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Title:

Design and Implementation of an Overhead Fault Passage Indicator for Medium Voltage Network

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Abstract

Fault Passage Indicators (FPIs) (also called FCIs: Faulted Circuit Indicators) have been under development for the last 70 years including new capabilities to satisfy the needs of the Distribution Network Operators. For overhead lines, the FPI hangs on the conductor between two poles, where the FPI mechanical support is also part of the sensor. In underground cables, the FPI surrounds the conductor and the insulation (without the shield) and is allocated mostly in the MV/LV substation. The device itself mainly contains the sensor, the controller for processing the data, the indication means, a reset interface and a system to power the device. Therefore, the FPI are designed to be compact and easy to install. The FPI normally includes a visual indication of the fault (a LED, a flag, etc.). The recent developed one includes more circuits such as memory and communication facility.

In this work, Fault Passage Indicator has been implemented first in PC using Matlab-Simulink, then tested using Power System Simulink Model under several operating and fault conditions.

Dedication

I dedicate my dissertation work to my family and many friends.
A special feeling of gratitude to my loving parents, whose words of encouragement and push for tenacity ring in my ears. My sisters have never left my side and are very special to me. I also dedicate this dissertation to my many friends that supported me throughout the process and who have along the years, become my second family.

KHELIOUEN Mustapha/LAKHDARI Ahmed Mounir

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First of all, we pay our obeisance to Allah, the almighty to have bestowed upon us good health, courage, and inspiration. After Allah, we would like to express our sincere and deepest gratitude to our supervisor, Pr. HAMID BENTERZI for guidance and help during the project. His expertise, invaluable guidance, constant encouragement, understanding, patience, and criticism added considerably to our experience.

And giving us this golden opportunity to do this wonderful project on the Fault Passage Indicator, Secondly we would also like to thank our parents and friends who helped us a lot in finalizing this project within the limited time frame.

Table of Contents

List of Tables

List of Figures

List of Abbreviations & Acronyms

CB	Circuit Breaker
DCU	Data Concentrator Unit
FPI	Fault Passage Indicator
GPRS	General Packet Radio Service
IEC	International Electromechanical Commission
IPK	Pick Up Current
LTE	Long Term Evolution
OC	Over Curent
OV	Over Voltage
SCADA	Supervisory Control and Data Acquisition
TDS	Time Delay Setting
UV	Under Voltage

Chapter I :
General introduction

1. General introduction

Failure in power system distribution and transmission is unavoidable event due to number of undesirable nature accidents or human-errors (lightings, wind damage, ice loading, tree falling, bird shorting, vehicles hitting, people contacting, digging into underground cable…….), for that Power companies are in immense pressure to reduce outage time for customers and increase reliability of the system which means making the protection of the system better as it can be.

Overhead lines are vulnerable to faults, because of the system equipment exposed to extreme weather conditions. Identification of fault on medium voltage distribution network is tedious and time consuming, because of the complexity of network, relatively less advanced infrastructure and access to locations. Under these circumstances, fast location of fault plays a major role. Fault passage indicators (FPIs) helps in identification and location of fault.

The first fault indicators came onto the market from Horstmann (Germany) in 1946. The Schweitzer Manufacturing Company introduced a product to the United States in 1948. The first fault indicators were manual reset devices. Later fault indicators automatically reset on system restoration or after a set period of time. In the late 70’s, a conductor mounted and pole mounted fault indicator were introduced using di/dt technique and sensitivity. More recent fault indicators communicate their status (tripped or reset) via cell signal or radio to a central station, handheld device, or pole-mounted receiver and remotely programmable overhead line indicator.

The use of this device reduces the total outage time by guiding the locating crew straight to the faulted cable section we can translate that in terms of better SAIDI (System Average Interruption Duration Index) and CAIDI (Customer Average Interruption Duration Index) indexes. [15]

In order to understand the function of FPI, software FPI Simulink based-model must be realized, modeling of FPI offer an economic and feasible alternative to studying the performance of device and optimizing its settings. Electric power utilities use computer-based models to confirm how they would perform during systems disturbances and normal operating conditions and to make the necessary corrective adjustment on the model settings.

The goal of this project is to explain the working process of a Simulink model for a Fault Passage Indicator in Medium voltage network. Inside the modeling, continuous V-I measurement, input and chosen reference comparison and fault type detection were designed. The Fault Passage Indicator characteristic was set to be easily manageable based on the desirable and demand of the chosen network.

This report is divided into five chapters:

-Chapter one: presents a general introduction.

-Chapter two: presents an Overview about power system protection and faults.

-Chapter three: deals with FPI composition and working principle.

-chapter four: describes the design model using SIMULINK/MATLAB and tools required for simulation, and testing the developed FPI model using also SIMULINK.

-Chapter five: presents conclusion and further works.

Chapter II :

Overview about power system protection and faults

Introduction

System protection has evolved over the years from relatively primitive devices with limited capability to complex system that involves extensive hardware and software. These modern protective systems are more selective in their detection and operation and often require greater analytical effort in their application. [5]

In this chapter we will take an over view about power system protection and faults analysis.

II. Part one: power system and protection

II.1.1. Power system

Electric power system encompasses power generation, transmission, distribution and utilization of electric power.

There are three major categories of energy for electricity generation which are fossil fuels (coal, natural gas, and petroleum), nuclear energy, and renewable energy sources

The main components of an Electric Power System are:

(a) Generators

(b) Transformers (Power Transformer, Current Transformer and Potential Transformer)

(c) Lines (Transmission and Distribution Lines)

(d) Switchgear (Circuit Breaker, Relays, Bus bars, Disconnect Switch etc.)

(e) Other components include Lightning arrester, Insulator etc.

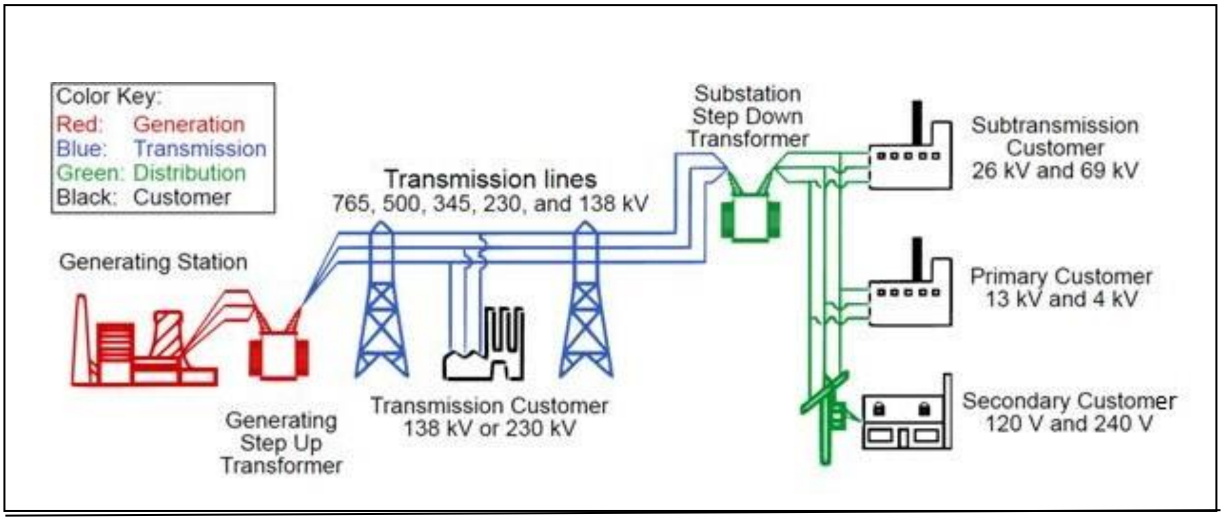


Figure 2.1: Power supply network

In electrical generating power stations, electrical power is generated at medium voltage level that ranges from 10 kV to 30 kV. This level of voltage is increased at different suitable levels, it may be at 120 kV or 220 kV or 400 kV This high voltage level is maintained to transmit the power to a long distant substation via transmission lines at the end point of the transmission lines, in the substation, the step down transformers are used to step down the voltage level to meet the requirements of customers at the distribution level. [7]

Here is a block diagram for the different parts of the electric power system:

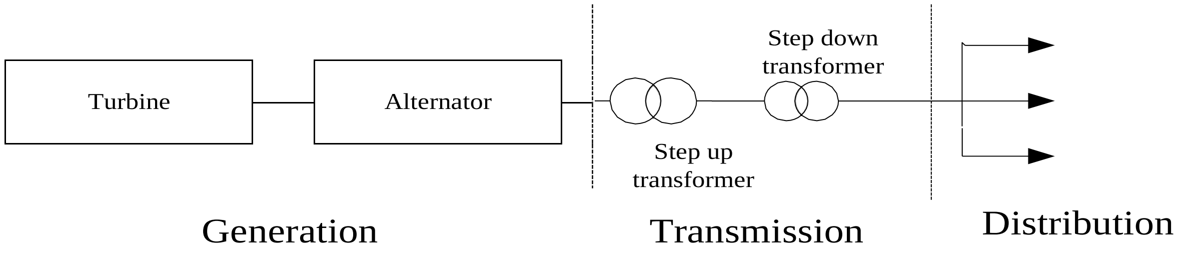


Figure 2.2: block diagram for the different parts of the electric power system

II.1.2 -Power system protection

System protection is the art and science of detecting problems with power system components and isolating these components. In a power system, fault can develop in any of the components i.e. generators, buses, transformers and vulnerable transmission lines that are exposed to the environment, Protective systems help to minimize power system damage and reduce the cost of repair. [5] It safeguards the total power system, guarantees continuity of supply and ensures the safety of personnel from hazardous voltages. Protective systems ensure maximum profit on the huge capital outlay on power supply network and equipment, and it also ensures that consumers get reliable service. [4].

There are various levels of protection on the supply network, as discussed below.

- **Protection scheme at the generation level**

(a) Generator phase to phase winding protection (differential relay)

(b) Anti-motoring protection (reverse or directional relay)

(c) Over-excitation protection (directional or reverse-power relay)

(d) Phase-overvoltage protection (overvoltage relay)

(e) Safeguard against current supply or field voltage loss (offset mho relay).

- **Protection scheme at the transmission level**

Transmission lines are spread over a significant geographic area, and as a result, they are exposed to variety of hazards. Typical causes of line faults include lightning, wind, ice, snow salt spray, birds, airplanes, automobiles and man. The line fault could be line to ground, line to line or earth (leakage) faults. Power lines experience more faults than any other components of the system. The protection devices include:

(a) Distance relay protection.
(b) Over current relay protection.
(c) Earth fault relay protection.
(d) Standby earth fault protection.
(e) Restricted earth fault relay.

- **Power transformer protection**

Transformers are the most expensive and critical power system component [12], and it requires utmost protection to ensure longevity. Transformer failure may result in a lengthy and costly power outage. Transformer protection usually takes the following form:

(a) Differential relay protection offers the best form of protection for both ground and phase faults,
(b) Restricted earth fault protection scheme in which the protective relay operates to trip the primary and secondary transformer breaker but not the line breaker,
(c) Over current and earth fault protection which comprises two over current relay and one earth fault relay,
(d) Thermal relay protection which responds to the copper winding’s temperature increase due to increase in load, causing the auxiliary cooling system (fan or pump) to operate,
(e) Buchholz protection in which the protective relay operates in response to sudden pressure rise and gas development, internal arcing faults, and slow decomposition of insulating materials.

- **Protection scheme at the distribution level**

Normally distribution lines and feeders are protected by over current relays. Over current relays are used as primary as well as in backup protection relays for the distribution networks. There is a different scheme of protection for radial distribution systems and for distribution systems with distributed energy resources [1].

II.1.3 -Types of protective devices:

Fuses: Fuses are the oldest protective devices that have survived from the age of electricity to the present times. This can be attributed to their intuitive simplicity. The fuse allows the normal current to flow but it melts itself out, thus breaking the circuit, when the current exceeds a certain amount of time. It combines the functions of sensing, comparing, and interrupting the current into one. [5]

Protective relay: Relays are compact analog, digital, and numerical devices that are connected throughout the power system to detect intolerable or unwanted conditions within an assigned area. They are designed to maintain a high degree of service continuity and limit equipment damage.

Circuit breaker: A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit its basic function is to detect a fault condition and, by interrupting continuity, to immediately discontinue electrical flow. Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit breakers are made in varying sizes, from small devices that protect an individual household appliance up to large switchgear designed to protect high voltage circuits feeding an entire city.

Auto-Reclosers: They are circuit breakers equipped with a mechanism that can automatically close the breaker associated with Over-current relays. They are used in distribution Systems. [5]

II.1.4 -Protective system design considerations:

Every protective scheme which is designed to isolate a faulty element of a power system, is required to satisfy the following four basic requirements

(a) Reliability: It is the ability of the relay system to operate under the predetermine condition.

(b) Selectivity: It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system.

(c) Sensitivity: It is the ability of a system to identify an abnormal condition that exceeds a nominal “pick up” or detection threshold value and which initiates protective action when the sensed quantities exceed that threshold. [12]

(d) Economy: The most important factor in the choice of a particular protection scheme is the economic aspect. Sometimes it is economically unjustified to use an ideal schema of protection and compromise methods have to be adopted. As a rule, the protective gear should not cost more than five percent of total cost. However, when the apparatus to be protected is of utmost importance, economics considerations are often subordinate to reliability.

(e) discrimination: It is the ability of a protective system to discriminate between a transient abnormal condition “switching action” and fault condition even both exceed its setting points but it operates only when the latter appears.

Part two: fault causes and analysis

II.2.1 Faults:

Faults are any unusual phenomena that may occur on the transmission line, and which will lead to the flow of high current through the conductors and to a considerable voltage drop; knowing that these conditions will lead to serious damage to the electric system.

Here after is a discussion about the faults causes and how to analyze the problems in order to better protect the equipment and ensure power supply continuity. [5]

II.2.2 Faults causes:

Here is a variety of faults affecting the transmission system, which mainly depend on five (05) factors:

- Insulations.
- Electrical causes.
- Thermal causes.
- Mechanical causes.
- Climatologic.
- Human activity or error.

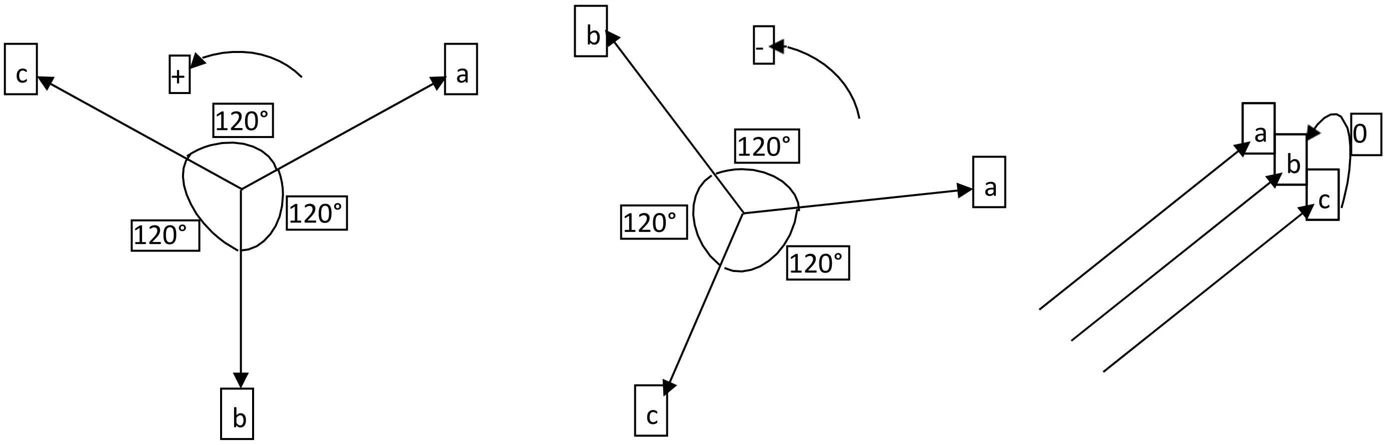
II.2.3 Line modeling using Symmetrical Component Transformations:

The power system is considered to be a balanced symmetrical three phase system. But whenever a fault occurs somewhere in the system, the network becomes asymmetrically unbalanced, which is interpreted by the appearance of unbalanced voltages and currents. However, there is one case where the system is symmetrically faulted, it is when a three phase fault occurs since the fault involves all three phase equally at the same time.

In an asymmetrically faulted system, neither the currents nor the voltages will possess three phase symmetry. The impedance matrices of generators, transformers and lines will all be non-diagonal. We will no longer limit the analysis to one phase because coupling will exist between phases, and it becomes a must to treat the three phases individually.

Symmetrical component method is a very powerful tool in fault analysis and protective relay design. It allows engineers to have a wider view and thus make more intelligent choices in selecting settings of protective relays. [11]

Symmetrical component method assumes that any three-phase unbalanced phasors of currents or voltages in a power system can be represented by three balanced sets of currents or voltages; these sets are positive-, negative- and zero-sequence. As shown in figure2.4.1 below:



Positive sequence Negative sequence Zero sequence

Figure 2.3: Sequence components

Let I_a, I_b *and* I_c be the 3-phase currents (unbalanced) at some point of the network. By definition, each phase current is written as the sum of three components as:

$$\begin{cases} I_a = I_{a_+} + I_{a_-} + I_{a_0} \\ I_b = I_{b+} + I_{b-} + I_{b0} \text{...} \\ I_c = I_{c_+} + I_{c_-} + I_{c_0} \end{cases} \text{(I)}$$

Where:

- $(\boldsymbol{I_{c_+}}, \boldsymbol{I_{b_+}}, \boldsymbol{I_{a_+}})$ is a set of balanced currents having the abc sequence (then we name them **positive sequence of currents**).
- $(\boldsymbol{I_{c_-}}, \boldsymbol{I_{b_-}}, \boldsymbol{I_{a_-}})$ is a set of balanced currents having the acb sequence (then we name them **negative sequence of currents**).
- $(\boldsymbol{I_{c_0}}, \boldsymbol{I_{b_0}}, \boldsymbol{I_{a_0}})$ is a set of balanced currents having equal magnitudes and phases (then we name them **zero sequence of currents**).

Let α be a phase shifter and designate a complex number:

$$\alpha = e^{j\frac{2\pi}{3}} = -\frac{1}{2} + j\frac{\sqrt{3}}{2}$$

With the obvious implication of:

$$\alpha^2 = e^{-j\frac{2\pi}{3}} = -\frac{1}{2} - j\frac{\sqrt{3}}{2}$$

Then, $1 + \alpha + \alpha^2 = 0$

The sequence currents can be written mathematically as:

$$\left\{\begin{array}{ll} I_{b_+} = \alpha^2 I_{a_+}, & I_{c_+} = \alpha I_{a_+} \\ I_{b_-} = \alpha I_{a_-}, & I_{c_-} = \alpha^2 I_{a_-} \\ \multicolumn{2}{c}{I_{c_0} = I_{b_0} = I_{b_0}} \end{array}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(II)}$$

Substituting the relations from equation (II) into equation (I) gives:

$$\left\{\begin{array}{l} I_a = I_{a_+} + I_{a_-} + I_{a_0} \\ I_b = \alpha^2 I_{a_+} + \alpha I_{a_-} + I_{a_0} \\ I_c = \alpha I_{a_+} + \alpha^2 I_{a_-} + I_{a_0} \end{array}\right.$$

Or in matrix form:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ \alpha^2 & \alpha & 1 \\ \alpha & \alpha^2 & 1 \end{bmatrix} \times \begin{bmatrix} I_{a_+} \\ I_{a_-} \\ I_{a_0} \end{bmatrix}$$

If we define: $I_p = \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$; $I_s = \begin{bmatrix} I_{a_+} \\ I_{a_-} \\ I_{a_0} \end{bmatrix}$ then: $\boxed{\boldsymbol{I_p = \mathcal{T} I_s}}$

Where: $\boldsymbol{\mathcal{T}} = \begin{bmatrix} 1 & 1 & 1 \\ \alpha^2 & \alpha & 1 \\ \alpha & \alpha^2 & 1 \end{bmatrix}$ is: the **Symmetrical Component Transformation Matrix.**

We note that from the definition of $\boldsymbol{\alpha}$, we have: $\alpha^* = \alpha^2$, $(\alpha^2)^* = \alpha$, $\alpha - \alpha^2 = j\sqrt{3}$

We can easily check that: $det(\boldsymbol{\mathcal{T}}) = 3(\alpha - \alpha^2) = 3j\sqrt{3} \neq 0$

This means $\boldsymbol{\mathcal{T}}$ has an inverse matrix $\boldsymbol{\mathcal{T}^{-1}} = \frac{1}{3}\begin{bmatrix} 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \\ 1 & 1 & 1 \end{bmatrix}$ => $\boxed{\mathbf{I_s} = \boldsymbol{\mathcal{T}^{-1} I_p}}$

Then: $$\left\{ \begin{array}{l} \boldsymbol{I_p} = \boldsymbol{\mathcal{T}}\mathbf{I_s} \\ \mathbf{I_s} = \boldsymbol{\mathcal{T}^{-1} I_p} \end{array} \right\} \ldots\ldots\ldots\ldots (III)$$

We have applied the S.C.T to current phasors, but we may apply it to voltage phasors as well:

We define: $V_p = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$ and $V_s = \begin{bmatrix} V_{a+} \\ V_{a-} \\ V_{a0} \end{bmatrix}$ then:

$$\boxed{\boldsymbol{V_p} = \boldsymbol{\mathcal{T}}\mathbf{V_s} \quad => \quad \mathbf{V_s} = \boldsymbol{\mathcal{T}^{-1} V_p}}$$

$$\left\{ \begin{array}{l} \boldsymbol{V_p} = \boldsymbol{\mathcal{T}}\mathbf{V_s} \\ \mathbf{V_s} = \boldsymbol{\mathcal{T}^{-1} V_p} \end{array} \right\} \ldots\ldots\ldots\ldots (IV)$$

Then, a transmission line operated under unbalanced conditions can be described by equations of the form:

$$V_p = Z \times I_p \quad or \quad I_p = Y \times V_p$$

Where **Z** and **Y** are full 3 × 3 matrices. If we use equations (III) and (IV), we will obtain:

$$\left\{ \begin{array}{l} \mathcal{T}V_s = Z.\mathcal{T}I_s \\ \mathcal{T}I_s = Y.\mathcal{T}V_s \end{array} \right. \quad => \quad \left\{ \begin{array}{l} \boldsymbol{V_s = \mathcal{T}^{-1}Z.\mathcal{T}I_s = Z_s I_s} \\ \boldsymbol{I_s = \mathcal{T}^{-1}Y.\mathcal{T}V_s = Y_s V_s} \end{array} \right\} \ldots\ldots\ldots\ldots (V)$$

Where:

$\boldsymbol{Z_s = \mathcal{T}^{-1}Z\,\mathcal{T}}$ and $\boldsymbol{Y_s = \mathcal{T}^{-1}Y\,\mathcal{T}}$ are the symmetrical component transformed matrices.

Whenever we replace **Z** by **Z$_s$** and **Y** by **Y$_s$,** we have the same performance equations (mathematically) both in the **abc** system or in the sequence system. In practice it turns out that even **Z** and **Y** are full matrices, **Z$_s$** and **Y$_s$** are **diagonal** for the elements mostly used in electrical engineering power systems; this means there is no coupling between the positive, negative, and zero sequence systems. This **“decoupling feature”** has made the S.C.T such a widely used tool.
Considering a power transmission line operated under unbalanced condition, such that:

$$\boldsymbol{I_a + I_b + I_c = 0}$$

The figure2.4.1 shows a power transmission line operated under balanced condition:

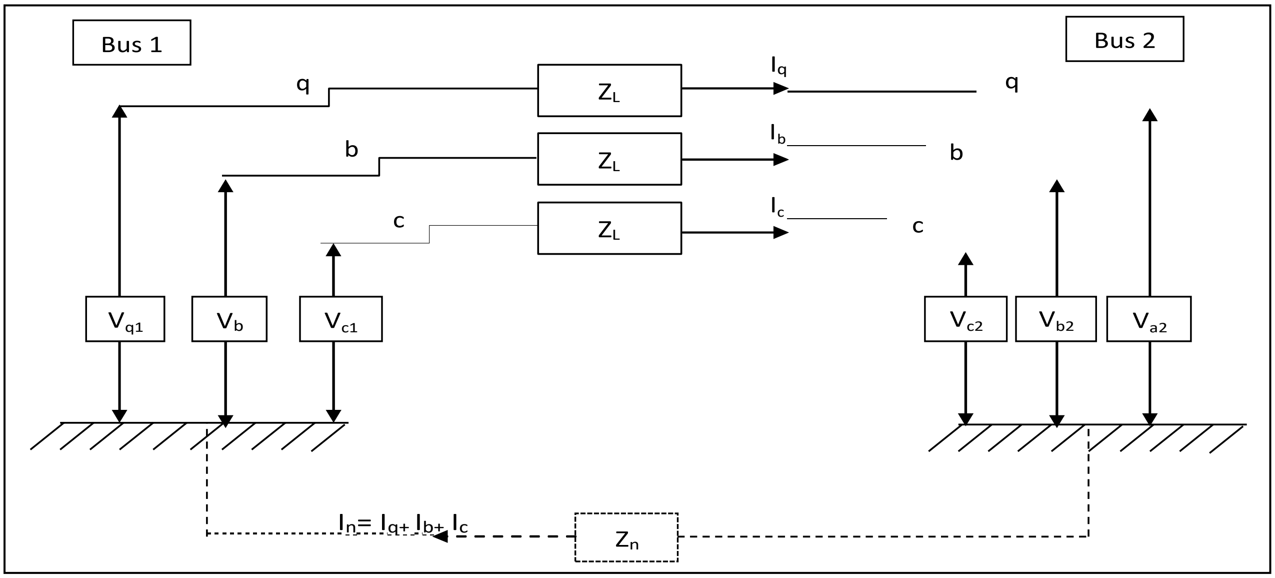


Figure 2.4: A power transmission line operated under balanced condition.

The non-zero current $\mathbf{I_n}$ causes a voltage drop across the ground impedance $\mathbf{Z_n}$.

Using Kirchhoff's voltage law, we can write the voltage drop through the line as:

$$\left\{\begin{array}{l} \boldsymbol{V_{a1} - V_{a2} = I_a Z_L + (I_a + I_b + I_c) Z_n = \Delta V_a} \\ \boldsymbol{V_{b1} - V_{b2} = I_b Z_L + (I_a + I_b + I_c) Z_n = \Delta V_b} \\ \boldsymbol{V_{c1} - V_{c2} = I_c Z_L + (I_a + I_b + I_c) Z_n = \Delta V_c} \end{array}\right.$$

If we let: $\Delta V_p = \begin{bmatrix} \Delta V_a \\ \Delta V_b \\ \Delta V_c \end{bmatrix}$ and $I_p = \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$, we can write: $\boldsymbol{\Delta V_p = Z\ I_p}$

Where the matrix **Z** is: $$\boldsymbol{Z = \begin{bmatrix} Z_L + Z_n & Z_n & Z_n \\ Z_n & Z_L + Z_n & Z_n \\ Z_n & Z_n & Z_L + Z_n \end{bmatrix}}$$

If we apply the S.C.T and use equation (V), we will get: $\boldsymbol{Z \underset{s}{=} \mathcal{T}^{-1} Z . \mathcal{T}}$

Then, $$\boldsymbol{Z_s = \begin{bmatrix} Z_L & 0 & 0 \\ 0 & Z_L & 0 \\ 0 & 0 & Z_L + 3Z_n \end{bmatrix}}$$

Which is a diagonal matrix, and it is applicable for both abc and acb sequences.

By definition the diagonal elements of $\mathbf{Z_s}$ are called respectively:

$\boldsymbol{\mathfrak{z}_+ = Z_L}$ Positive-sequence impedance of the line.

$\boldsymbol{\mathfrak{z}_- = Z_L}$ Negative-sequence impedance of the line.

$\boldsymbol{\mathfrak{z}_0 = Z_L + 3Z_n}$ Zero-sequence impedance of the line.

Applying the S.C.T to the equation $\Delta \boldsymbol{V_p} = \boldsymbol{Z}.\boldsymbol{I_p}$ with and using equations (IV) and (I) yields:

$$\Delta \boldsymbol{V_s} = \begin{bmatrix} V_{a+1} - V_{a+2} \\ V_{b+1} - V_{b+2} \\ V_{c+1} - V_{c+2} \end{bmatrix} = \begin{bmatrix} \mathfrak{z}_+ & 0 & 0 \\ 0 & \mathfrak{z}_- & 0 \\ 0 & 0 & \mathfrak{z}_0 \end{bmatrix} \times \begin{bmatrix} I_{a_+} \\ I_{a_-} \\ I_{a_0} \end{bmatrix}$$

By taking each phase, the generator emf V is written with respect to positive, negative and zero sequence impedances as follows:

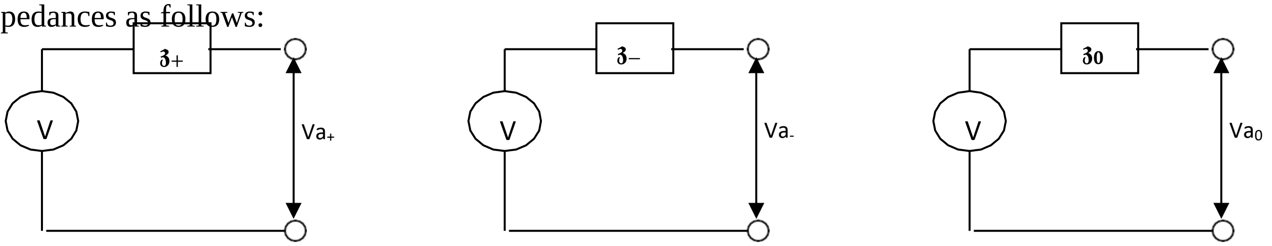


Figure 2-4

2.4.1 Positive sequence single phase diagram **2.4.2** Negative sequence single phase diagram **2.4.3** Zero sequence single phase diagram

$$\begin{cases} V - V_{a+} = \mathfrak{z}_+ I_{a+} \\ V_{a-} = -\mathfrak{z}_- I_{a-} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathrm{VI}) \\ V_{a0} = -\mathfrak{z}_0 I_{a0} \end{cases}$$

II.2.4 Fault types:

The faults occurring on the transmission line may fall in on of the five fault types which are:

1. Single phase to ground fault (a-g, b-g, c-g).
2. Phase to phase fault without ground contact (a-b, b-c, c-a).
3. Phase to phase fault with ground contact (a-b-g, b-c-g, c-a-g)
4. Three phase fault without ground contact (a-b-c).
5. Three phase fault with ground contact (a-b-c-g)

In addition to these ones, we have two more faults that may occur which are:

a. Single-phase open circuit fault.
b. Cross-country faults.

II.2.5 Equations and network connections for different types of faults:

Using the above power transmission line model under unbalanced condition, and by determining the voltage and current at the fault location, it is possible to define the fault and connect the sequence networks to represent the fault condition.

For shunt faults of zero impedance, and neglecting load current, the equations defining each fault (using phase to neutral values) can be written as in the coming sections:

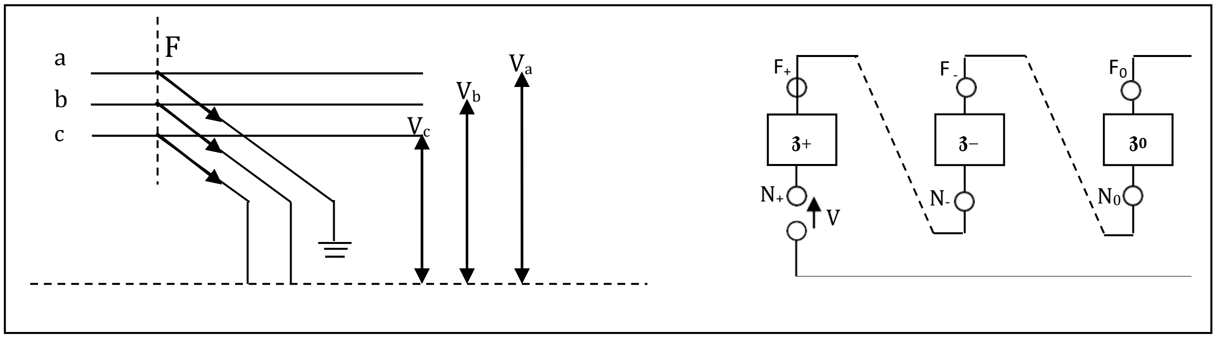
Note: In the following equations describing the faults it is assumed that the fault is solidly grounded i.e. there is no fault impedance $\mathbf{Z_f}$ between the phase and the ground.

II.2.5.1 Single phase to earth fault (A-E):

The single phase to earth fault can be described by the following equation:

$$\begin{cases} I_b = 0 \\ I_c = 0 \\ V_a = 0 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(1-5)}$$

Then, the circuit defining the line and the equivalent circuit of the line when this type of faults occurs are shown in figure2.5:



a) Circuit defining the fault b) The equivalent circuit of the line

Figure 2.5: The circuit defining the single phase to earth fault together with the equivalent circuit.

Converting equation 2.5.1 into sequence quantities, we obtain:

$$I_{a+} = I_{a-} = I_{a0} = \frac{1}{3} I_a \qquad and \qquad V_{a+} = -(V_{a-} + V_{a0})$$

Substituting $V_+, V_-\ and\ V_0$ from equation (VI), we obtain:

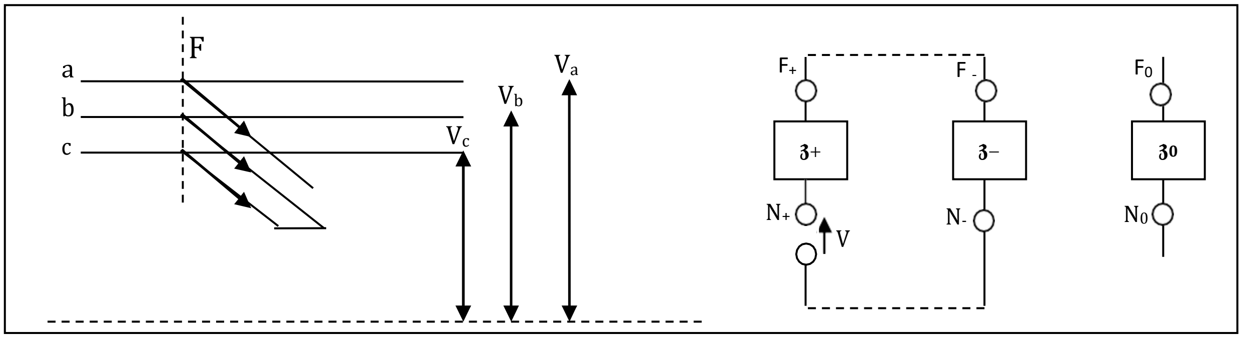
$$V - \mathfrak{z}_+ I_{a+} = \mathfrak{z}_- I_{a-} + \mathfrak{z}_0 I_{a0} \qquad => \quad \boldsymbol{V = I_{a+}(\mathfrak{z}_+ + \mathfrak{z}_- + \mathfrak{z}_0)}$$

II.2.5.2 Phase to phase fault (B-C):

This type of fault is characterized by the following equation:

$$\begin{cases} I_a = 0 \\ I_b = -I_c \\ V_b = V_c \end{cases} => \begin{cases} I_{a+} = -I_{a-} \\ I_{a0} = 0 \\ V_{a+} = V_{a-} \end{cases}$$

Then, the circuit defining the line and the equivalent circuit of the line when this type of faults occurs are shown in figure 1-6:



a) Circuit defining the fault b) The equivalent circuit of the line

Figure 2.6: The circuit defining phase to phase fault together with the equivalent circuit.

Then, using equation (VI) we get:

$$V - I_{a+}\mathfrak{z}_{+} = I_{a-}\mathfrak{z}_{-} + I_{a0}\mathfrak{z}_{0} \qquad but \quad I_{a0} = 0 \;\; then:$$

$$V - I_{a+}\mathfrak{z}_{+} = I_{a-}\mathfrak{z}_{-} \qquad => \qquad \boldsymbol{V = I_{a+}(\mathfrak{z}_{+} + \mathfrak{z}_{-})}$$

II.2.5.3 Phase-phase to earth fault (B-C-E):

This type of faults is described by the following equations:

$$\begin{cases} I_a = 0 \\ V_b = 0 \\ V_c = 0 \end{cases} => \begin{cases} I_{a+} = -(I_{a-} + I_{a0}) \\ V_{a+} = V_{a-} = V_{a0} \end{cases}$$

Then, the circuit defining the line and the equivalent circuit of the line when this type of faults occurs are shown in figure 2.7:

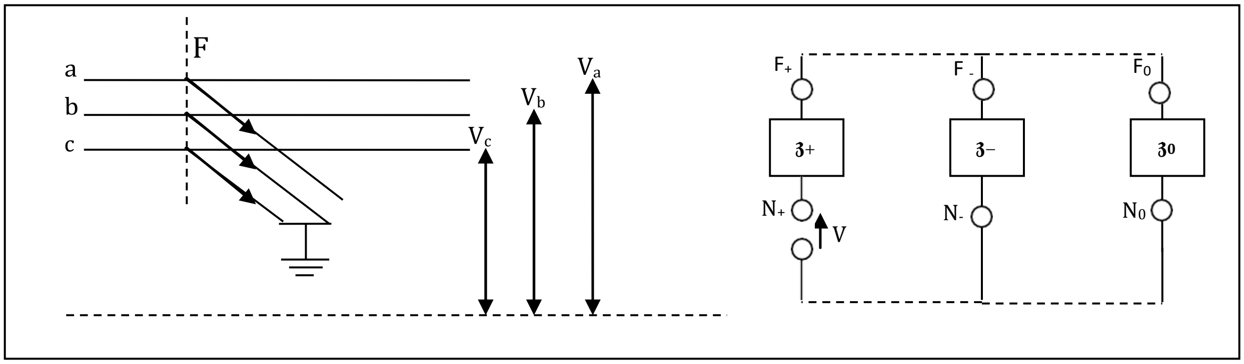


Figure 1-7: The circuit defining phase- phase to earth fault together with the equivalent circuit.

Then, using the equation (VI) we get:

$$I_{a-}\mathfrak{z}_{-} = I_{a0}\,\mathfrak{z}_{0} \qquad => \qquad \begin{cases} \boldsymbol{I_{a0}} = -\dfrac{\mathfrak{z}_{-}\boldsymbol{I_{a+}}}{\mathfrak{z}_{0}+\mathfrak{z}_{-}} \\ \boldsymbol{I_{a-}} = -\dfrac{\mathfrak{z}_{0}\boldsymbol{I_{a+}}}{\mathfrak{z}_{0}+\mathfrak{z}_{-}} \end{cases} \quad \ldots\ldots\ldots\ldots \textbf{(2.5.3.a)}$$

Now, equating V_{a+} and V_{a0} and using equation (VI), we get:

$$\boldsymbol{V - \mathfrak{z}_{+}I_{a+} = -\,\mathfrak{z}_{-}I_{a-}} \quad \boldsymbol{or} \quad \boldsymbol{V = \mathfrak{z}_{+}I_{a+} - \,\mathfrak{z}_{-}I_{a-}}$$

Then, substituting I_{a-} from equation (2.5.3.a), we get:

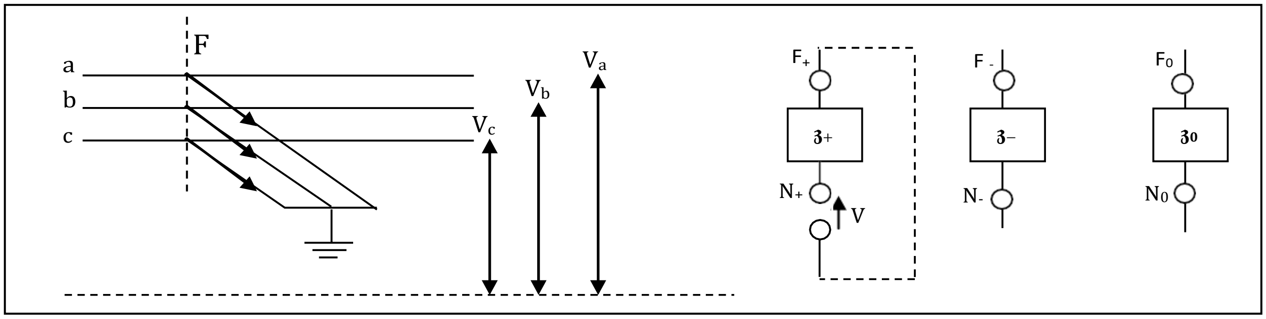
$$V = [\mathfrak{z}_{+} + \frac{\mathfrak{z}_{0}\mathfrak{z}_{-}}{\mathfrak{z}_{0}+\mathfrak{z}_{-}}]\,I_{+} \quad => \quad \boldsymbol{I_{+} = V} \times \frac{(\mathfrak{z}_{0}+\mathfrak{z}_{-})}{\mathfrak{z}_{+}\mathfrak{z}_{0} + \mathfrak{z}_{+}\mathfrak{z}_{-} + \mathfrak{z}_{0}\mathfrak{z}_{-}}$$

II.2.5.4 Three phase fault (A-B-C and A-B-C-E):

A three phase fault is defined by the equations:

$$\begin{cases} I_{a} + I_{b} + I_{c} = 0 \\ V_{a} = V_{b} \\ V_{b} = V_{c} \end{cases}$$

Then, the circuit defining the line and the equivalent circuit of the line when this type of faults occurs are shown in figure:



a) Circuit defining the fault

b) The equivalent circuit of the line

Figure 2-8: The circuit defining three phase to earth fault together with the equivalent circuit.

Assuming that the fault includes earth then using the above equation together with sequence equations, yields:

$$\begin{cases} \boldsymbol{V_{a0} = V_{a}} \\ \boldsymbol{V_{a+} = V_{a-} = 0} \end{cases} \qquad and \qquad \boldsymbol{I_{a0} = 0}$$

Then substituting $\boldsymbol{V_{a+} = 0}$ and $\boldsymbol{V_{a-} = 0}$ in equations (VI) yields:

$$\begin{cases} \boldsymbol{I_{a-} = 0} \\ \boldsymbol{V = \mathfrak{z}_{+}I_{+}} \end{cases}$$

II.2.6 Fault detection:

All power system elements are equipped with one or more protection schemes. The purpose of these protection schemes is to detect faults on the system. When the protective relays have detected a fault, they send trip signals to the circuit breaker or breakers, which in turn clear the fault from the system. [9]

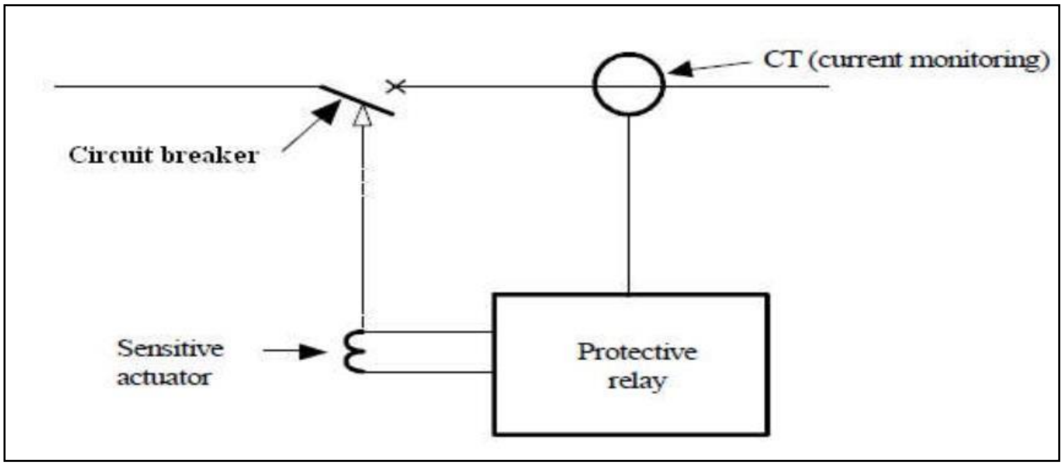


Figure 2-9: Protection system.

Conclusion:

The power systems generally are subjected to many types of faults, occurring at different moments and which cause a lot of damage to electric equipment that will lead to huge economic losses. For this reason protection systems have been introduced.

Fault or short circuit studies are an essential tool for power system engineering. Our aim here is to be able to calculate the fault conditions and to provide the protective equipment designed to isolate the faulted zone from the remainder of the system in the appropriate time.

After the isolation a fast restoration is needed for the good reliability of the network, that’s mean a fast localization of the fault is required. Thus, in the next chapter, the fault passage indicator is presented.

Chapter III :

FPI composition and working principle

Introduction

Fault passage indicators (FPI) are used to fast locate earth-faults or short-circuit in power distribution networks. They are the most cost-effective way to improve the reliability and safety of overhead and underground distribution network. The damaged line section can be located from the network, as soon as a fault occurs. While the service team repairs the damaged cable, the rest of the network can be powered up. In this way, and because of the fast localization, the down-time of the network can be minimized to increase the quality of the infrastructure.

III.1 System Composition

In order to get the best results out of the FPI we should have the following:

III.1.1 fault passage indicator: There are three main elements of the modern fault passage indicator which are sensor, Communication tool and led.

-Sensor: a device clipped on the overhead lines on each phase so that to measure current and Voltage presence in this phase and compute fault detection algorithm accordingly.

-Led: provides a local light indication on occurrence of fault depending on its type.

-Communication tool: A short-range radio interface is embedded with the Fault Sensing Indicator (FPI) or a fiber optic lines used so that to allow the (FPI) communicate with the **Data Concentrator Unit** (DCU) mentioned later.

Figure 3.1: FPI hanging around an overhead conductor

III.1.2 Data Concentrator Unit: Installed inside or outside the Ring Main Unit (or Cable Distribution Box, Switch Cabinet). One data concentrator unit can receive fault signal sent by sensors through a wireless signal or fiber optic and send to central station through GPRS/3G/4G LTE cellular network. The data concentrator Unit is mainly composed of industrial modem.

Figure 3.2: Data Concentrator Unit

III.1.3 Monitoring central station:

Includes one set data server with software system. Monitoring central station usually setup in power utility office, power substation, etc. When receiving the fault message from the data concentrator unit, combined with GIS system, the maintenance crew man could quickly locate the fault site and trouble-shoot. The software system could be SCADA or other software platform, usually power utility companies have their own software system. [16]

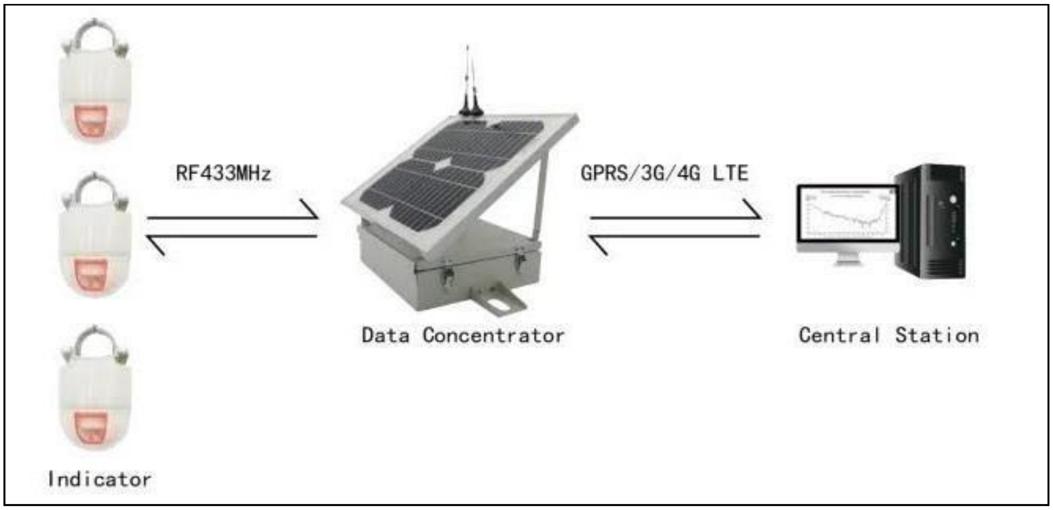


Figure 3.3: sending the signal to the central station

III.2 System parameters:

The Fault detection systems shall be designed to operate on a Medium overhead network with the following characteristics:

- Nominal Operation Voltage: 30KV for 30KV networks and 10KV for 10KV networks.
- System Maximum/Minimum Voltage: 32 kV/8KV.
- Frequency: 60 Hz or 50Hz.
- No. Of phases: 3 phases.
- Type of neutral earthing:
  For 30KV: Earth through earthing transformer.
  For 10KV: Solidly grounded system.

One single product shall be proposed to cover the whole range of above characteristics: Particularly, the same product should be installed on any network for 10KV and 30 kV.

III.3 System specification:

1) **Inrush restraint:** A fault passage indicators (FPI) design feature to minimize false tripping due to current inrush during energization of the circuit.

2) **Automatic reset:** Automatic reset control parameters include voltage, current, and time, and combinations of these three.
3) **proximity effect:** The magnetic induction effect of load or fault current flowing in an adjacent wire, cable, or ground conductor that may cause fault passage indicator (FPI) to malfunction (i.e., false trip, fail to trip, or reset incorrectly).
4) **Trip level:** The threshold current that will cause the fault passage indicator (FPI) to operate.

III.4 Working principle:

The device itself mainly contains the sensor, the controller for processing the data, the indication means, a reset interface and a system to power the device. Therefore, the FPI are designed to be compact and easy to install. The FPI normally includes a visual indication of the fault (a LED, a flag, etc.). The recent developed one includes more circuits such as memory and communication facility. Every fault indicator, earth-fault and short-circuit indicators, monitors the network constantly. As soon as a fault current higher than the trip value is detected, the fault will be indicated.

To avoid wrong indications, most models of fault indicators are analyzing the measured fault signal with the help of a microcontroller. Wrong indications caused by peaks, e.g. due to switching operations, will be prevented (setting of response delay as given in **Table 3.1** and **3.2**).

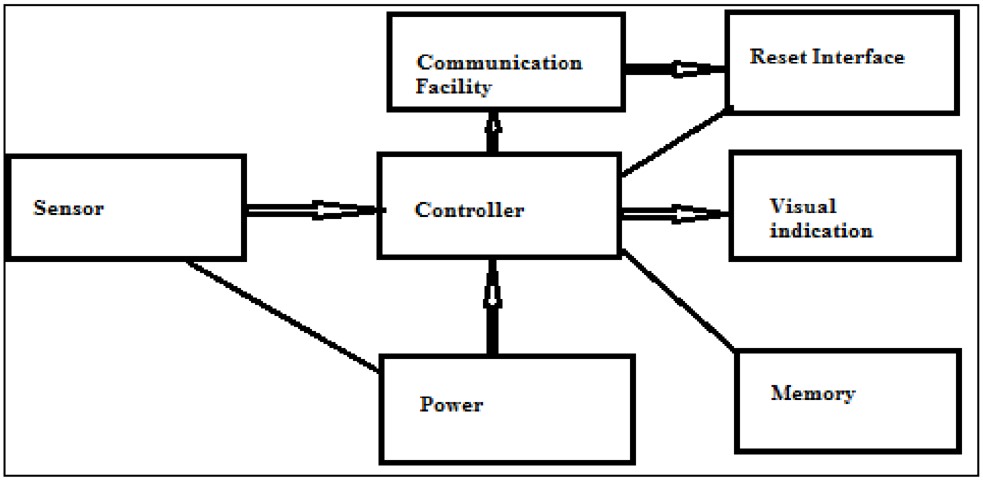


Figure 3.4: Simplified block diagram of a fault passage indicator.

Table 3.1: U.S. Time-Overcurrent Equations

Curve type	Operating time
U1 (moderately inverse)	$Tp= T\text{-}TRIP = TDS*(0.0226+\frac{0.0104}{M^{0.02}-1})$
U2 (inverse)	$Tp= T\text{-}TRIP = TDS*(0.180+\frac{5.95}{M^{2}-1})$
U3 (very inverse)	$Tp= T\text{-}TRIP = TDS*(0.0963+\frac{3.88}{M^{2}-1})$
U4 (extremely inverse)	$Tp= T\text{-}TRIP = TDS*(0.02434+\frac{5.64}{M^{2}-1})$
U5 (short-time inverse)	$Tp= T\text{-}TRIP = TDS*(0.0026+\frac{0.00342}{M^{0.02}-1})$

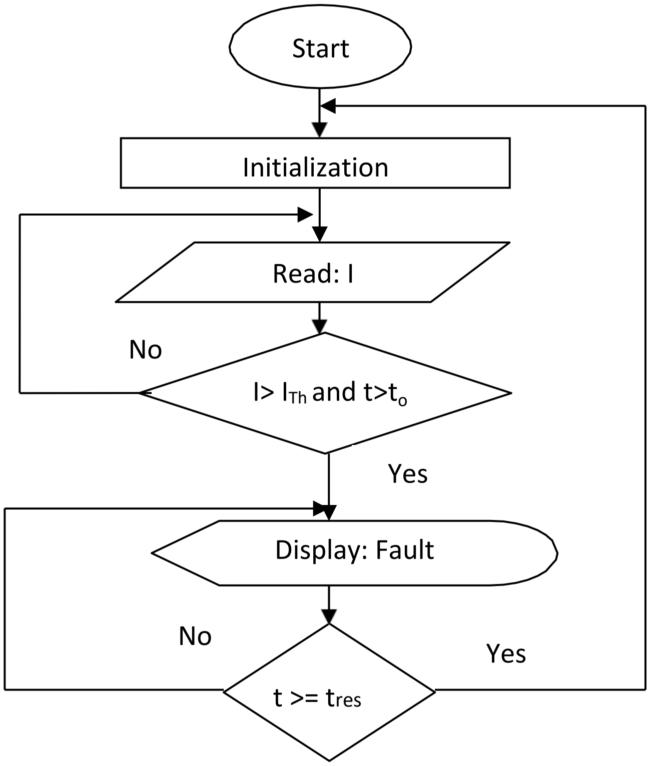
M = Measured Current / Pickup Current. [14]

Table 3.2: IEC Time-Overcurrent Equations

Curve type	Operating time
U1 (standard inverse)	$Tp= T\text{-}TRIP = TDS*(\frac{0.14}{M^{0.02}-1})$
U2 (very inverse)	$Tp= T\text{-}TRIP = TDS*(\frac{13.5}{M^{1}-1})$
U3 (extremely inverse)	$Tp= T\text{-}TRIP = TDS*(\frac{80}{M^{2}-1})$
U4 (long-time inverse)	$Tp= T\text{-}TRIP = TDS*(\frac{120}{M^{1}-1})$
U5 (short-time inverse)	$Tp= T\text{-}TRIP = TDS*(\frac{0.05}{M^{0.04}-1})$

M = Measured Current / Pickup Current. [14]

The following flowchart simplifies the operation of the FPI:



I =current in the line

I_{Th}=threshold current

t_o = time delay

(for the transient fault)

t_{res} = reset time

Figure3.5: Flowchart of the operation principle of FPI.

- **Locating the Fault**

  The root cause of every fault, even a temporary one, should be determined. If root cause is left undetermined, then there is the chance that a safety risk remains, or another outage could occur. After a fault occurs and the protection clears the fault, fault indicators lead you directly to the location of the fault. Modern digital protective relays and recloser tell you the distance to the fault, but ambiguity remains because there are usually many taps and branches along a feeder that would yield the same distance to the fault. The relay or recloser cannot tell if fault current traveled further down the main feeder or branched off somewhere but fault indicators can.

As we can see in **figure 3.6** it represent a system which consist of many branches with FPIs installed in the lines, the red points are the FPIs tripped to indicate the fault, where is the red crosses are the possible fault locations given by the distance relay, if we use only protective relays, we have to search for the fault in five different locations but using (FPI) we can directly find the exact fault location.

So, from the previous discussion we can say that using FPIs will reduce the down time of the system and this is mean an increasing in the reliability of the system.

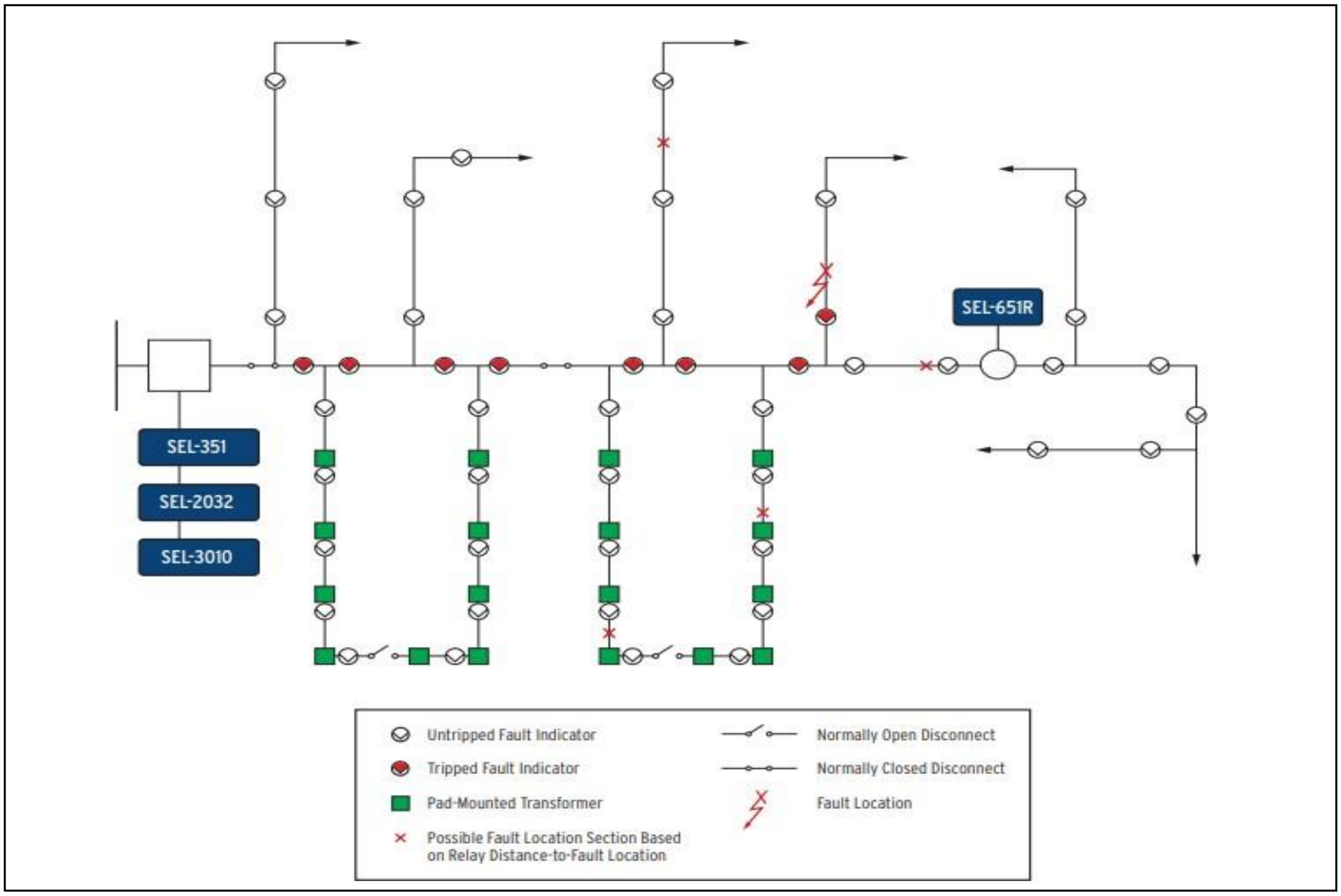


Figure 3.6: working principle of FPIs

III.5 different types of FPI:

3.5.1 Overhead Line Fault Passage Indicator

without communication: The faults are displayed locally via LEDs on the device. Depending on the fault condition, a flashing light dependent on the fault type is generated

with communication: In addition to the local LED display, short circuits or ground faults indicated status are transmitted via a secure wireless connection to a gateway (Data Concentrator Unit), which establishes the connection via GPRS to the Monitoring central station were the maintenance crew man could quickly locate the fault site and trouble-shoot.

3.5.2 Underground Fault Passage Indicator

Remote Cable Line Fault Indicator:

Remote Cable Line fault indicator is used in 6~35KV Cable line distribution networks, usually installed in Ring Main Unit, Cable Distribution Box, Switch Cabinet, enable the electricity distribution network engineers to quickly identify the faulty section of network and restore power supplies to customers on healthy sections in the shortest time possible.

Cable Line Fault Indicator:

Cable Line Fault indicator is used in the same line power distribution networks power range with the same installing with different communication mean using fiber optics instead of wireless signals. [16]

Conclusion:

The main function of fault passage indicating system is to identify faults occurring in the downstream section from the point of its installation in the medium voltage power system. This is achieved by continuous monitoring of voltage presence and current flow in medium voltage line.

Any increase in current along with absence of voltage is signaled by the equipment. Fault condition is indicated by flashing lights in FPI; this information is sent using radio signals to the communication gateway installed nearby for onward transmission to SCADA system at the control center through a suitable communication channel.

Using this system, the utility acquires information regarding the section of the line having fault. This identification helps eliminate the patrolling of entire line for finding the fault, ultimately reducing restoration time.

Chapter IV :

Design, simulation and testing

Introduction

The operation principles and application procedures of FPI have been presented in previous chapters. A Fault Passage Indicator design integrated in a distribution network is proposed in this chapter. The proposed FPI model and tools required for testing, as well as results and discussion are also presented.

VI.1. Proposed FPI in Distribution Network (Design and Simulation)

The methodology for modeling FPI integrated in distribution network using MATLAB/SIMULINK is discussed in this chapter.

The suggested block diagram is shown in Fig.4.1.

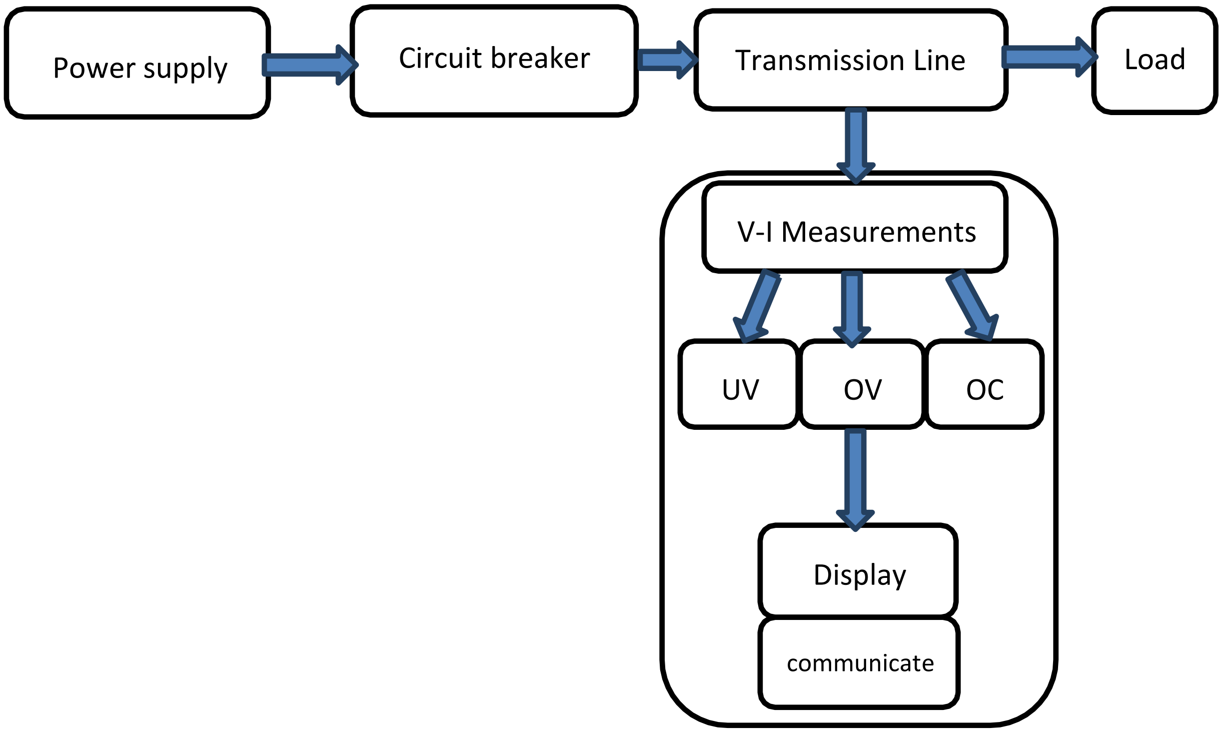


Figure 4.1: The general block diagram of the FPI scheme.

VI.2. Simulation part

VI.2.1. Definition of Simulink

Simulink is a graphical extension to Matlab; it allows design, simulation and analysis of dynamic systems by means of an extensive range of tools for algorithm development, data visualization and access, and numerical computations, this is guaranteed by set of bloc libraries like:

SimPowerSystems library which contains a collection of blocs that are intended to build models related to power systems domain. The figure4.2 shows a snapshot of the SimPowerSystems library.

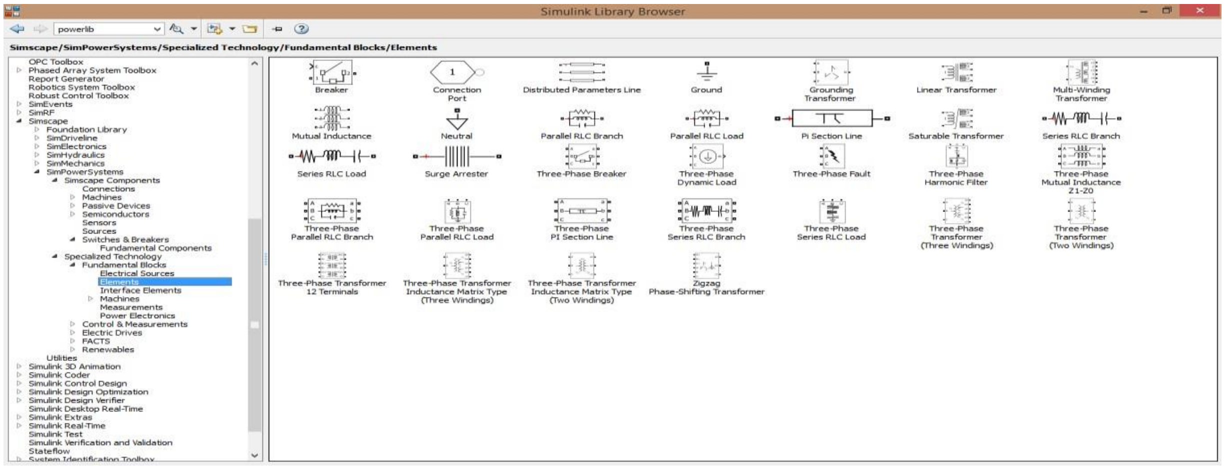


Figure 4.2: SimPowerSystems library

Block Diagram
In Fig. 4.3, we simulate a simple power system embedded with FPI.

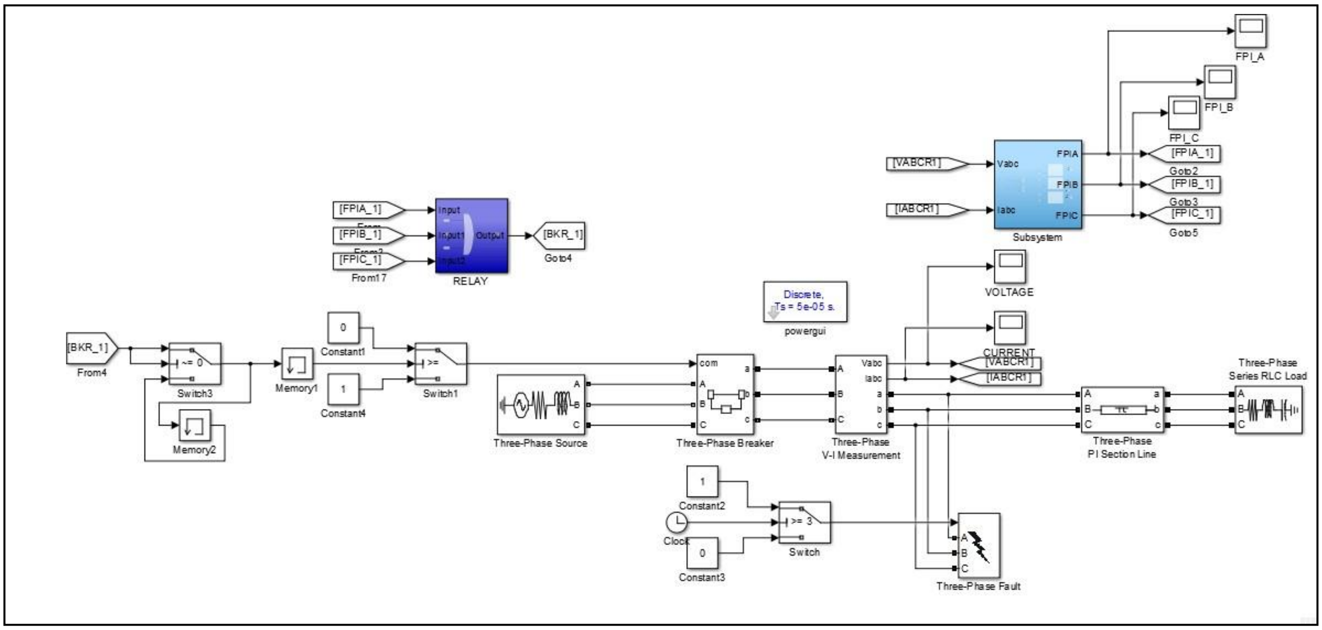


Figure 4.3: Medium Voltage distribution network diagram

The block diagram includes:

Generators: feeds the power network with three phase signals.

Circuit breakers: to protect the power network and break the power at any given moment getting the signal from the relay.

Relay: to control the CBs by opening and closing getting its signal from the FPI.

FPI: to detect the fault and communicate with the relay and display the type.

FPI Simulink model-based design

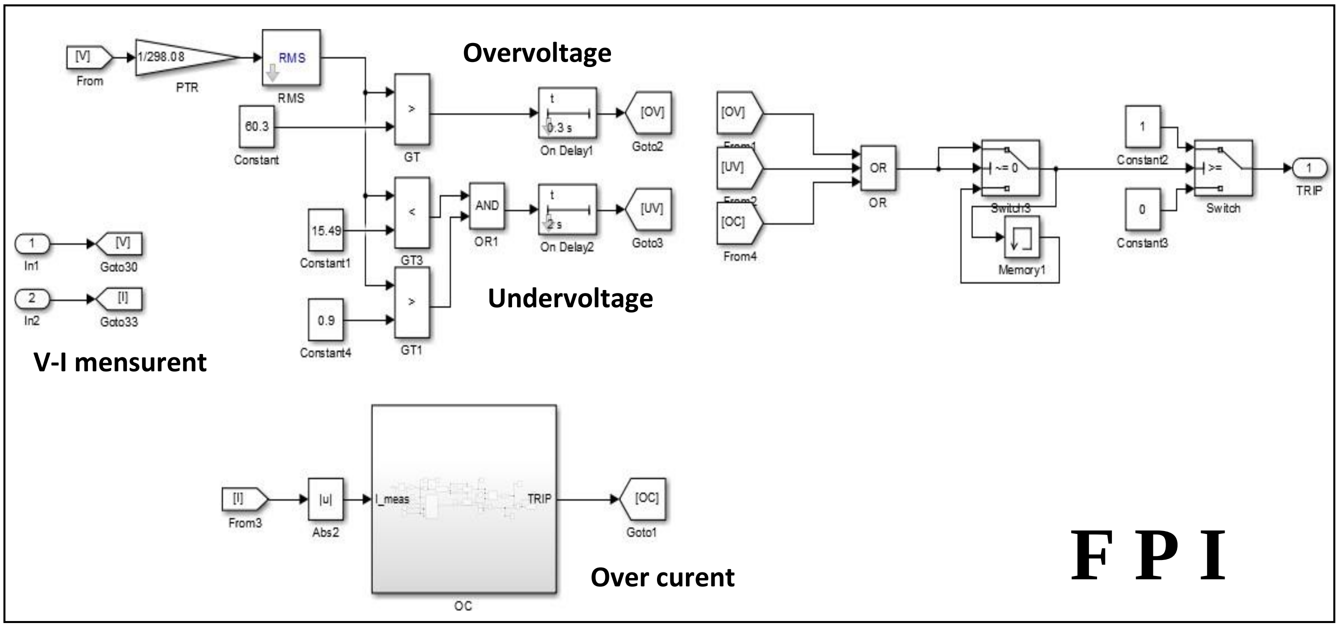


Figure4.4: FPI Simulink model

Figure 4.4 shows the components of the FPI that consists of 3 subsystems (over voltage, under voltage and over current), two input signals from the VI measurement that will go through the different blocks inside the FPI continuously checking for any changes in the voltage or the current that will trigger the FPI and it will send the output signal to the corresponding relay which send it to the CB, in the same time the FPI scoop shows the existence of the fault, that will allow us to identify the type, the placement and the corresponding time.

For the over voltage and under voltage blocks, the V-I measurement tool input which goes through PT then a different comparator to analyze and detect any unwanted or undesirable changes that will lead to triggering the FPI.

The over current block which is shown below have a current input from the VI measurement

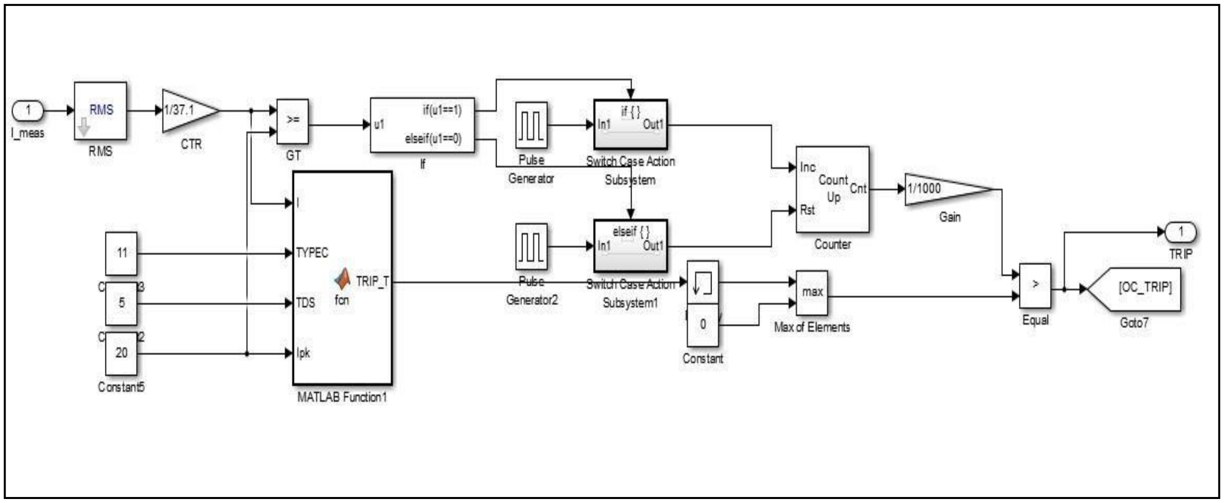
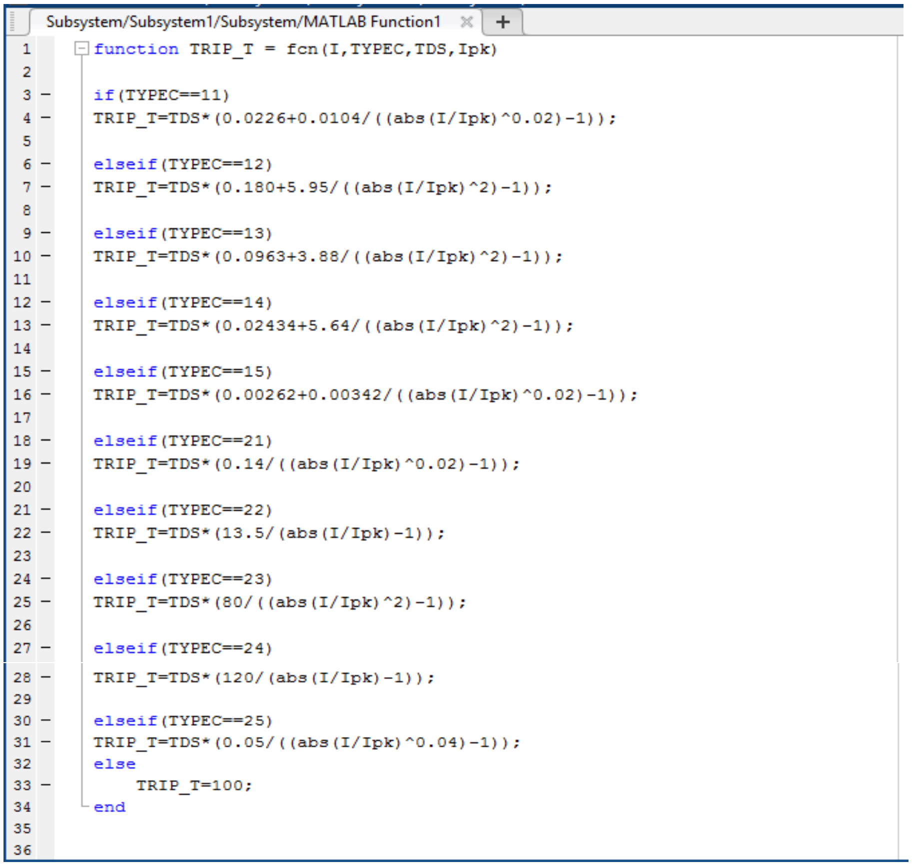


Figure 4.5: over current block

Figure 4.5 shows the overcurrent block, first the input coming from the VI-measurement is compared to a chosen constant Ipk , for greater value of the input the counter loop will trigger and start counting and continuously comparing it with T-TRIP signal coming from the **MATLAB function block** which consist of 4 inputs **I**=input current, **TYPE C**= type of the curve (US equations / IEC equations),**TDS**= time delay setting and **Ipk**= pick up current.

For **MATLAB function block** is a block to calculate T-TRIP (time) according to the 4 inputs using the equations of the standard curves in the tables shown in the previous chapter giving the user the ability to choose the curve type, Ipk and TDS.

Using the curve equations mentioned in chapter 3, we wrote a program on MATLAB function which gives us the ability to choose the appropriate curve by changing the TYPE constant during the configuration.



```
function TRIP_T = fcn(I,TYPEC,TDS,Ipk)

if(TYPEC==11)
TRIP_T=TDS*(0.0226+0.0104/((abs(I/Ipk)^0.02)-1));

elseif(TYPEC==12)
TRIP_T=TDS*(0.180+5.95/((abs(I/Ipk)^2)-1));

elseif(TYPEC==13)
TRIP_T=TDS*(0.0963+3.88/((abs(I/Ipk)^2)-1));

elseif(TYPEC==14)
TRIP_T=TDS*(0.02434+5.64/((abs(I/Ipk)^2)-1));

elseif(TYPEC==15)
TRIP_T=TDS*(0.00262+0.00342/((abs(I/Ipk)^0.02)-1));

elseif(TYPEC==21)
TRIP_T=TDS*(0.14/((abs(I/Ipk)^0.02)-1));

elseif(TYPEC==22)
TRIP_T=TDS*(13.5/(abs(I/Ipk)-1));

elseif(TYPEC==23)
TRIP_T=TDS*(80/((abs(I/Ipk)^2)-1));

elseif(TYPEC==24)
TRIP_T=TDS*(120/(abs(I/Ipk)-1));

elseif(TYPEC==25)
TRIP_T=TDS*(0.05/((abs(I/Ipk)^0.04)-1));
else
    TRIP_T=100;
end
```

Figure4.6: MATLAB curves equations

VI.3. Fault Passage Indicators testing

To test the FPI, we are going to create different types of fault in the power network which is simulated using MATLAB/SIMULINK.

The parameters of the power system model using SIMULINK and the settings of the FPI model are mentioned in **table 4.1**.

	Parameters	Value
	Voltage	Normal operation case :8.0 kv<Vp-p<32 kv OV case: Vp-p>32 kv UV case: Vp-p<8.0 kv
	Frequency	60 Hz
	FPI settings	Vmax=32kv Vmin=8.0kv OV delay=0.3s UV delay=2.0s

Table 4.1: power system simulation parameters

VI .4.Testing procedures

First step: create the fault type using the appropriate block.

Second step: simulate faults in MATLAB/SIMULINK**.**

Third step: observe the results using the scope tool.

VI .4.1.Simulation of the faults:

The results of the tests being performed are presented using the graphs display of current, voltage and FPIs output signal as shown in the figures.

VI .4.1.1.Over voltage:

Scope of current:

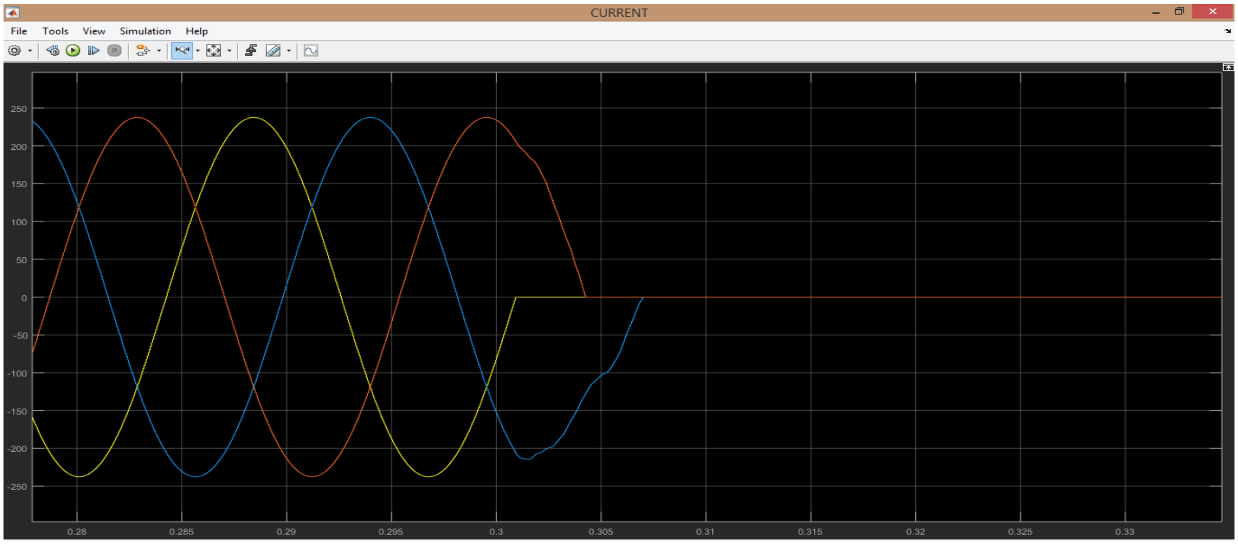


Figure 4.7: line current response during OV fault

Scope of voltage:

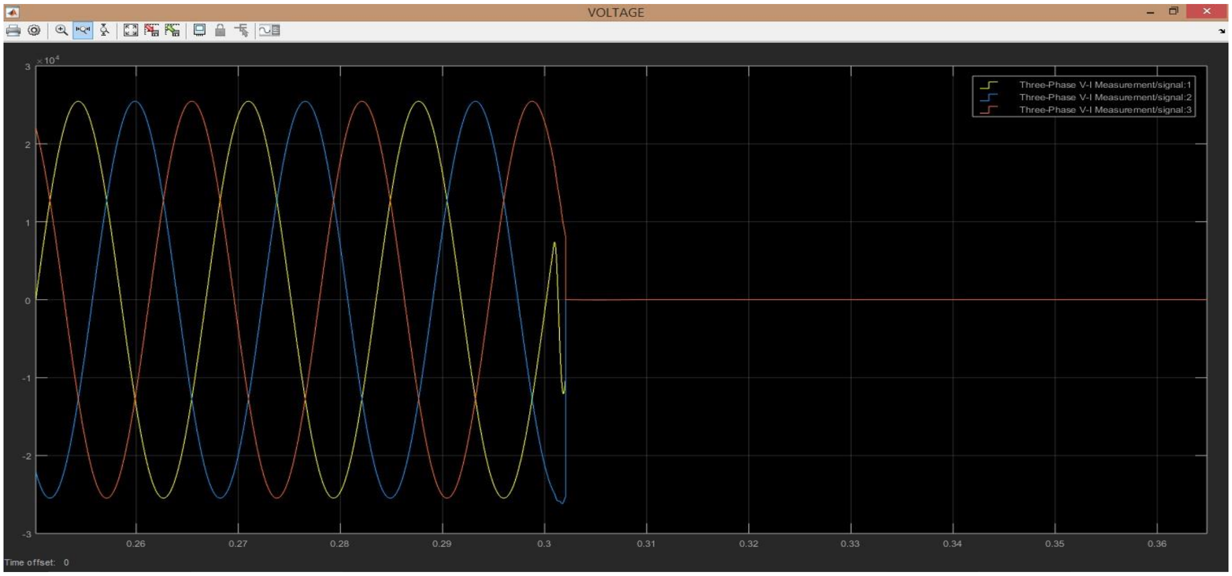


Figure 4.8: line voltage response during OV fault

Scope of FPIs:

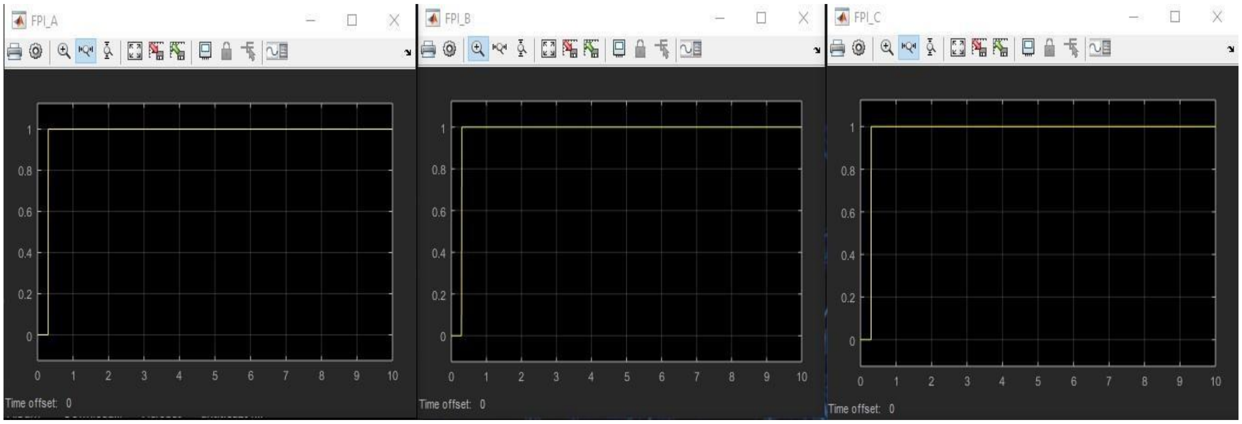


Figure 4.9: FPIs response during OV fault

The FPIs detects the fault after 0.3s and indicate it, the current and voltage went to 0 after receiving the CB signal with a delay less than 50 ms .

VI .4.1.2.Under voltage:

Scope of current:

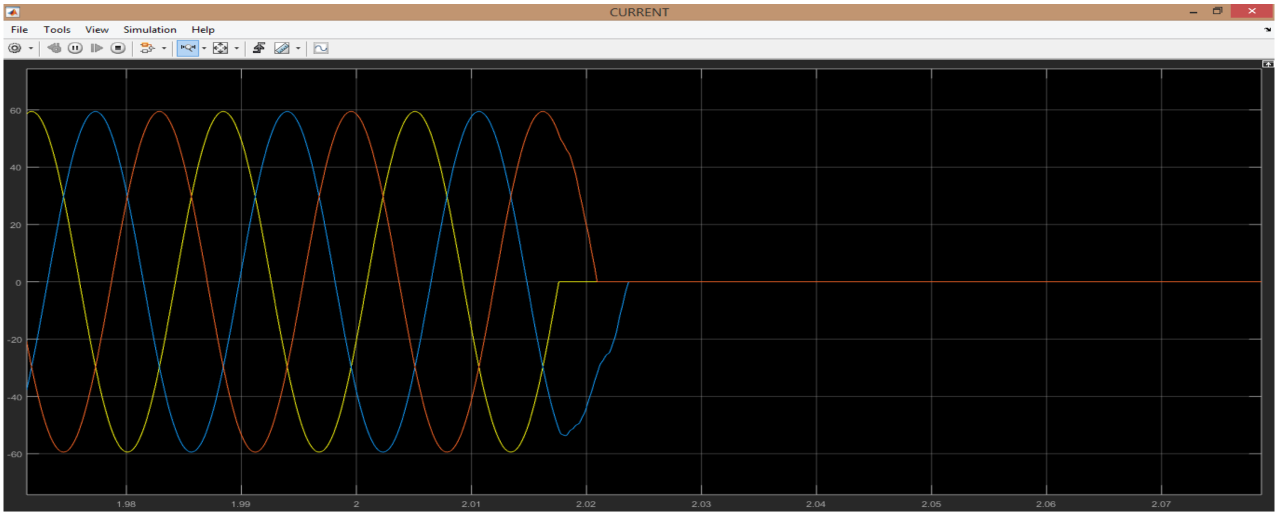


Figure 4.10: line current response during UV fault

Scope of voltage:

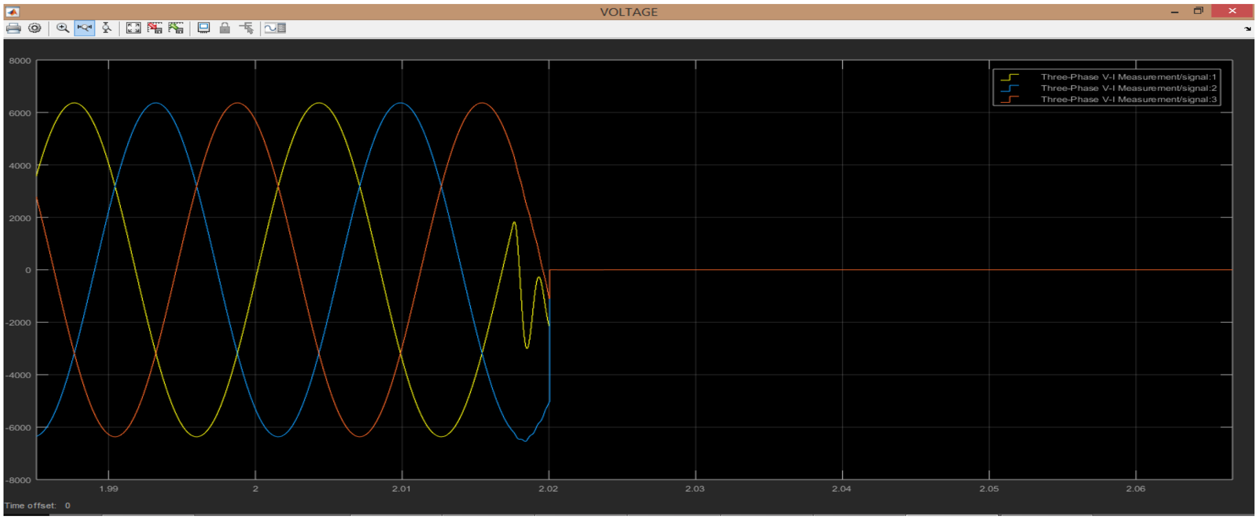


Figure4.11: line voltage response during UV fault

Scope of FPIs:

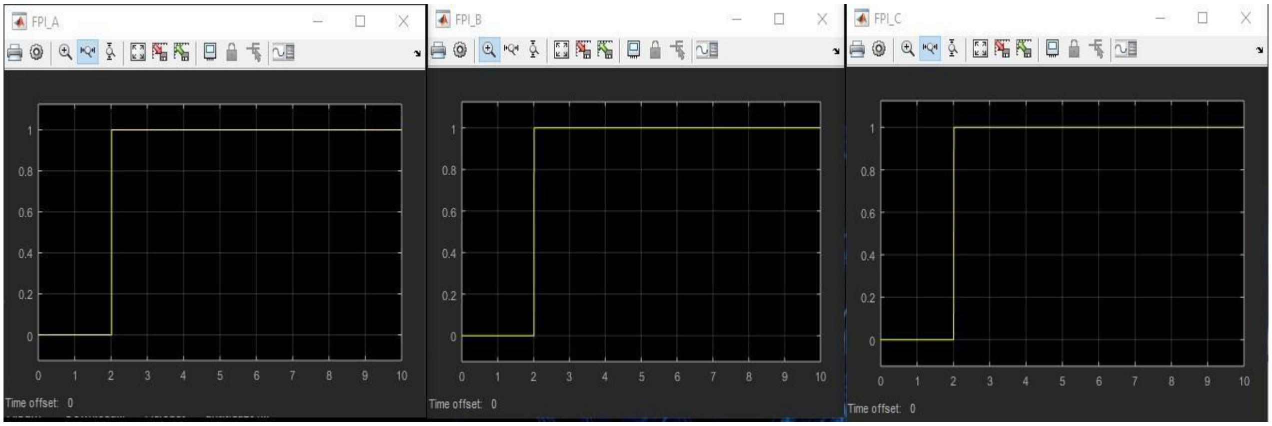


Figure4.12: FPIs response during UV fault

The FPIs detects the fault after 2.0s and indicate it, the current and voltage went to 0 after receiving the CB signal with a delay less than 50 ms .

VI .4.1.3.a. single line to ground (phase A-G):

Scope of current:

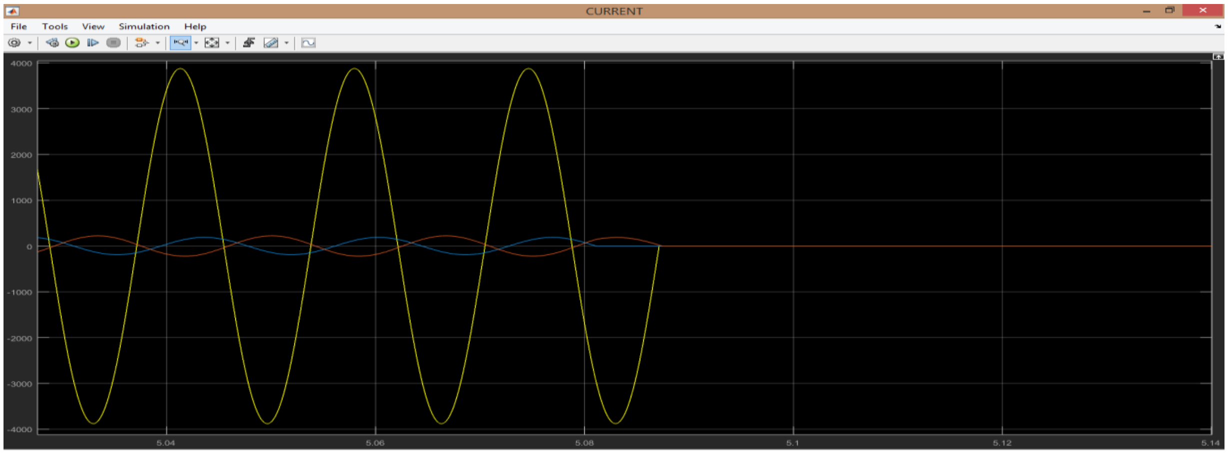


Figure4.13: line current response during L-G fault

Scope of voltage:

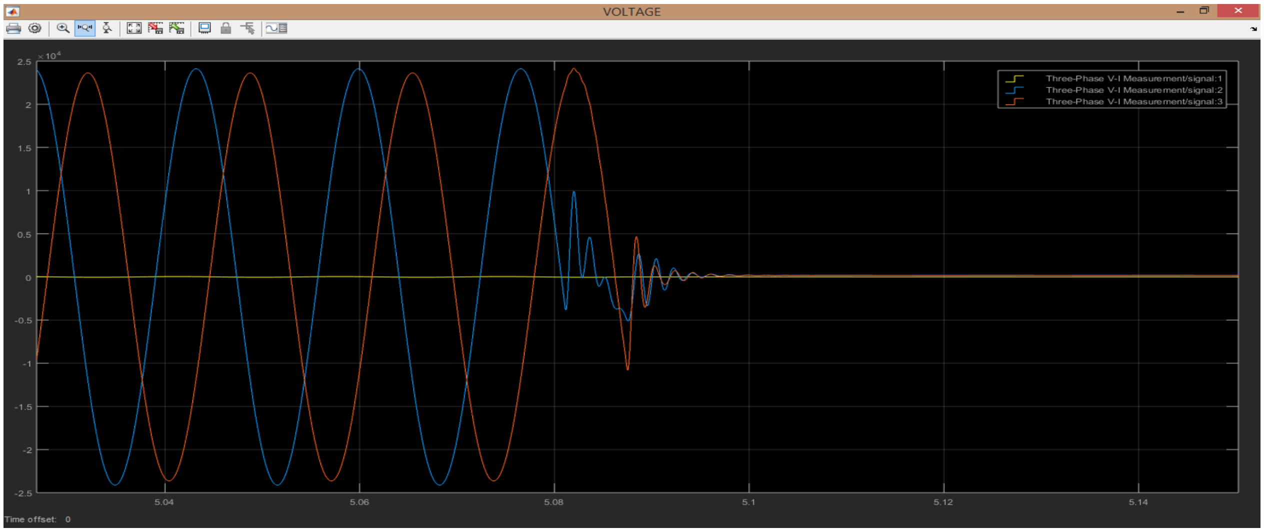


Figure4.14: line voltage response during L-G-A fault

Scope of FPIs:

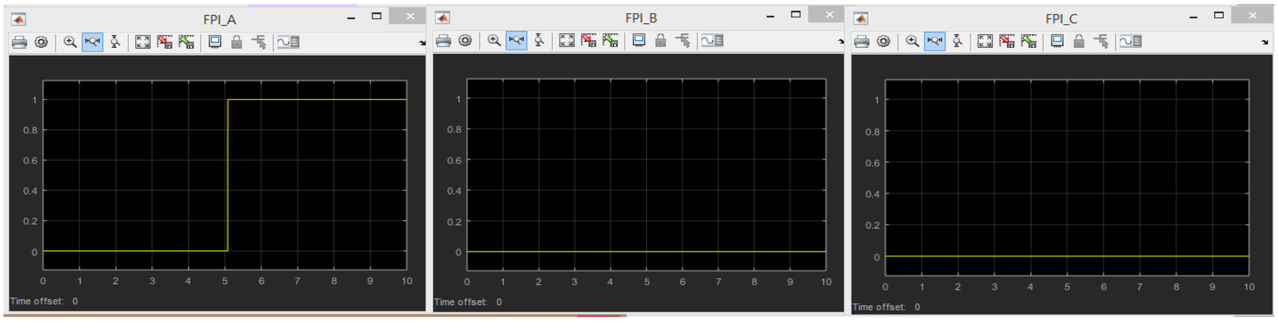


Figure3.15: FPIs response during L-G-A fault

VI .4.1.3.b. single line to ground (phase B-G):

Scope of current:

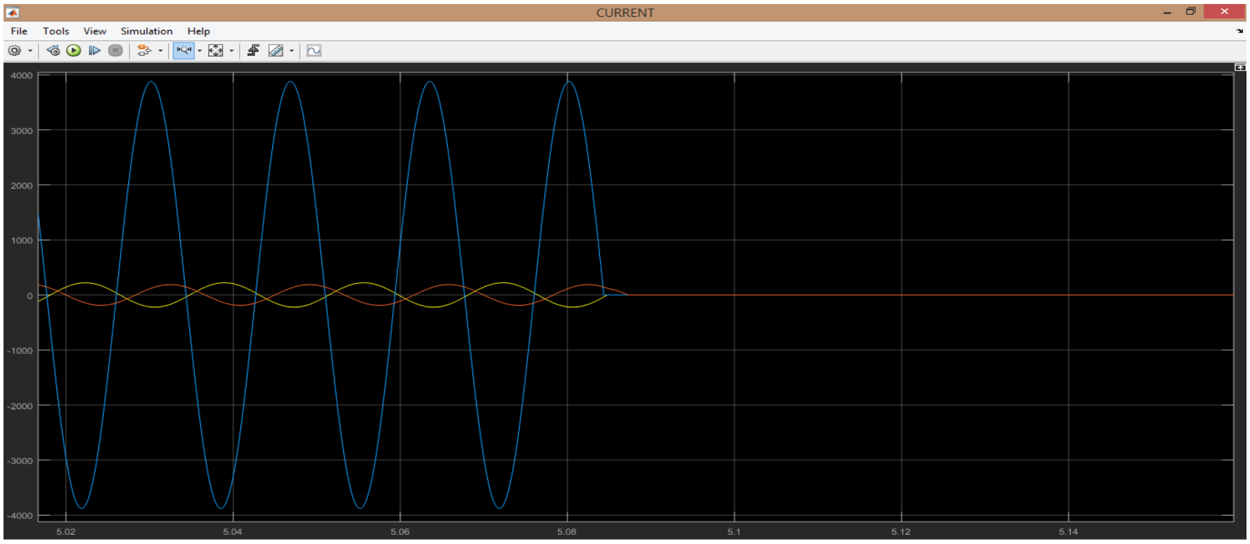


Figure4.16: line current response during B -G fault

Scope of voltage:

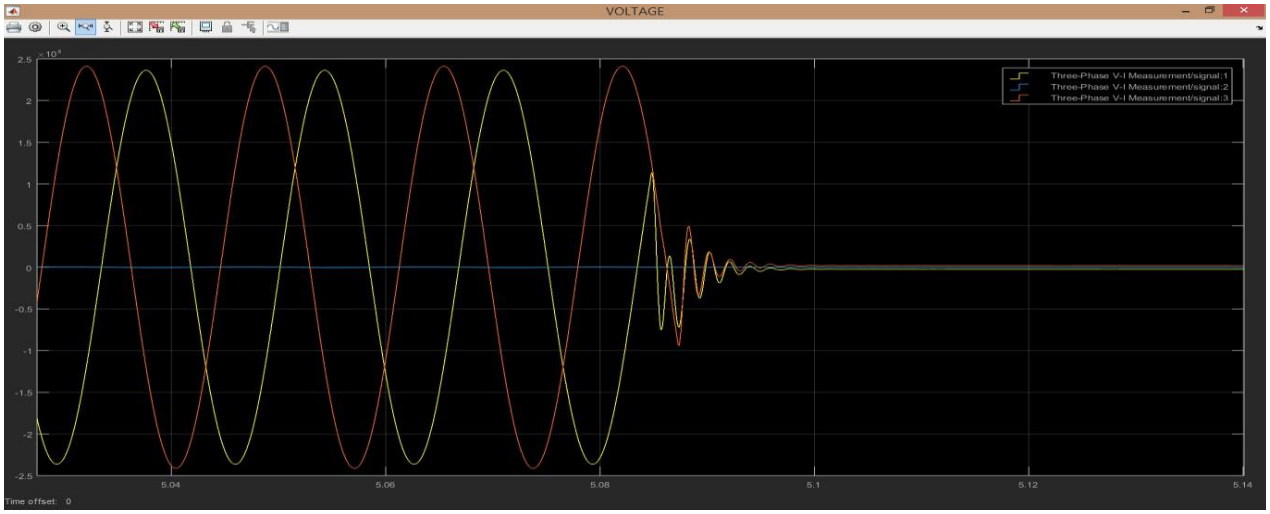


Figure4.17: line voltage response during B-G fault

Scope of FPIs:

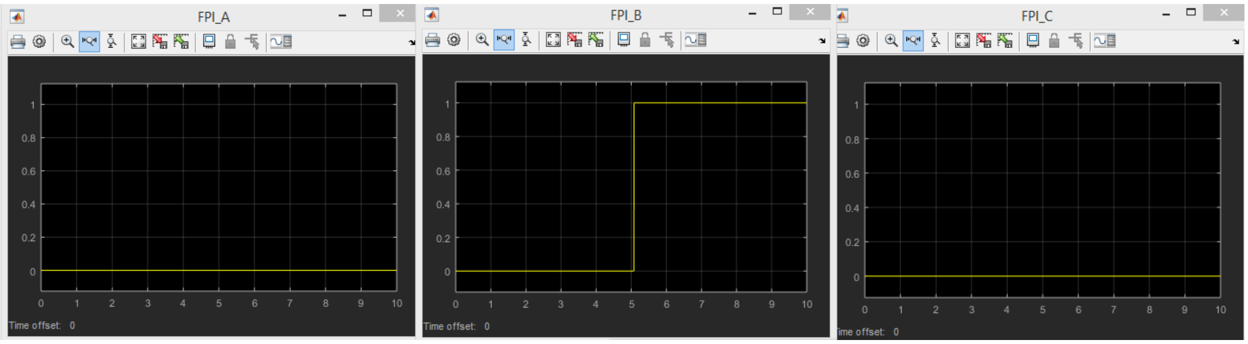


Figure4.18: FPIs response during B-G fault

VI .4.1.3.c. single line to ground (phase C-G):

Scope of current:

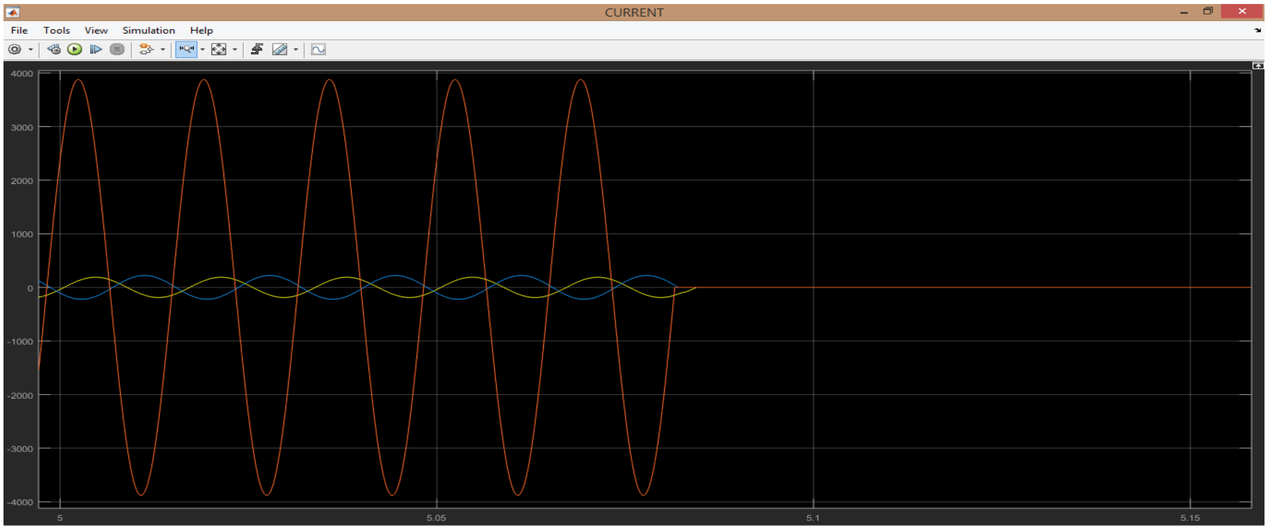


Figure4.19: line current response during C -G fault

Scope of voltage:

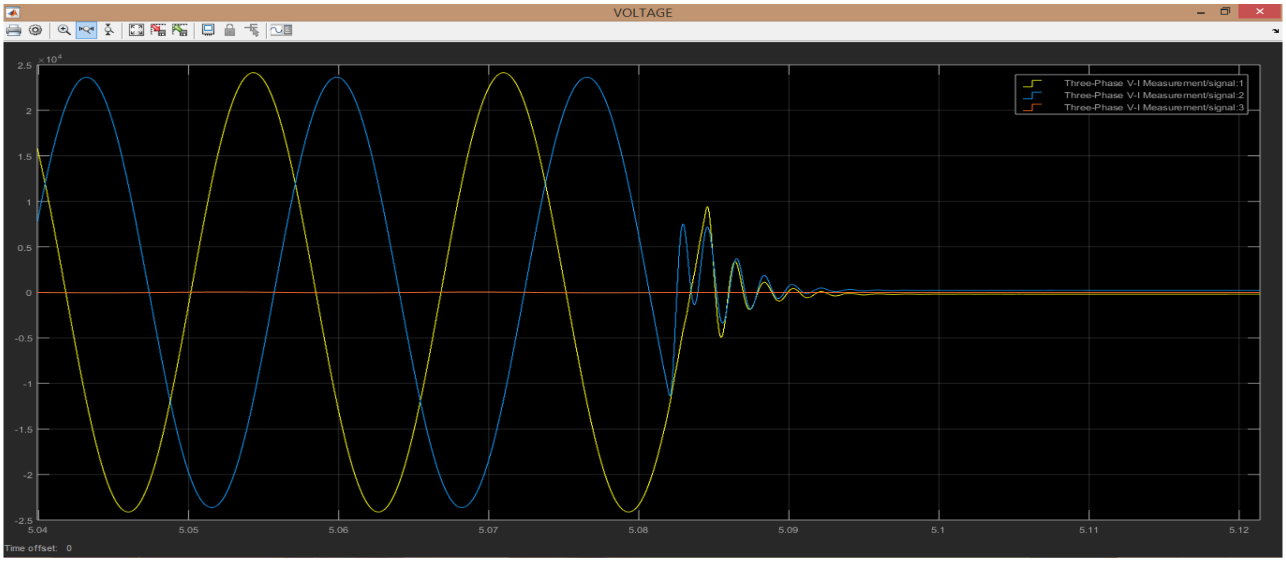


Figure4.20: line voltage response during C-G fault

Scope of FPIs:

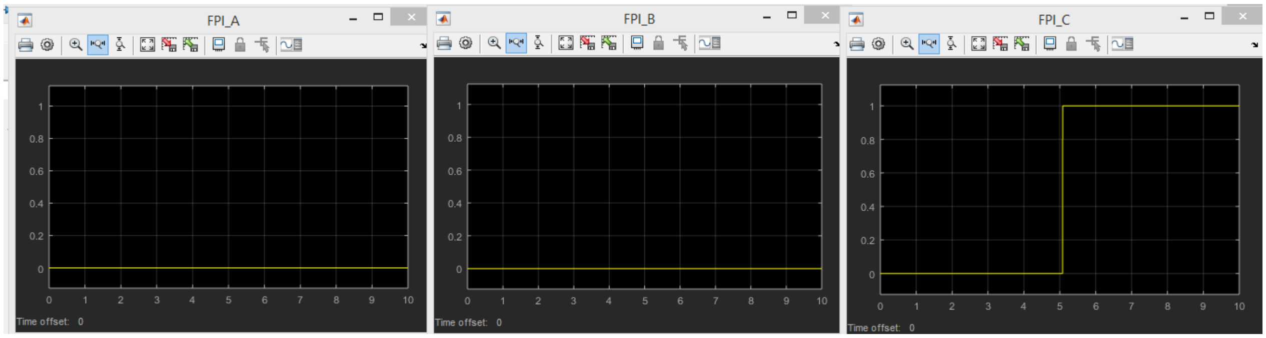


Figure4.21: FPIs response during C -G fault

The FPIs detects the fault after 2.08s corresponding to the U1 (moderately inverse) and indicate it, on A, B or C phase depends on the faulty phase

The current and voltage went to 0 after receiving the CB signal with a delay of less than 50 ms.

VI .4.1.3.d. double line AB to ground:

Scope of current:

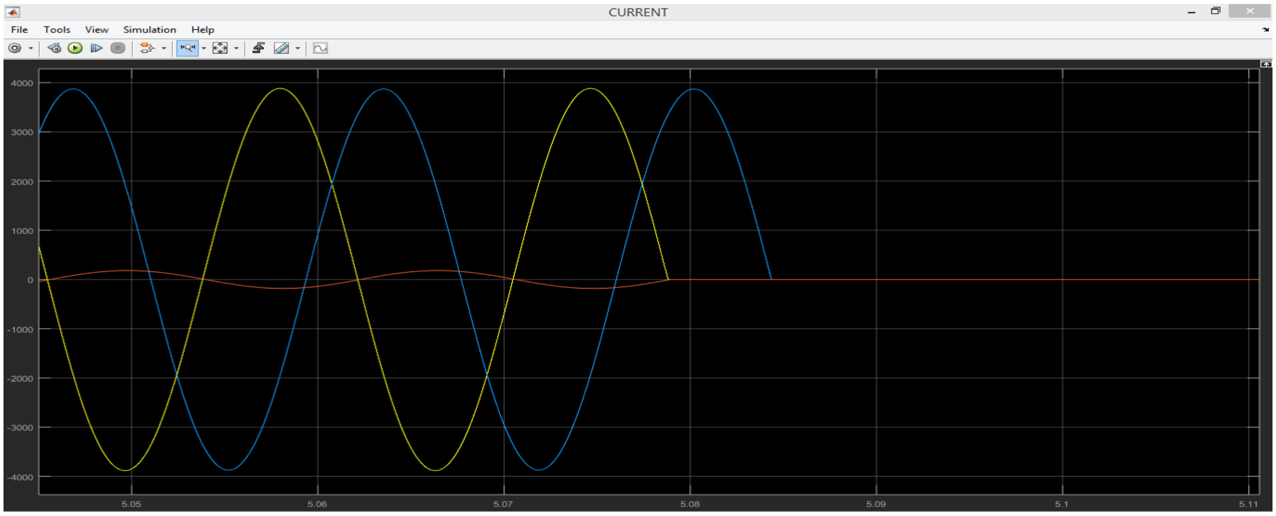


Figure4.22: line current response during G-AB fault

Scope of voltage:

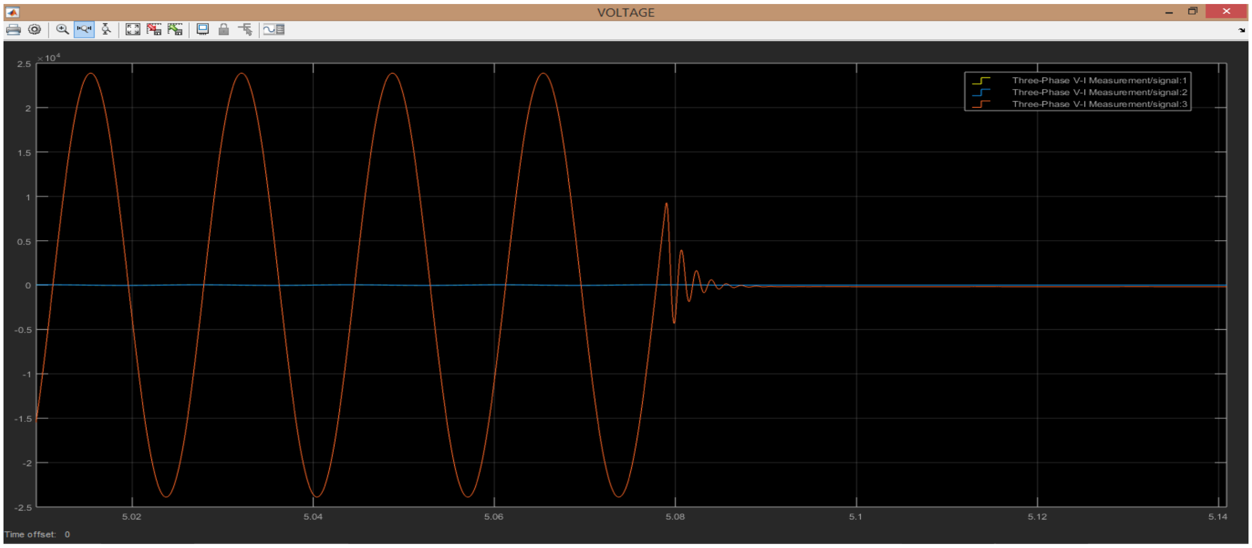


Figure 4.23: line voltage response during G-AB fault

Scope of FPIs:

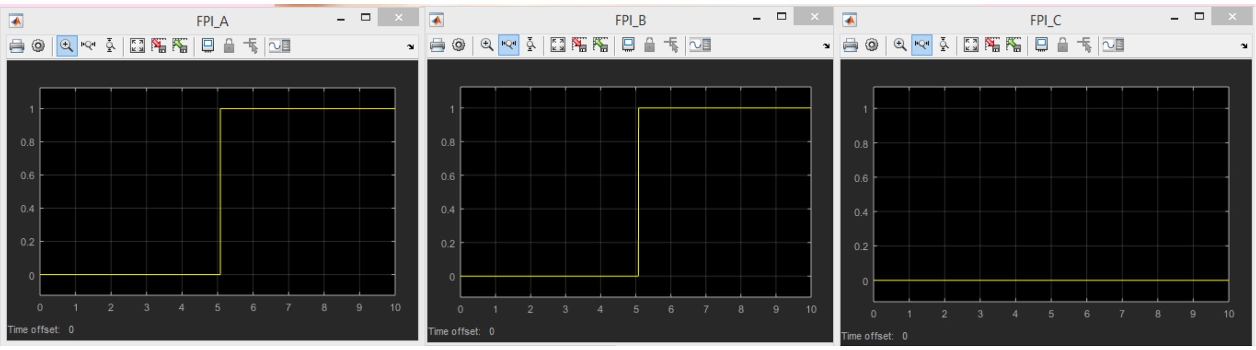


Figure4.24: FPIs response during G-AB fault

VI .4.1.3.e. double line to ground (AC-G):

Scope of current:

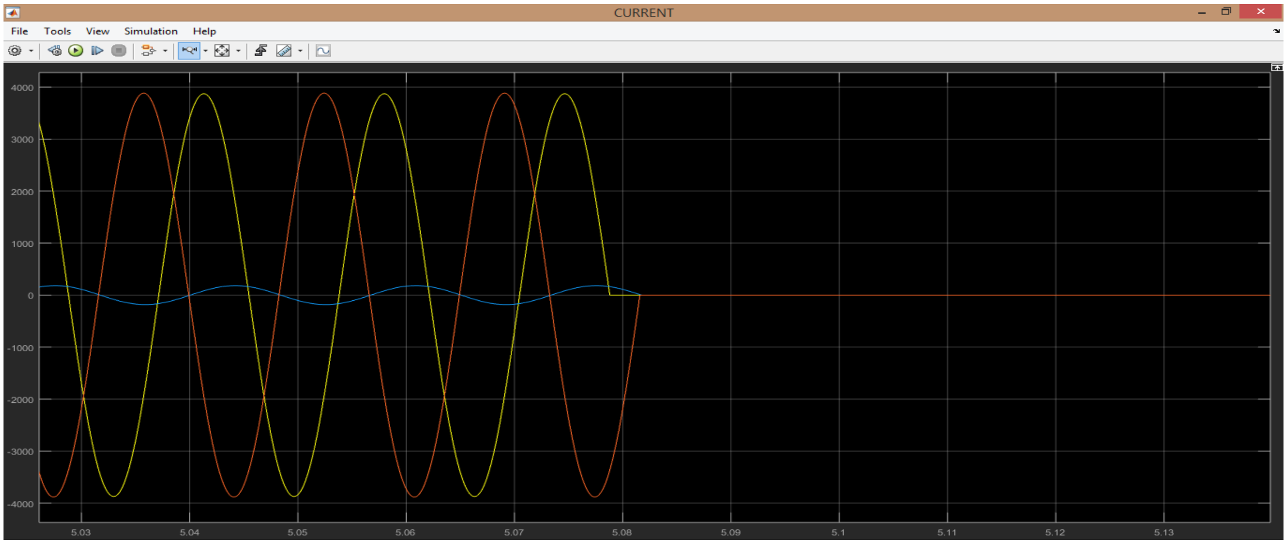


Figure4.25: line current response during G-AC fault

Scope of voltage:

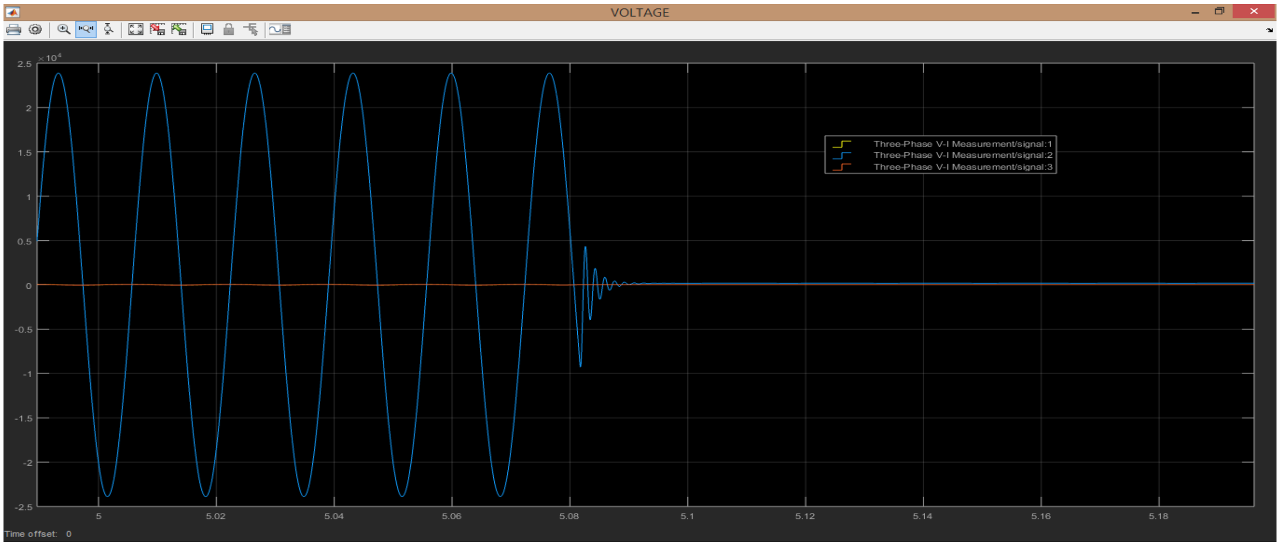


Figure 4.26: line voltage response during G-AC fault

Scope of FPIs:

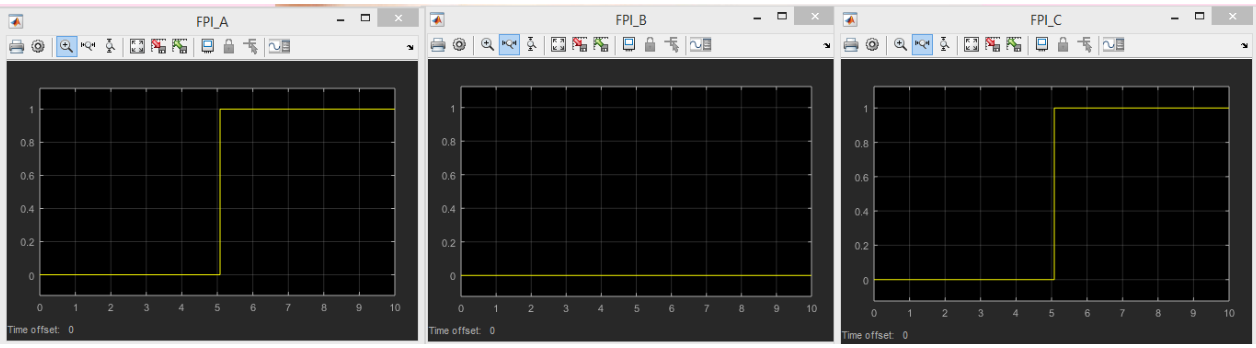


Figure4.27: FPIs response during LL-G (AC-G) fault

VI .4.1.3.f. double line to (ground-BC-G):

Scope of current:

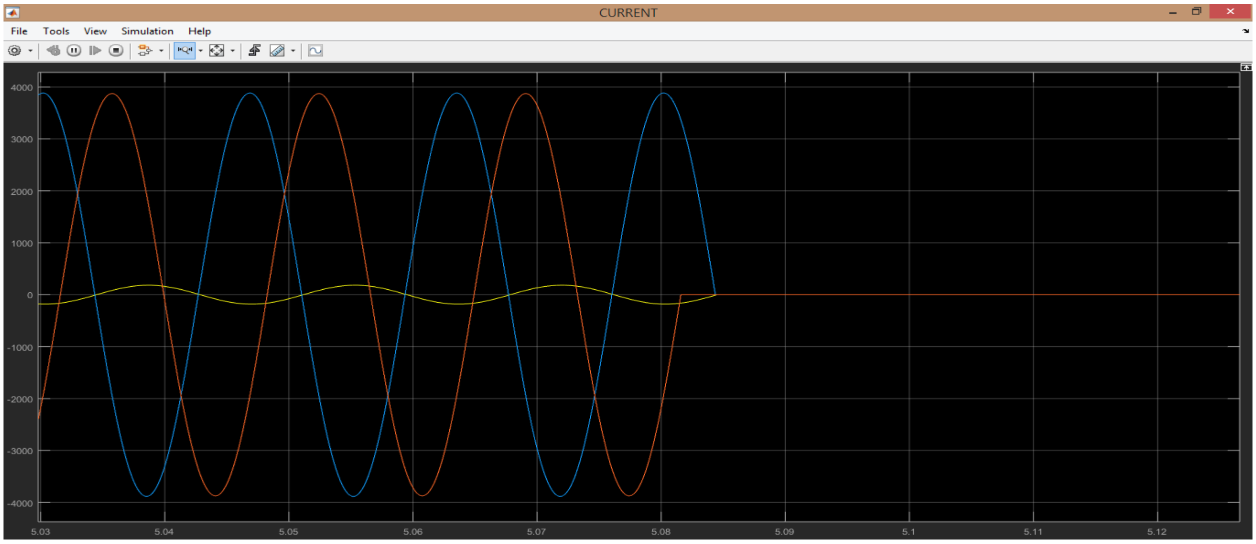


Figure4.28: line current response during LL-G-BC fault

Scope of voltage:

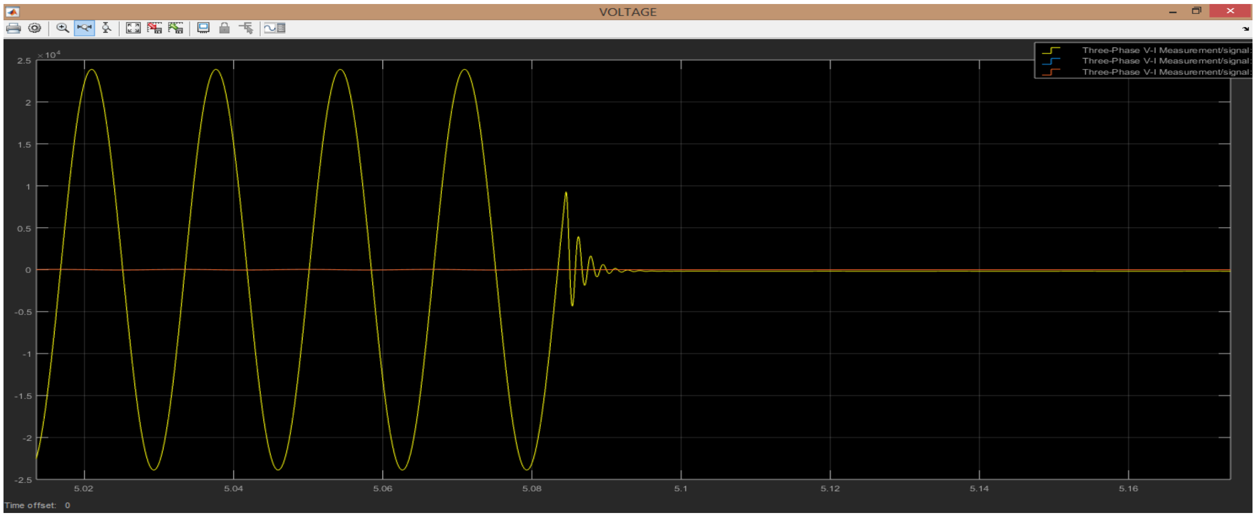


Figure 4.29: line voltage response during LL-G (BC-G) fault

Scope of FPIs:

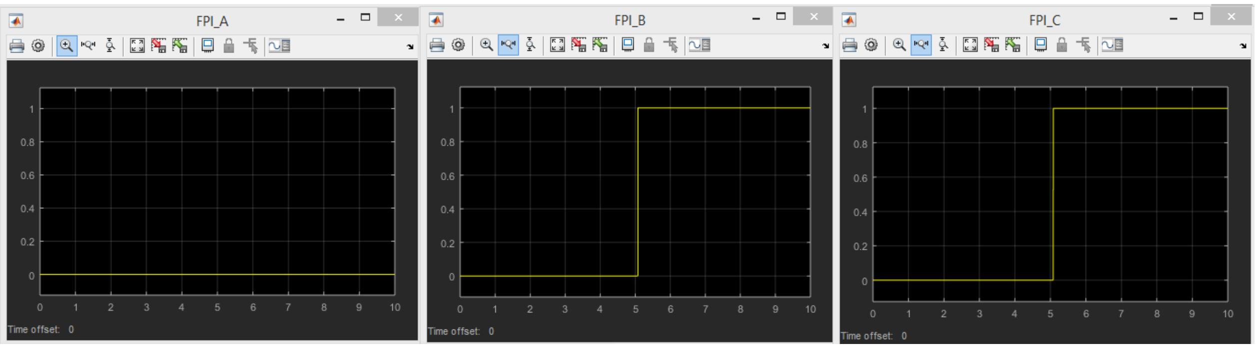


Figure4.30: FPIs response during LL-G(BC-G) fault

The FPIs detects the fault after 2.08s corresponding to the U1 (moderately inverse) and indicate it, on AB-G, AC-G or BC-G phases depends on the faulty phases.

The current and voltage went to 0 after receiving the CB signal with a delay of less than 50 ms

VI .4.1.3.g. line to line-AB:

Scope of current:

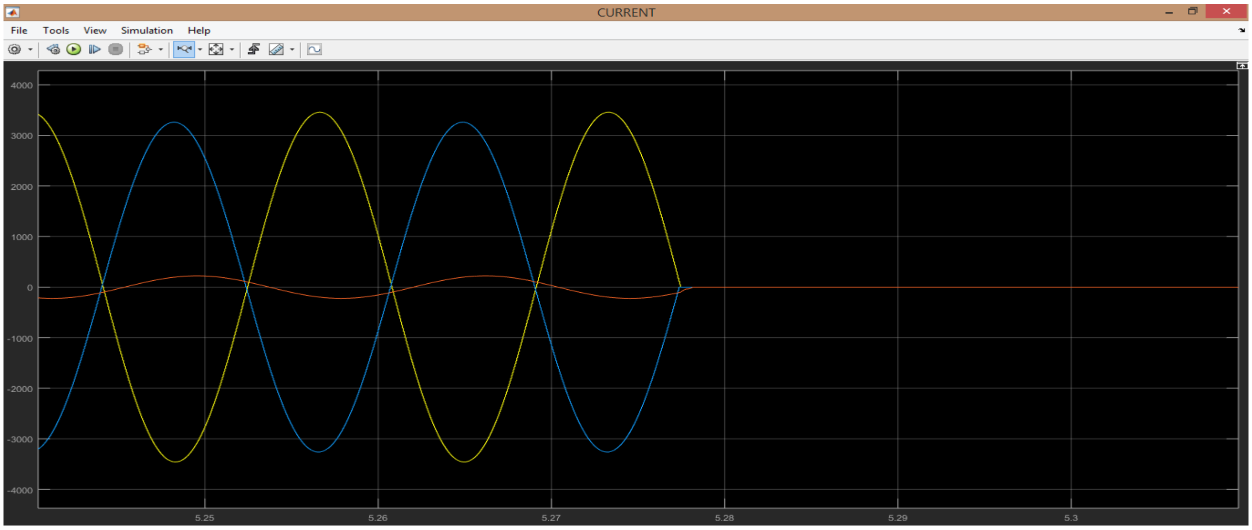


Figure4.31: line current response during LL-AB fault

Scope of voltage:

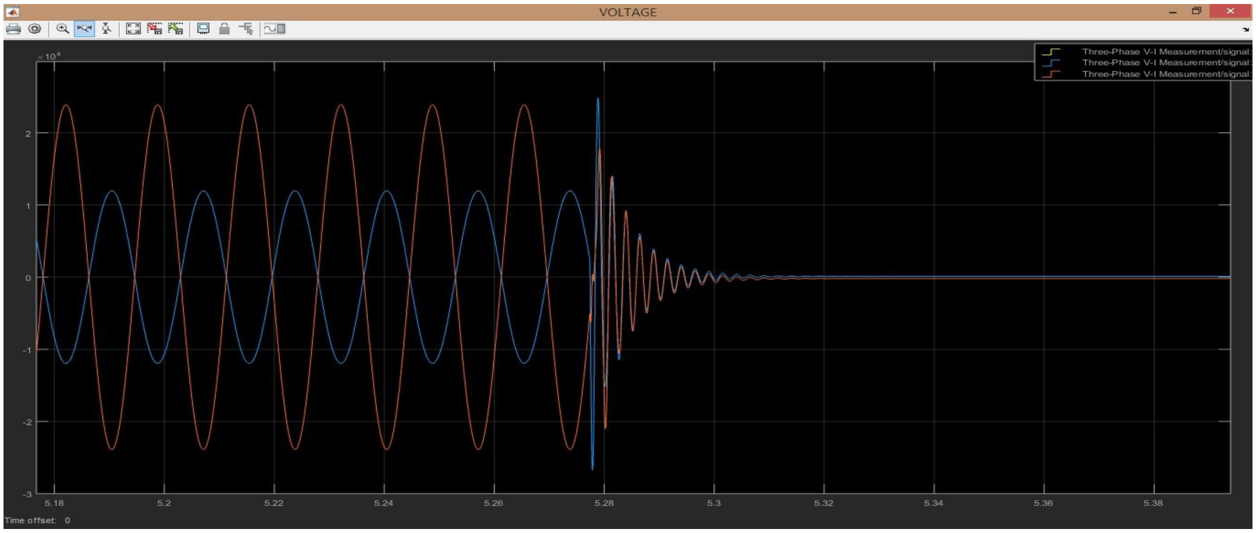


Figure4.32: line voltage response during LL-AB fault

Scope of FPIs:

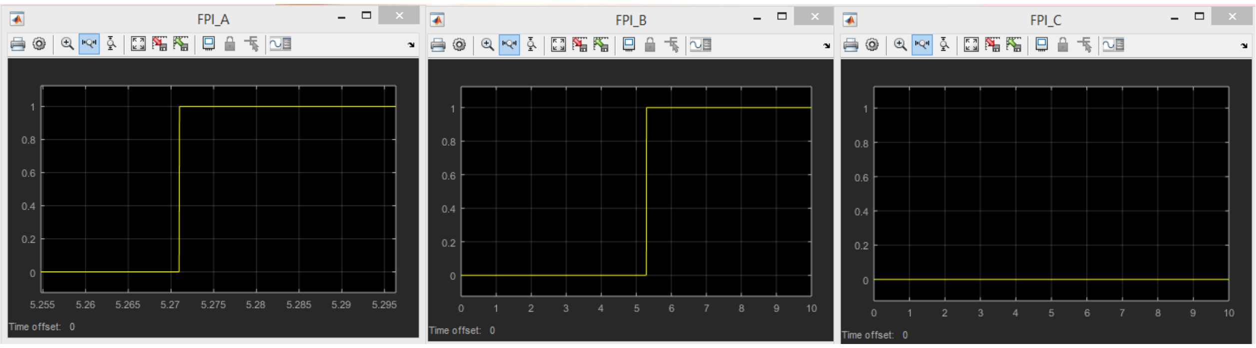


Figure4.33: FPIs response during LL-AB fault

VI .4.1.3.h. line to line-AC:

Scope of current:

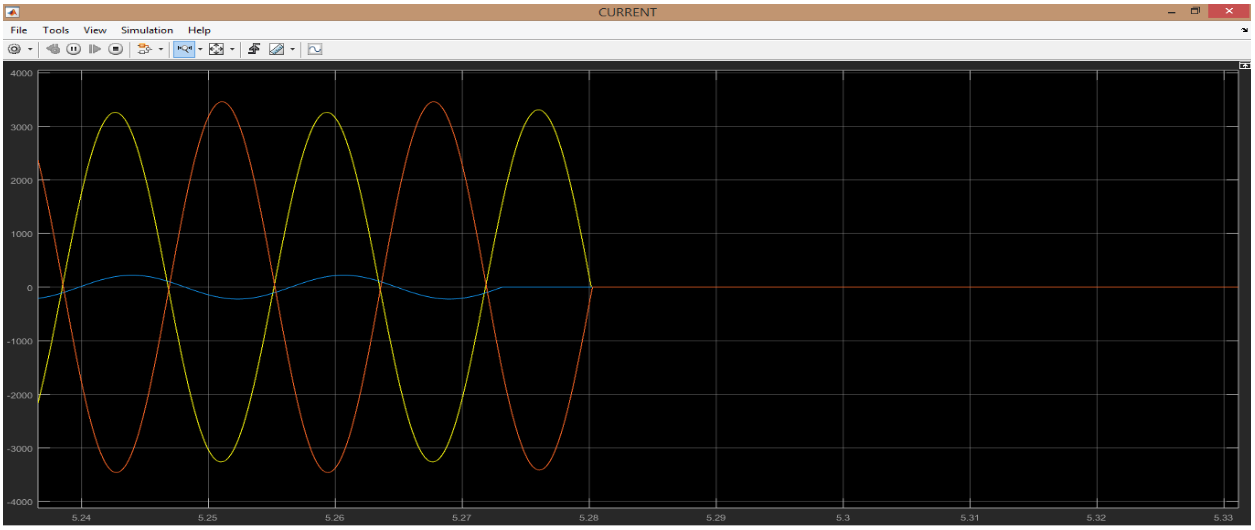


Figure4.34: line current response during LL-AC fault

Scope of voltage:

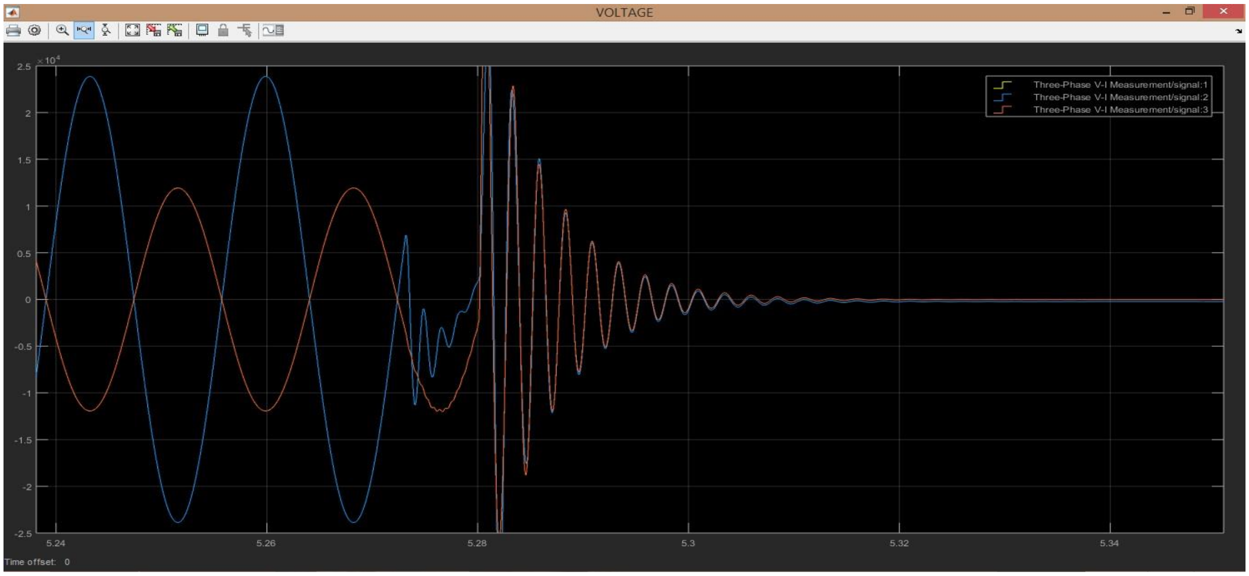


Figure4.35: line voltage response during LL-AC fault

Scope of FPIs:

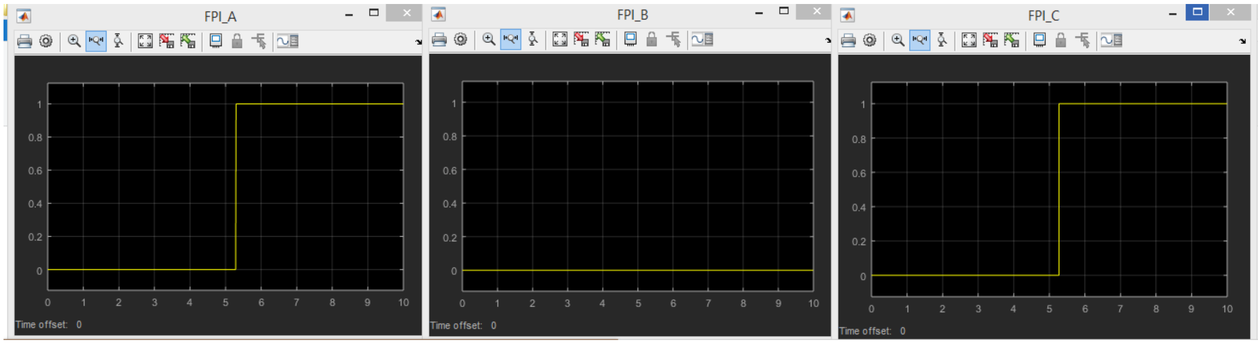


Figure4.36: FPIs response during LL-AC fault

VI .4.1.3.i. line to line-BC:

Scope of current:

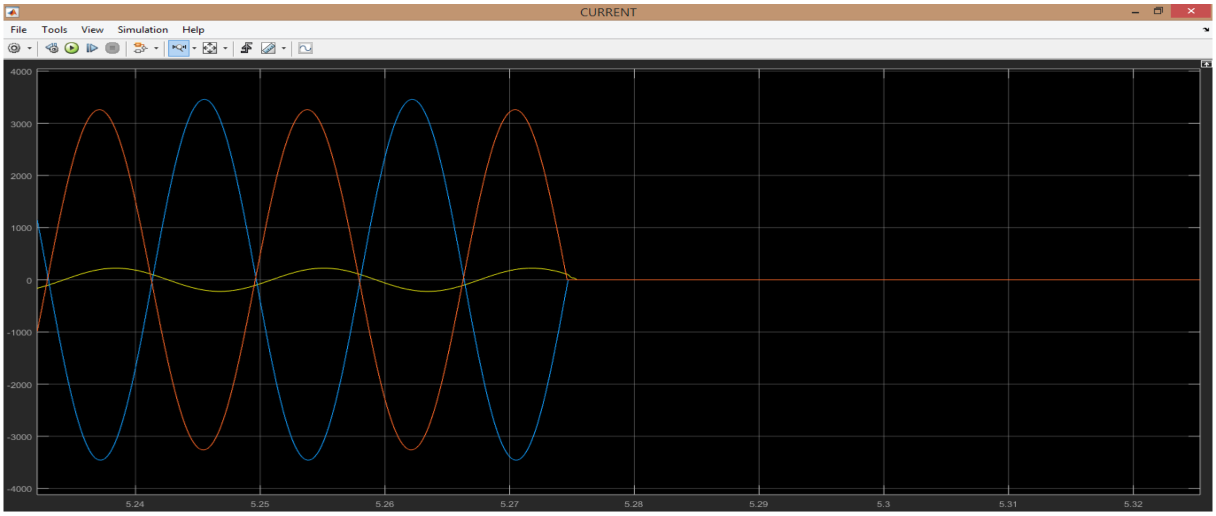


Figure4.37: line current response during LL-BC fault

Scope of voltage:

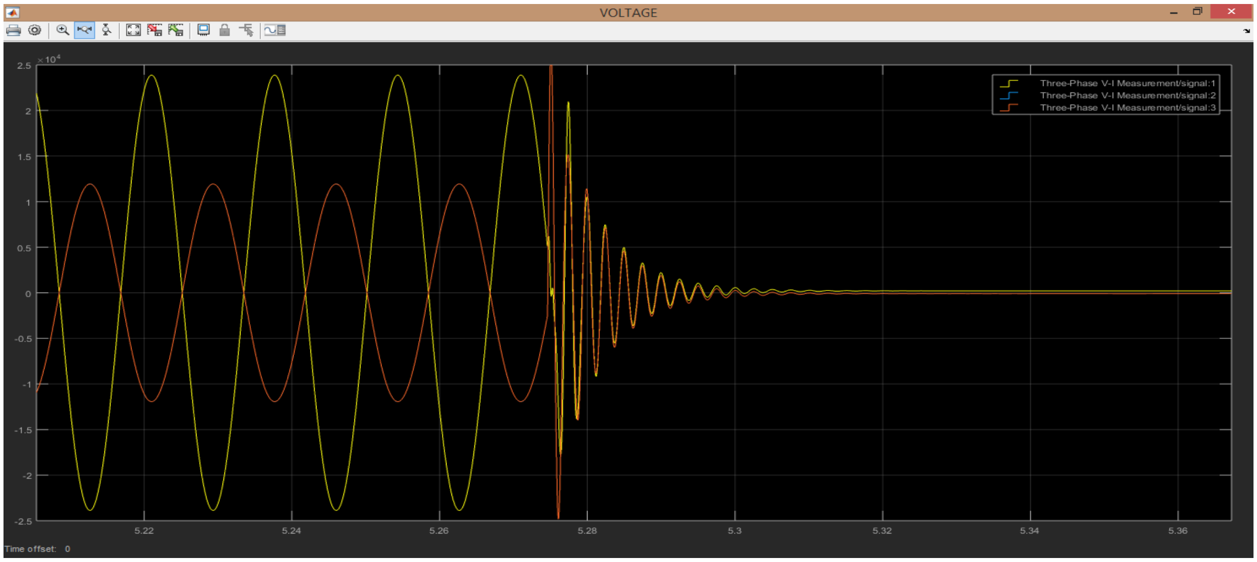


Figure4.38: line voltage response during LL-BC fault

Scope of FPIs:

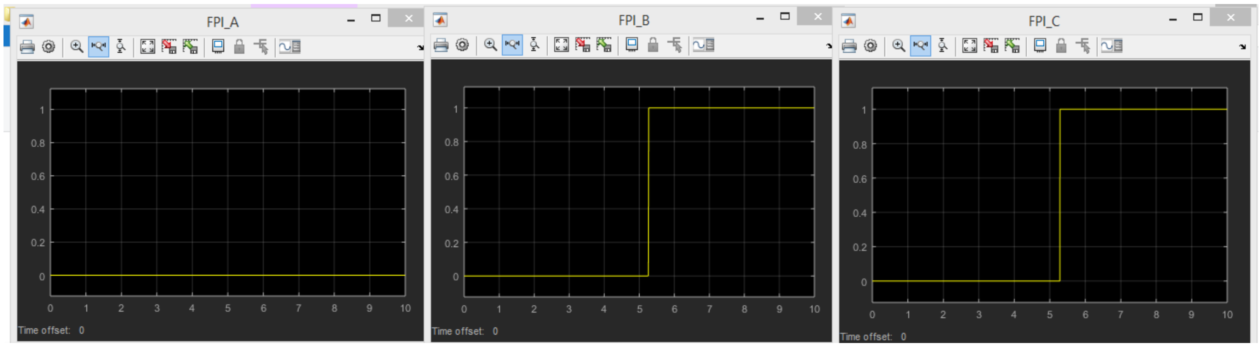


Figure4.39: FPIs response during LL-BC fault

The FPIs detects the fault after 2.27s corresponding to the U1 (moderately inverse) and indicate it, on AB, AC or BC phases depends on the faulty phases.

The current and voltage went to 0 after receiving the CB signal with a delay of less than 50 ms.

VI .4.1.3.k. three line to ground/three line:

Scope of current:

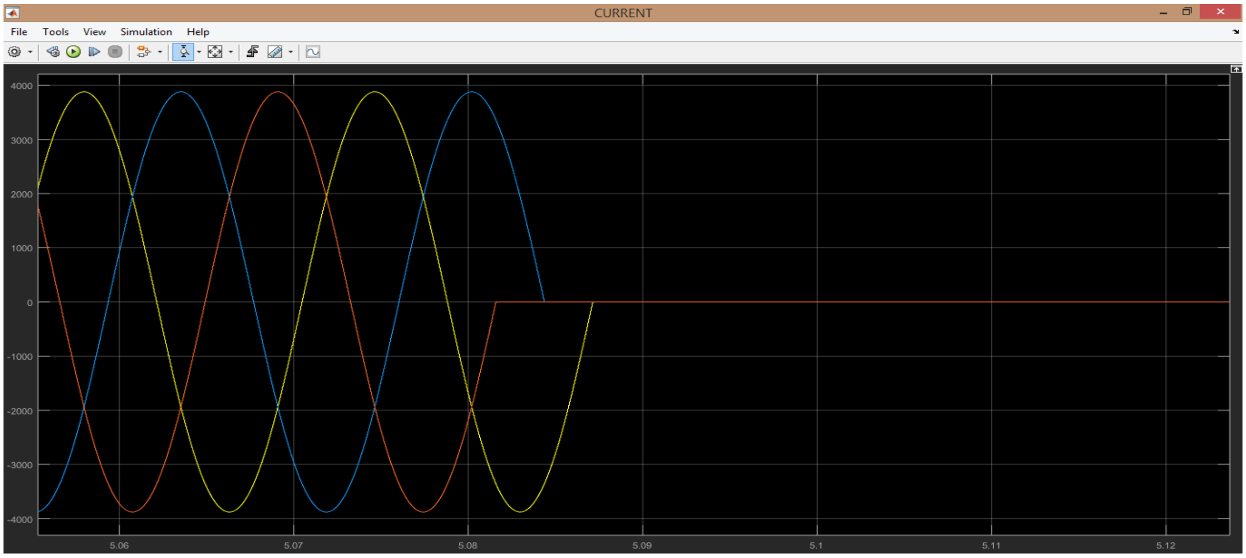


Figure4.40: line current response during LLL-G fault

Scope of voltage:

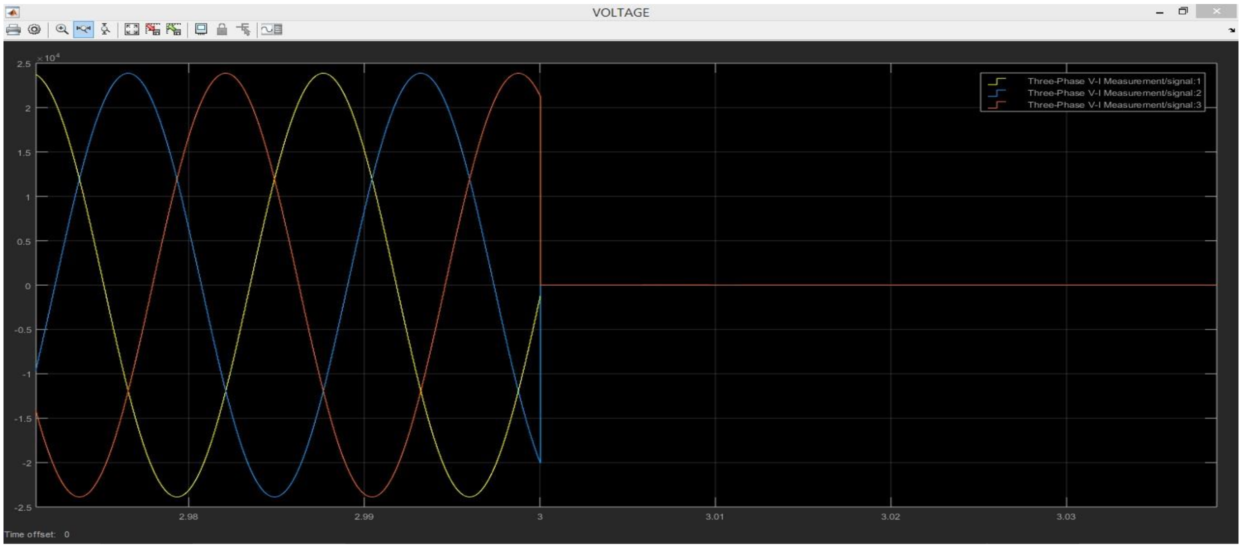


Figure4.41:line voltage response during LLL-G fault

Scope of FPIs:

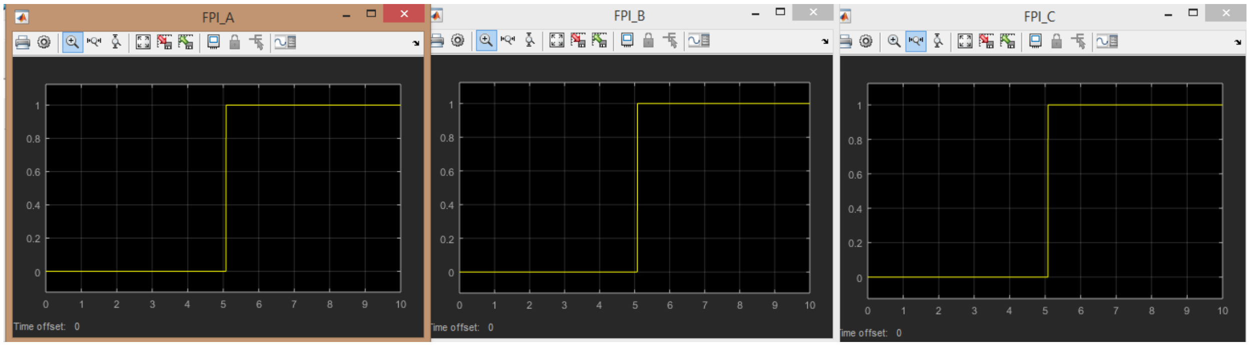


Figure4.42:FPIs response during LLL-G fault

The FPIs detects the fault after 2.08s corresponding to the U1 (moderately inverse) and indicate it, on all the phases because of the nature of the fault (three phase to ground).

The current and voltage went to 0 after receiving the CB signal with a delay of less than 50 ms.

VI .4.1.4.a. U.S Time-Overcurrent Equations(U5 short-time inverse TYPEC-15):

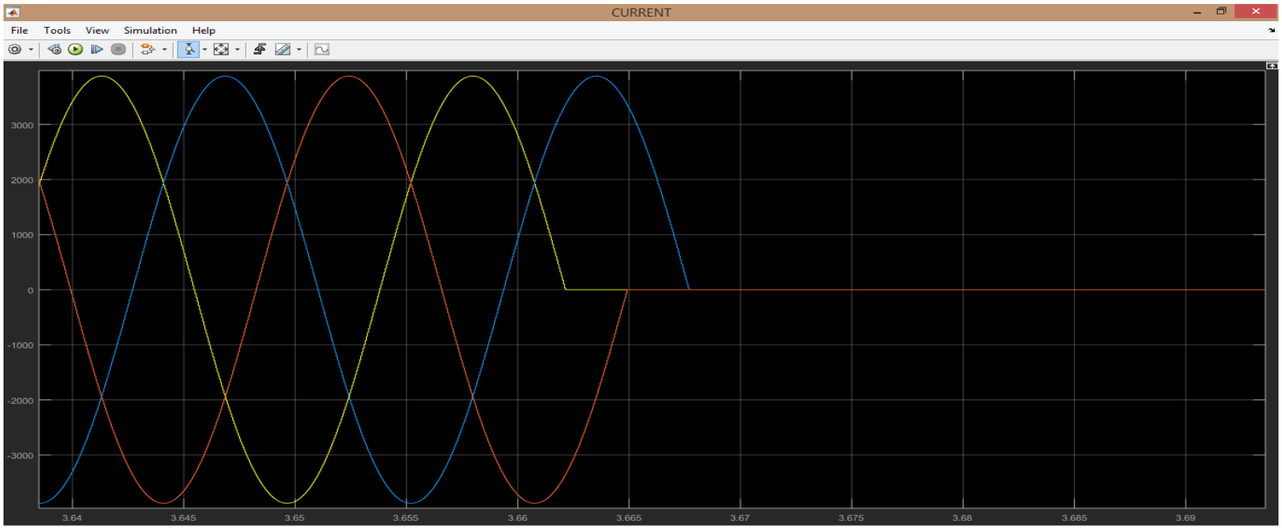


Figure4.43: line current response during LLL-G-TYPEC-15 fault

The current scoop shows the change in the responding time due to the change of the curve type indicating 1.66s corresponding to U5 (short-time inverse) U.S curve.

VI .4.1.4.b. IEC Time-Overcurrent Equations(U5 short-time inverse TYPEC-25):

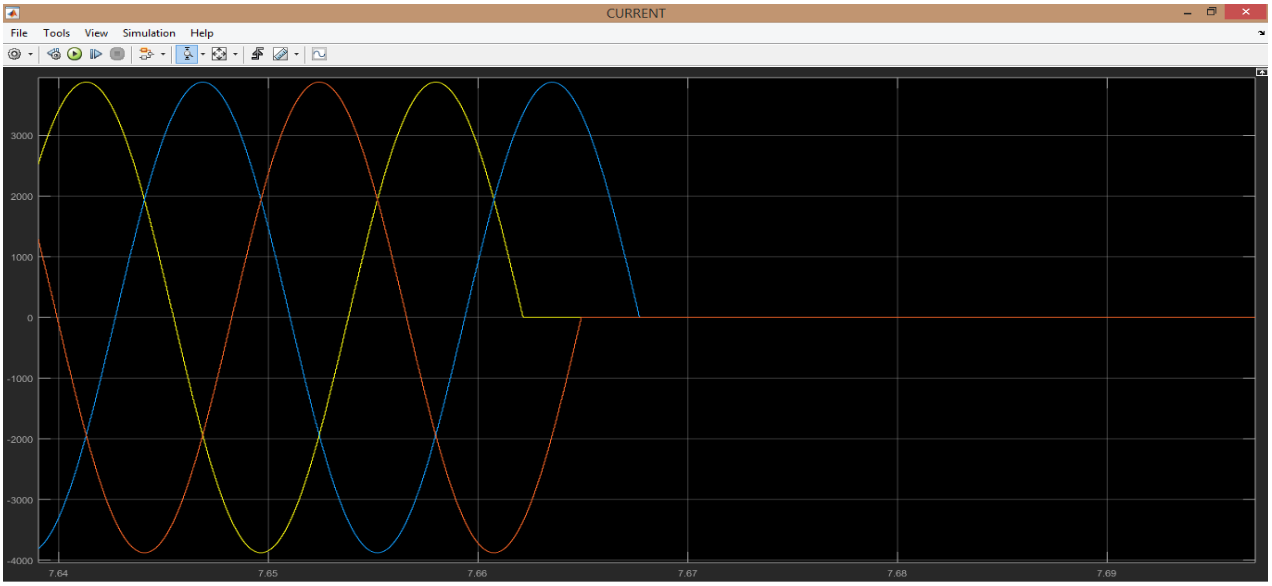


Figure3.44: line current response during LLL-G-TYPEC-25 fault

The current scoop shows the change in the responding time due to the change of the curve type indicating 4.66s corresponding to U5 (short-time inverse) IEC curve.

VI .5. Testing results discussion

All figures show the displayed curves of the three lines voltages and currents and the response of its corresponding FPIs during a simulation of a different type of faults, the duration of simulation is 10s.

The following points maybe drawn from the testing results:

* The simulation results are generally as it is expected theoretically. The indication of the FPI the delay of response to trigger and the tripping time are as it is expected.

* The simulated FPIs were able to differ between permanent and transient faults, and the indication of the fault type can be deduced from the resulting graphs that shows the activated FPIs during each fault.

* During the OV testing, the FPIs were set to work after 0.3s of the fault then the relay sends a trip signal to the CB to trip the system, we can see that in the current and voltage graphs that are the expected results.

* During the UV testing the FPIs were set to work after 2s of the fault then the relay sends a trip signal to the CB to trip the system, we can see that in the current and voltage graphs which is the expected results.

*For the OC testing we have multiple type of faults, we simulate the most of them, the fault is created after 3s of the simulation time then the indication and tripping will be done according to a chosen equation that decide the delay time.

*The chosen equation can be selected from a set of multiple equations called" time overcurrent curve equation", the selected one will decide the type of the response curve (moderately inverse, inverse, very inverse, extremely inverse and short-time inverse) both IEC and U.S standards [14].

Chapter V:
General conclusion

General conclusion:

In this work, a fault passage indicator integrated in a simple power system network has been designed using MATLAB-SIMULINK, after that the designed FPI has been tested by generating a different type of faults to examine the FPI work.

Initially, we have presented a general definition of power system protection, presenting its different schemes and levels. We also defined some protective devices, such as circuit breaker, Fuses, Auto-Reclosers and protective relays.
Consequently, a discussion about the faults causes and how to analyze the problems in order to better protect the equipment and ensure power supply continuity is introduced. The most powerful method in fault analysis which is symmetrical component method is described, and then a simple protection system has been highlighted.

Then we proceeded to look at the fault passage indicator and its system composition and its different types, we also presented its working principle and how effective it is in fast localization the faults.

Finally, we designed a fault passage indicator integrated in a Distribution Network using the MATLAB-SIMULINK software, then we simulated the design with different types of faults, the FPI was successfully indicate the faults and generate trip signals with indication of the fault type according to the scoop outputs.

After the test, it can be noticed that the obtained results satisfy the principle operation of the fault passage indicator (FPI) and its characteristics, Moreover, it can be concluded that this designed model has the following advantages:

1- Selectivity of indication between transient and permanent faults.

2- Detection and indication of undervoltage and overvoltage faults.

3- Detection and indication of over current faults.

4- This project can be considered as start point for future student to study and implement this designed module or develop it with more specifications.

Further improvements can be adapted to our design by adding an algorithm that can analyze the outputs and give the name of the fault on a screen directly.

In the beginning, we were supposed to implement and realize our designed FPI using the appropriate tools, but unfortunately due to the COVID-19 pandemic, we were obliged to stop in this point, so we can consider the realization of our project as further work.

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