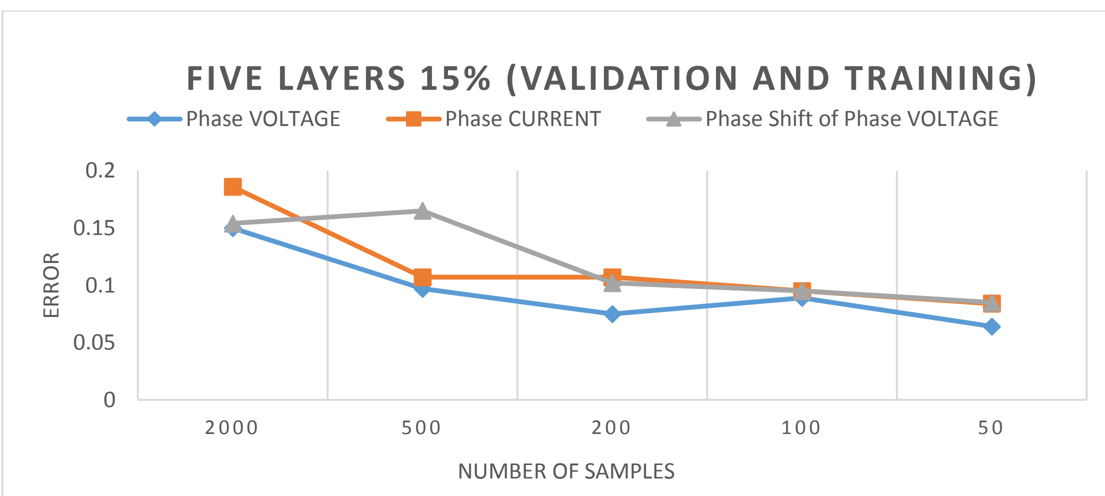

Figure 5-23: ANN Results for the Fault Classification with All Possible Type of Fault Five Layers and 15% Validation and Training.

Figure (5-24) is the result of the NN by increasing the number of the hidden layers. The internal and external effects with the least error (0.000001%).

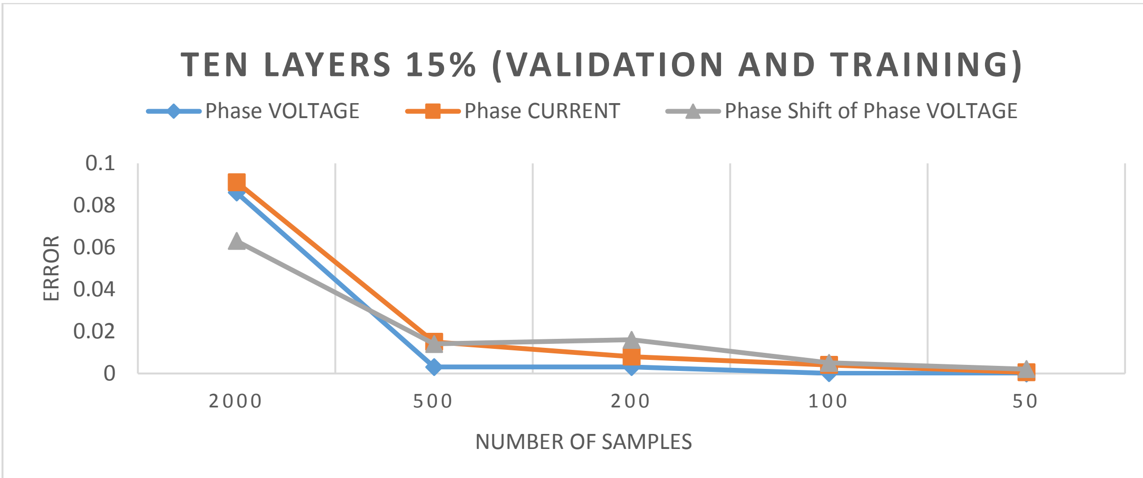

Figure 5-24: ANN Results for the Fault Classification with All Possible Type of Fault Ten Layers and 10% Validation and Training.

The last three charts (5-22 and 23) are close to the previous two charts (5-19 and 20) respectively by the percentage of the error, with the same number of sampling, variables, number of layers, but figure (5-24) is the competitive one. As a result, the best design of this method founded by (50) samples, ten layers, (15% of validation and testing), the voltage variable and ANN algorithm were giving the best result.

Furthermore, the last three charts below from (5-25 to 27) show the comparison between the same variable with different layers, validation and testing. Thus, it is clearly that the voltage variable gives better results than the current or even the phase shift of phase voltages. Therefore, the Neural Network is one of the best algorithms that can classify the fault in the transmission line. Neural networks, in general, provide an authoritative, an attractive and immune alternative approach for the development of a classification for the Transmission Line system.

Figure (5-25) shows the comparison between the Voltages with different conditions.

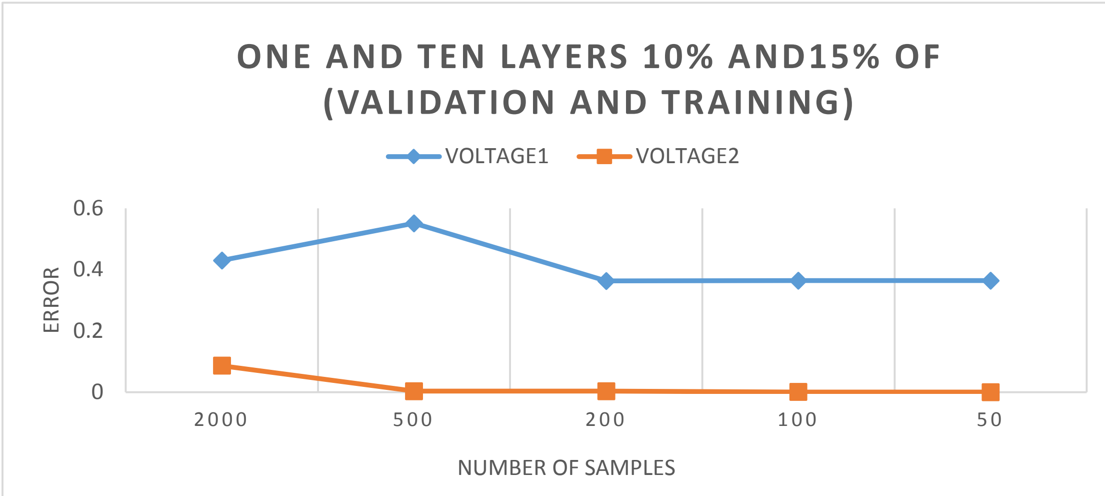

Figure 5-25: The Comparison of the ANN Results for the Voltage Variable Between One Layer 10% of Validation and Training with Ten Layers 15% of Validation and Training.

Figure (5-26) shows the comparison between the Currents with different conditions.

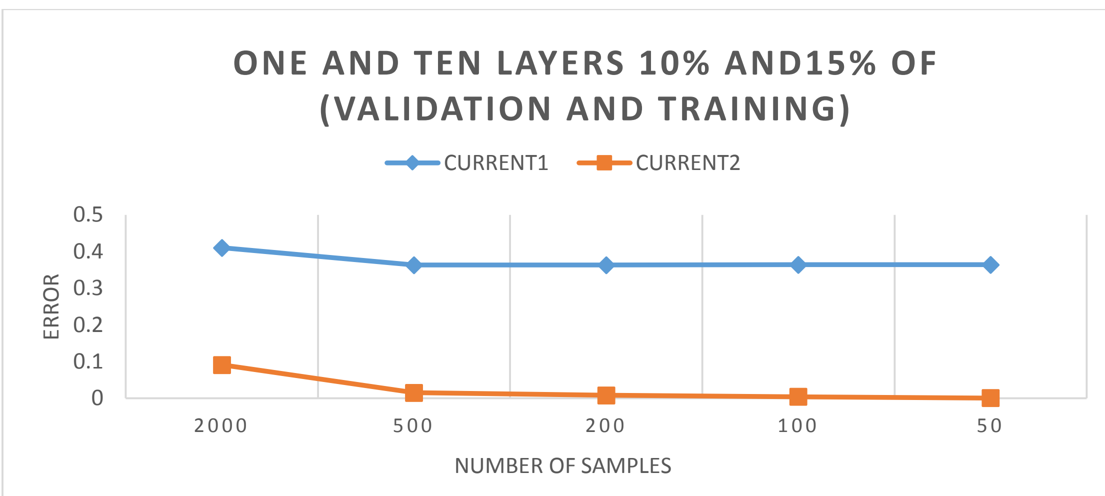

Figure 5-26: The Comparison of the ANN Results for the Current Variable Between One Layer 10% of Validation and Training with Ten Layers 15% of Validation and Training.

Figure (5-27) shows the comparison between the Phase Shift of Phase Voltages with different conditions.

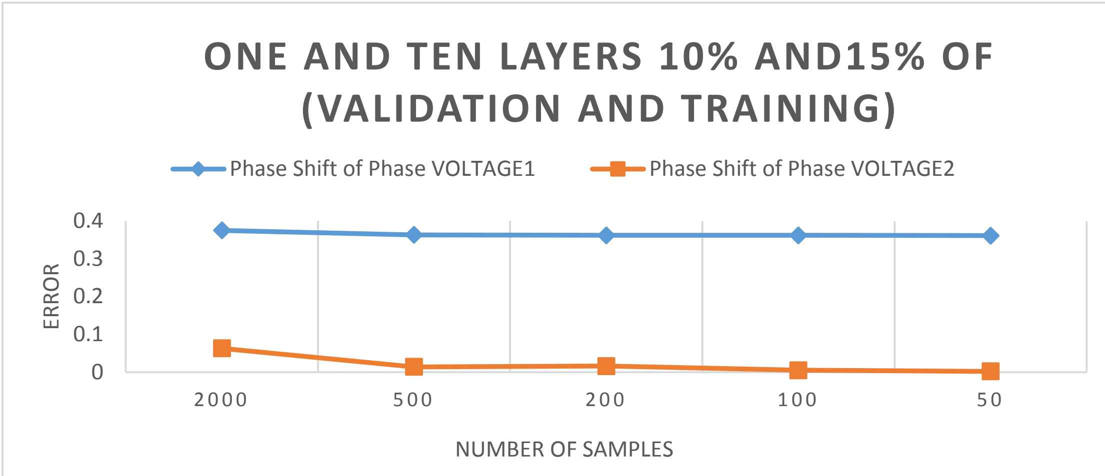

Figure 5-27: The Comparison of the ANN Results for the Phase Shift of the Phase Voltages Variable Between One Layer 10% of Validation and Training with Ten Layers 15% of Validation and Training.

Table 5-1: Transmission Line Fault Classification Results.

FAULT TYPE	SERIES	SHUNT	PH_A	PH_B	PH_C	GND
NORMAL	0	0	0	0	0	0
A-G	6.71e-5	1	0.9998	1.08e-5	9.12e-5	0.9994
B-G	4.22e-5	1	0.0045	1	0.0001	0.9993
C-G	1.39e-5	1	2.55e-5	1.23e-5	1	0.9986
A-B	2.71e-5	1	0.9999	1	12.8e-5	0
A-C	0	1	1	0	0.999	0
B-C	0	0.999	0	1	0.999	0
A-B-G	0	0.999	0.999	1	0	0.999
A-C-G	0	1	0.999	0	0	0.999
B-C-G	0	1	0	0.999	0.999	0.998
A-B-C	0	1	1	1	1	1
A-B-C-G	0	1	1	1	1	1
A-OPEN	1	0	0.999	0	0	0
B-OPEN	1	0	0	0.989	0	0
C-OPEN	1	0	0	0	1	0
A-B-OPEN	0.999	0	0.999	0.999	0	0
A-C-OPEN	0.999	0	0.999	0	0.999	0
B-C-OPEN	0.989	0	0	0.999	0.999	0

5.3 Fault Localization Results

5.3.1 Mathematical Calculation

The fault localization can be divided in to two parts based on the type of the Electrical Power System components as below:

1. The uncompensated network it is easy to find the fault location according to Ohm’s law then solve the equation and find the impedance after that calculating the inductance per the length of the transmission line.
2. The compensated network it is very complex to find the fault location because the impedance will be changing all the time of the fault and the reason of that is the behavior of the compensation in time of the fault as below:
   a. Dropping in the voltage: The compensation will work as a capacitor.
   b. Jumping in the voltage: The compensation will work as an inductor.

   Therefore the impedance that is calculated will be representing the total impedance as the equation below:

$$5\boldsymbol{Z}_{\boldsymbol{Actual}} = \begin{cases} \boldsymbol{Z}_{\boldsymbol{calculated}} + \boldsymbol{Z}_{\boldsymbol{compasation}} & \textbf{\textit{Capacitor case}} \\ \boldsymbol{Z}_{\boldsymbol{calculated}} - \boldsymbol{Z}_{\boldsymbol{compasation}} & \textbf{\textit{Inductor case}} \end{cases} \quad (5\text{-}1)$$

Thus the actual impedance is the only impedance that achieved the fault localization. Therefore, the tables below explains the ability of the ANN regarding to the type of the fault and the type of the network.

Table (5-2 and 3) below show three types of the results and the error for the best type for the single line to ground fault with and without compensation.

Table 5-2: Single Line to Ground Fault Localization Results for the Uncompensated Network.

Type of fault	Actual distance (meter)	Estimated distance (meter)			Error of the Generalized ANN
		Equations	ANN	Generalized ANN	
SLG	5000	5630	5031	5022	3.67E-05
SLG	10000	10690	9993	10003	5.00E-06
SLG	20000	20960	19990	19985	2.50E-05
SLG	40000	41480	39990	40020	3.33E-05
SLG	50000	51650	49999	49940	1.00E-04
SLG	100000	102500	99960	99920	1.33E-04
SLG	150000	152900	149900	150000	0.00E+00
SLG	200000	203100	199900	199900	1.67E-04
SLG	250000	253200	249900	250100	1.67E-04
SLG	300000	304000	299900	300000	0.00E+00

Table 5-3: Single Line to Ground Fault Localization Results for the Compensated Network.

Type of fault	Actual distance (meter)	Estimated distance (meter)			Error of the Generalized ANN
		Equations	ANN	Generalized ANN	
SLG	5000	6817	5010	4987	2.17E-05
SLG	10000	13280	10020	10010	1.67E-05
SLG	20000	25640	19960	19990	1.67E-05
SLG	40000	50970	39970	40020	3.33E-05
SLG	50000	63660	49920	49950	8.33E-05
SLG	100000	128800	99940	100000	0.00E+00
SLG	150000	190800	149900	149900	1.67E-04
SLG	200000	255700	200000	200000	0.00E+00
SLG	250000	326300	250200	250400	6.67E-04
SLG	300000	398600	300100	300100	1.67E-04

Table (5-4 and 5) below show three types of the results and the error for the best type for the Double line and Double line to ground fault with and without compensation.

Table 5-4: Double Line and Double Line to Ground Fault Localization Results for the Uncompensated Network.

Type of fault	Actual distance (meter)	Estimated distance (meter)			Error of the Generalized ANN
		Equations	ANN	Generalized ANN	
DL/DLG	5000	5028	4979	5000	0.00E+00
DL/DLG	10000	10060	10120	9946	9.00E-05
DL/DLG	20000	20120	19970	20000	0.00E+00
DL/DLG	40000	40270	40000	40070	1.17E-04
DL/DLG	50000	50360	49930	50030	5.00E-05
DL/DLG	100000	101200	100100	100100	1.67E-04
DL/DLG	150000	152200	150000	150100	1.67E-04
DL/DLG	200000	208000	200200	200100	1.67E-04
DL/DLG	250000	258900	250100	250000	0.00E+00
DL/DLG	300000	312000	300000	300000	0.00E+00

Table 5-5: Double Line and Double Line to Ground Fault Localization Results for the Compensated Network.

Type of fault	Actual distance (meter)	Estimated distance (meter)			Error of the Generalized ANN
		Equations	ANN	Generalized ANN	
DL/DLG	5000	5029	4988	5060	1.00E-04
DL/DLG	10000	10040	10010	10000	0.00E+00
DL/DLG	20000	20110	19990	20010	1.67E-05
DL/DLG	40000	40230	39970	40100	1.67E-04
DL/DLG	50000	50300	49970	50010	1.67E-05
DL/DLG	100000	100900	99980	100000	0.00E+00
DL/DLG	150000	152900	150000	150000	0.00E+00
DL/DLG	200000	202500	200000	200000	0.00E+00
DL/DLG	250000	261500	249900	250000	0.00E+00
DL/DLG	300000	318600	300000	300000	0.00E+00

Table (5-6 and 7) below show three types of the results and the error for the best type for the three phase and three phase to ground fault with and without compensation.

Table 5-6: Three Phase and Three Phase to Ground Fault Localization Results for the Uncompensated Network.

Type of fault	Actual distance (meter)	Estimated distance (meter)			Error of the Generalized ANN
		Equations	ANN	Generalized ANN	
3PH/3PH-G	5000	4957	5000	5000	0.00E+00
3PH/3PH-G	10000	9915	10000	10000	0.00E+00
3PH/3PH-G	20000	19830	20000	20000	0.00E+00
3PH/3PH-G	40000	39690	40000	40000	0.00E+00
3PH/3PH-G	50000	49640	50000	50000	0.00E+00
3PH/3PH-G	100000	99670	100000	100000	0.00E+00
3PH/3PH-G	150000	151500	150000	150000	0.00E+00
3PH/3PH-G	200000	203300	200000	200000	0.00E+00
3PH/3PH-G	250000	256400	250000	25000	0.00E+00
3PH/3PH-G	300000	312000	300000	300000	0.00E+00

Table 5-7: Three Phase and Three Phase to Ground Fault Localization Results for the Compensated Network.

Type of fault	Actual distance (meter)	Estimated distance (meter)			Error of the Generalized ANN
		Equations	ANN	Generalized ANN	
3PH/3PH-G	5000	5087	5004	4992	1.33E-05
3PH/3PH-G	10000	9922	9992	9985	2.50E-05
3PH/3PH-G	20000	19840	20000	19990	1.67E-05
3PH/3PH-G	40000	39710	40010	40020	3.33E-05
3PH/3PH-G	50000	49670	49990	49980	3.33E-05
3PH/3PH-G	100000	99710	100000	100000	0.00E+00
3PH/3PH-G	150000	150500	150000	150000	0.00E+00
3PH/3PH-G	200000	203500	200000	200000	0.00E+00
3PH/3PH-G	250000	257100	250000	250000	0.00E+00
3PH/3PH-G	300000	306600	300000	300000	0.00E+00

5.4 Discussion of the Results

5.4.1 Discussion of the Fault Detection

1. The New Composite relay has the abilities to detect the fault in the real time because the features of this digital relay work with all types of networks weather it has or has not compensation component.
2. The time in fault detection is playing a vital rule and become the challenge due to the extension in the Electrical Power System especially if it has a compensation system. So the New Composite relay algorithm proved to be the best in the detecting of the fault.
3. The New Composite Relay has the ability to detect any type of fault (series or shunt) with respect to all specific type of each one.
4. The New Composite Relay depending on the current signals only.
5. The New Composite relay is immune to any change in the network parameters even if there is any change in the load, and it can be coordinated and worked as a backup protection with any type of setting.
6. The New Composite relay has the ability to increase or decrease the delay.

5.4.2 Discussion of the Fault Classification

1. Using of the Feed Forward ANN is better than other algorithms because the fault considers as an abnormal and nonlinear behavior happens to the system that is leading to use the classifier that is treated with the linear and nonlinear system.
2. Selecting the classifier is depending on the system behavior.

3. According to the results and the comparisons, the classifier has the strong and the weak points and we can avoid the weak and improve the strong by defining the input in different ways and choose the input which archiving the best results.
4. The windowing approach was proving its effectiveness to classify all types of the fault and avoiding the overlapping in the information that was collected from the recorders to be the input to the classifier.
5. Choosing of the different features of each type of fault is the right way to get the desire output.
6. Also, more data will lead to wrong results as in the charts for the fault classification.
7. Most of the research used to use the voltage and the current signals or only the current signals. Practically, all the researches that were adopting the current signal as a part of the inputs or even the only variable is not useful because the current signals have the range from zero to the high rated and up (due to the fault situation). Furthermore, both magnitude and phase shift are changing all the time (based on the changing in the load).

5.4.3 Discussion of the Fault Localization

1. The fault localization using the ANN is not depending on the transmission line parameters. Therefore, it can localize the fault in spite of the changing in the load or the parameters of the system.
2. The problem with the ANN appears when the parameters are changing alternatively when the fault occurs.

3. The new proposed to return the system to the regular system is the best way to avoid the fluctuating in the signals.
4. The compensation network is the complex in fault localization.
5. Changing the position of the compensation in the network will produce the wrong analysis about the fault localization.
6. The control was designed according to the challenge in the fault localization with the compensation network.
7. The accuracy of the new system with the control was approved to be the best in fault localization with (both series and shunt) compensation network.

6. CONCLUSION AND THE SUGGESTION OF FUTURE WORK

The fault detection passes through many stages before of making the decision due to the system behavior. So the system may have a very short transient theoretically it considers this system in this moment lies in the faulty area and the protection system has to send the trip signal to the circuit breaker and isolate the faulty area quickly. The reasons of the delay here are to deal with the real systems and not only the ideal one and make sure this system will not send any unwanted signal. Also, the other factors may enter the same cause of the transient in the system like the first time turn on the system which very popular and in this time the protection system will wait until the specific time that was set it before. So the transient time not opened for a while, but there is a setting value when it reaches by the magnitude or the time which one will reach before will enforce the system to shut down. The New Composite relay has this ability to do all of that and prevent the unwanted trip signal. As a result, this type carry out all possible chance of abnormal behavior and successfully disconnect the fault in time.

The second issue was solved by the New Composite relay is the reality of the outside fault that is located out of the protection zone and again this system was treating with it as individual problem and satisfying to protect it because it considered as an over current.

The third issue is the time delay that can take it to isolate the system when the fault lies in the end of the system. Thus, the system divided the transmission line into few zones and each one is a backup for the next one.

Finally, this new protection system isolate as much as can the faulty area before it going backward and keep the rest system works probably.

The fault classification was built through the ANN, which is the best classifier that can deal with the linear and nonlinear systems. Therefore, the classifier has the ability to classify the fault fast, the system depending on one side information and it was used three ways to investigate about the best variables which can lead to the best result and as much as closed to the desire output.

In this research the variables were taking from the sending side were (Phase Voltage, Phase Current and the Phase Shift of the Phase voltage) under the same conditions. In spite of the Phase current achieved the desire output, but it was less than the accuracy of the Phase Voltage variable due to the small changes between the normal and abnormal situations. Moreover, the Phase voltage is the only variable has the same magnitude most of the time, but the other variables are changed as the load changing or even the transmission line parameters.

The classifiers' input came in the way which leads to fully satisfy to classify the fault accurately by (100%). So the input should not have a ripple all the time, but when it has a very small ripples that can be accepted because the ANN will not count the small changes in the input data.

Using of the Digital Signal Processing gives the classifier powerful to reach these impressive results, but the huge data for each situation will lose its effectiveness seed. Also, the overlapping data have the same if not more effect on the efficiency of the classifier. Thus, it was presenting the new technique that is called (windowing) to use the features that characterizes between each other. Therefore, this system has succeeded in determining the type of the fault fast and accurate.

The fault localization was designed and implemented using the ANN by the MATLAB/SIMULINK. Localizing the fault in the transmission is considered one of the big problem due to the type of the network because most of the electrical power systems have the compensation equipment in it. The pattern recognition is the way to design the localization system using the ANN, but with all of the strongest localizer performance it is still weak against the continuing of change when the fault occurred. So there has to have a system not affected by any internal or external changes.

The generalized ANN system has the higher performance as compare with the other types of localization method. Also, when the system has a compensation component the generalized ANN will not read the behavior correctly because the compensated network under the fault will work to increase the voltage when there is a drop voltage (works as a capacitor) and decrease the voltage (works as an inductor) when there is a jumping in the voltage. Therefore, designing of the localizer using the ANN faced the problem because the changing in the variables which are the input to the Generalized ANN will give another expectation to the system that leads to wrong estimation. Practically, it cannot provide better solution other than removing the reasons that led to provide the Generalized ANN with data that is differ from the training. Thus, the solution is return the system to the regular one by disconnecting the compensation component from the network which has proved its effectiveness. By using the same technique in the fault classification, the fault localization using the ANN gives the best results based on the small error of the estimation.

According to the training and the results, it is clearly that the ANN gives better estimation for the fault location as compare with the other methods. So, it can be described by few points as below:

1. The equation method will count any additional parameters that may be added by the power factor correction or any subsystem.
2. Best pattern recognition will provide a robust and immune localizer system against any changing may happen due to the fault.
3. Generalized the localizer has to be approved based on the cost of each component. Also this step will prevent any unviewed fail system.
4. The individual system will give error estimation when the length of the transmission line changed.
5. For the fast decision the generalized localizer gives the best results.
6. Providing more information to the ANN is not necessary to give better result.
7. Whenever the information not overlapping, the localizer will recognize the features.

In summary, the fault in the transmission line is unavoidable but it can be minimized by using the reliable components and designing the parameters according to the conditions and the limitations that should be available in the system based on the environment. Also, the transmission line has to have all possible expansion of the power due to the startup of the load and any expectation of the sudden fault due to the weather.

The future work is divided into four parts as below:

1. Using a prototype to verify this new Composite Relay and test it practically.
2. Apply multiple classifier for a perfect classifier and pattern recognition.
3. Enter the DSP technique by using the FFT and DFT before the ANN.
4. Signal tracking is another technique to detect the fault.

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