ANALYSIS OF FAULTS IN A POWER SYSTEM

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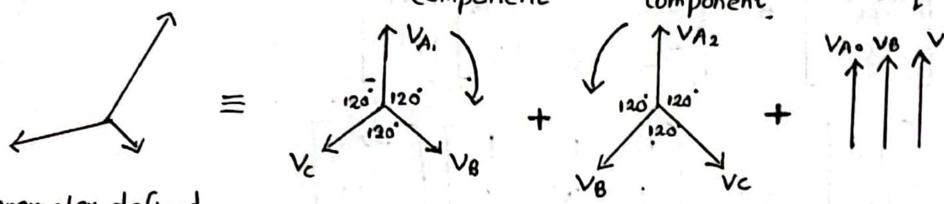
PRELIMINARY WORK

Positive Sequence component + Negative Sequence component + Zero sequence component



Parameter defined as vector

$\lambda = 1 \angle 120°$

(angle is anticlockwise)

$V_A = V\angle 0°$

$V_B = V\angle -120°$

$V_C = V\angle -240°$

$V_A = V\angle 0°$

$V_B = V\angle -240°$

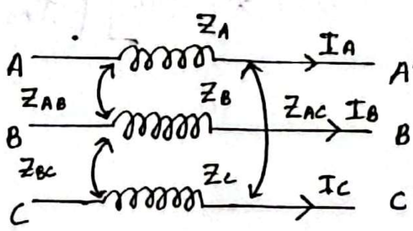
$V_C = V\angle -120°$

$V_A = V_B = V_C = V\angle 0°$

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda & \lambda^2 \\ 1 & \lambda^2 & \lambda \end{bmatrix} \begin{bmatrix} V_{A0} \\ V_{A1} \\ V_{A2} \end{bmatrix}$$

$$\begin{bmatrix} V_{A0} \\ V_{A1} \\ V_{A2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda & \lambda^2 \\ 1 & \lambda^2 & \lambda \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix}$$

Sequence impedence of transmission line



$Z_A = Z_B = Z_C = Z_S$ (self inductance)

$Z_{AB} = Z_{BC} = Z_{AC} = Z_m$ (mutual inductance)

$$V_{AA'} = I_A Z_S + I_B Z_m + I_C Z_m$$

$$V_{BB'} = I_A Z_m + I_B Z_S + I_C Z_m$$

$$V_{CC'} = I_A Z_m + I_B Z_m + I_C Z_S$$

$$\begin{bmatrix} V_{AA'} \\ V_{BB'} \\ V_{CC'} \end{bmatrix} = \begin{bmatrix} Z_s & Z_m & Z_m \\ Z_m & Z_s & Z_m \\ Z_m & Z_m & Z_s \end{bmatrix} \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix}$$

$$\begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda^2 & \lambda \\ 1 & \lambda & \lambda^2 \end{bmatrix} \begin{bmatrix} I_{A0} \\ I_{A1} \\ I_{A2} \end{bmatrix}$$

$$\begin{bmatrix} V_{A0} \\ V_{A1} \\ V_{A2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda & \lambda^2 \\ 1 & \lambda^2 & \lambda \end{bmatrix} \begin{bmatrix} V_{AA'} \\ V_{BB'} \\ V_{CC'} \end{bmatrix}$$

$$\begin{bmatrix} V_{A0} \\ V_{A1} \\ V_{A2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda & \lambda^2 \\ 1 & \lambda^2 & \lambda \end{bmatrix} \begin{bmatrix} Z_s & Z_m & Z_m \\ Z_m & Z_s & Z_m \\ Z_m & Z_m & Z_s \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda^2 & \lambda \\ 1 & \lambda & \lambda^2 \end{bmatrix} \begin{bmatrix} I_{A0} \\ I_{A1} \\ I_{A2} \end{bmatrix}$$

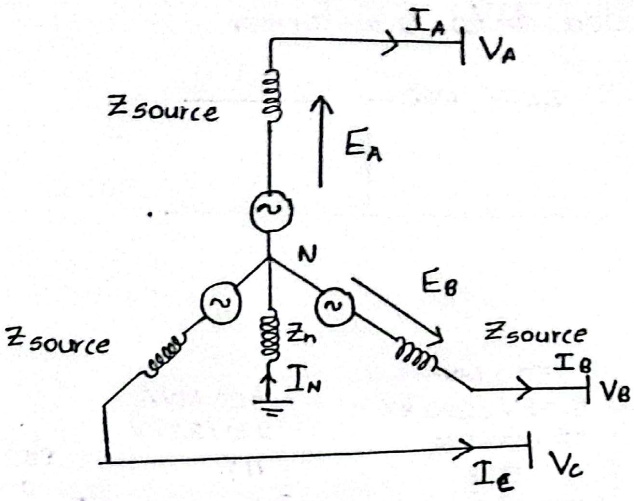
$$\begin{bmatrix} V_{A0} \\ V_{A1} \\ V_{A2} \end{bmatrix} = \begin{bmatrix} Z_s + 2Z_m & 0 & 0 \\ 0 & Z_s + (\lambda^2+\lambda)Z_m & 0 \\ 0 & 0 & Z_s + (\lambda^2+\lambda)Z_m \end{bmatrix} \begin{bmatrix} I_{A0} \\ I_{A1} \\ I_{A2} \end{bmatrix}$$

$$1 + \lambda + \lambda^2 = 0$$

$$Z_0 = Z_s + 2Z_m$$

$$Z_1 = Z_s - Z_m$$

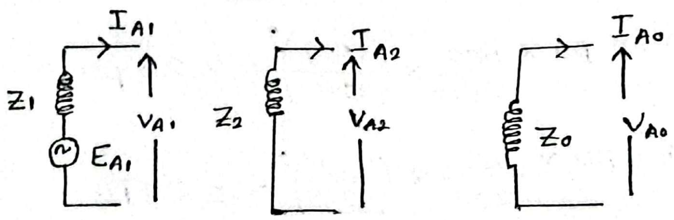
$$Z_2 = Z_s - Z_m$$



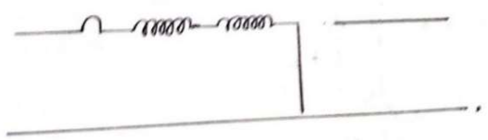
$$V_{AN} = E_A - I_A Z \text{ source}$$
$$V_{BN} = E_B - I_B Z \text{ source}$$
$$V_{CN} = E_C - I_C Z \text{ source}$$

$$V_{A1} = E_{A1} - I_{A1} Z_1$$
$$E_{A1} = \tfrac{1}{3}(E_A + \lambda E_B + \lambda^2 E_C)$$

$$V_{A2} = 0 - I_{A2} Z_2$$
$$V_{A0} = 0 - I_{A0} Z_0$$
$$\begin{aligned} V_{A0,N} &= V_n - I_{A0} Z_0' \\ &= -I_n Z_n - I_{A0} Z_0' \\ &= -(I_A + I_B + I_C) Z_n - I_{A0} Z_0' \\ &= -I_{A0}(3Z_n + Z_0') \\ &= \underline{\underline{-I_{A0} Z_0}} \end{aligned}$$



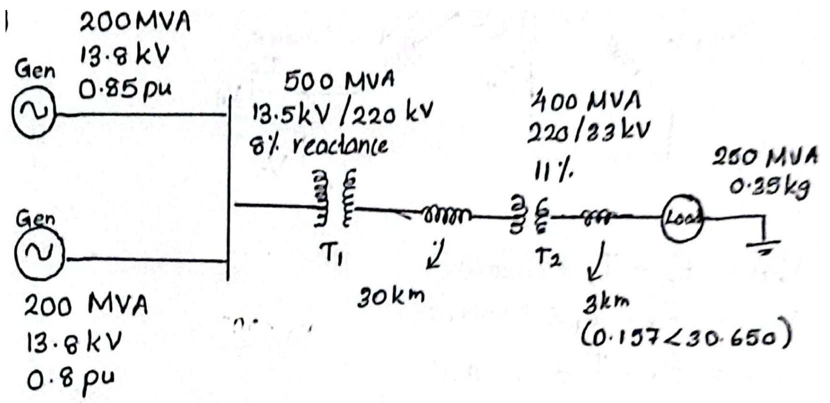
Star grounded delta transformer



1. The bus immpedence matrix is directly related to the fault current calculations and it provides the thevenin equivalent impedence for any bus system. During fault analysis the fault current can be quickly determines by using impedence matrix.The mai advantage of using the impedence bus matrix over the addmittance bus matrix is any modification of the network does not require a complete rebuilding of the impedence bus Formulation .when doing calculation using admittance bus matrix it takes too much time.

Steps in building the Z bus
Convert all component impedances to per-unit values and reference them to the slack bus. Create the initial impedance matrix by including all self and mutual impedances between buses.Use matrix reduction techniques to simplify the impedance matrix step by step. Recalculate and update the Z bus matrix for different fault conditions in the system.

2.



$$S_{base} = \sqrt{3}\, I_{base} V_{base}$$

$$S_{base} = \sqrt{3}\,\frac{V^2_{base}}{Z_{base}} \Rightarrow Z_b = \frac{\sqrt{3}V_b^2}{S_b}$$

(b- base)

$$Z_1 = \frac{\sqrt{3}V_1^2}{S_1}$$

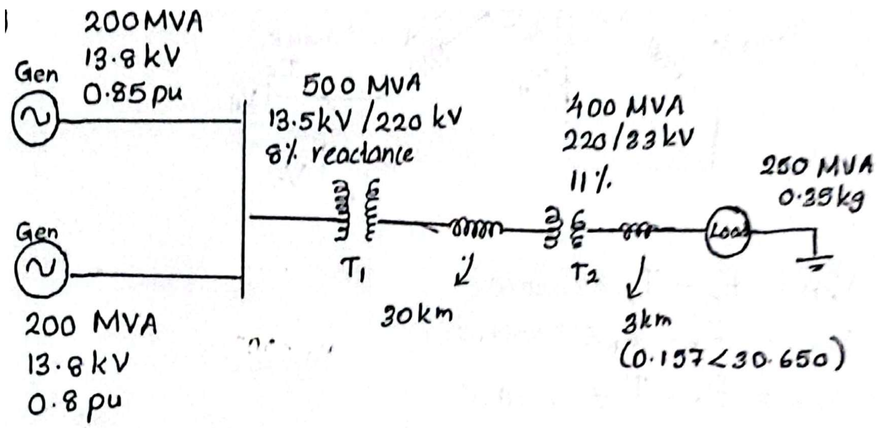
$$\frac{Z_1}{Z_b} = \frac{V_1^2}{V_b^2} \times \frac{S_b}{S_1}$$

$$Z_i = Z_{base} \times \frac{S_{base}}{S_i} \times \left(\frac{V_i}{V_{base}}\right)^2$$

converting impedence to base.

$$Z_{g1}(pu) = 0.85\ pu \times \frac{500}{200} \times \left(\frac{13.8}{13.5}\right)^2 = 2.22\ pu$$

$$Z_{g2}(pu) = 0.8\ pu \times \frac{500}{200} \times \left(\frac{13.8}{13.5}\right)^2 = 2.09\ pu$$



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$Z_{T2} = 0.11 \times \frac{500}{400}$ $\quad\quad$ $Z_{T1} = 0.08 \times \frac{500}{500}$

$= 0.1375\ pu$ $\quad\quad$ $= 0.08pu$

For the transmission line.

$$Z_{base} = \frac{V^2_{base}}{S_{base}} = \frac{220^2 \times 10^6}{500 \times 10^6} = 96.3pu$$

$$Z_{(T.L\ (pu))} = \frac{(0.45\angle 53.13) \times 30}{96.8} = 0.084 + 0.11j$$

$$Z_{cable}\ (pu) = \frac{(0.157\angle 30.65) \times 3}{33^2} \cancel{\times} 500 = 0.19 + 0.11j$$

For the load,

$$Z_L\ (pu) = \frac{250}{500} = 0.5pu$$

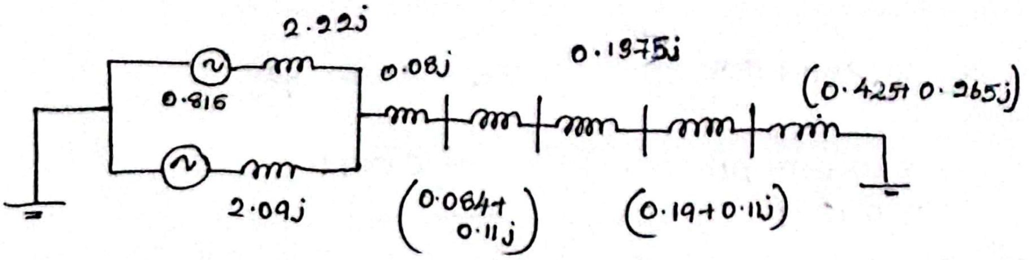
$$\begin{aligned} Z_{Load} &= 0.5\cos\phi + j0.5 \sin\{\cos^{-1}\phi\} \\ &= 0.5 \times 0.85 + j0.5 \times \sin\{\cos^{-1}(0.85)\} \\ &= 0.425 + 0.265j \end{aligned}$$

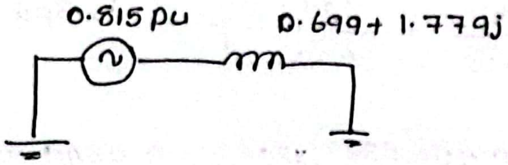
S_1 and g_2 //,

$$Z_g\ (pu) = \frac{2.22 \times 2.09}{(2.22 + 2.09)}\ pu = 1.0765j\ pu$$

$$\text{Voltage of the generator} = 0.797 \times \frac{13.8}{13.5}$$

$$= \underline{0.815pu}$$





$$I_{base} = \frac{S_{base}}{\sqrt{3}\, V_{base}} = \frac{500 \times 10^6}{\sqrt{3} \times 33 \times 10^3} = 8747.73\ A.$$

$$I_{f}(pu) = \frac{0.815}{0.699 + 1.779j} = 0.4264 \angle -68.58\ pu$$

$$I_{f}(A) = (0.4264 \angle -68.58\ pu) \times 8747.73$$
$$= \underline{\underline{3729.9 \angle -68.55\ pu}}$$

$$V = 0.815 \times 13.8\ kV$$
$$= \underline{\underline{11.247\ kV}}$$

3. The fault level of a system is the potential maximum fault current that is going through the circuit when the fault occurs. The fault level is determined based on the SteadyState condition of the network and is crucial for selecting protective devices. It helps in choosing circuit breakers and other switchgear with adequate short circuit making and breaking capacities. It also guides the design of bus bars, supporting structures, cables, and switchgear to withstand the thermal and mechanical stresses caused by faults. Also it is used for current based discrimination in protective switchgear and ensures that the protective devices are rated correctly for each network circuit. This process ensures the proper selection of protective devices for safe and reliable operation.

4. The main factors affecting fault current in a system are the fault's size, duration, type, and the behavior of the network's synchronous machines. During a fault, the current in the system increases, causing the synchronous machines to draw more magnetizing current which raises the reactive power demand. Large faults can also put mechanical stress on the machine's rotor and stator, potentially damaging the machine or forcing it to shut down.

5.

The voltage at generator $- 132 \times \frac{12}{132} = 12\,kV$

For the power system

Fault level $- 1500\,MVA \Rightarrow \frac{1500}{100} = 15\,pu$

Voltage $- 132 \times 1.02\,pu = 134.64\,kV$

per unit impedence $- \frac{1.02^2}{15} = 0.06936\,pu$

$$x/r = 8 \quad \therefore \frac{x}{Z} = \frac{8}{\sqrt{65}} = 0.99228$$

$$x_{0\,pu} = \frac{25}{Z_{base}} \qquad Z_{base} = \frac{V_{base}^2}{S_{base}} = \frac{132^2}{100} = 174.24$$

(for the lines)

$$= \frac{25}{174.24}$$

$$= 0.1435\,pu$$

$$x_{1pu} = \frac{15}{174.24} = 0.086\,pu$$

$$r = \frac{4}{174.24} = 0.023\,pu$$

<u>For the load</u> $(P = 100\,MW,\ PF - 0.9\ \text{lagging})$

$$S_{pu} = \frac{100}{0.9} = 111.11\,MVA \angle 25.84^\circ$$

$Z_{pu} - 0.9\,pu$

$R_{pu} = 0.9\cos(25.84) = 0.81\,pu$

$X_{pu} = 0.9\sin(25.84) = 0.3923\,pu$

<u>For the transformer</u>

$S = 50\,MVA \qquad 132/12\,kV$

$$X_{pu} = \frac{0.08 \times 100}{50} = 0.16\,pu$$

For the generator,

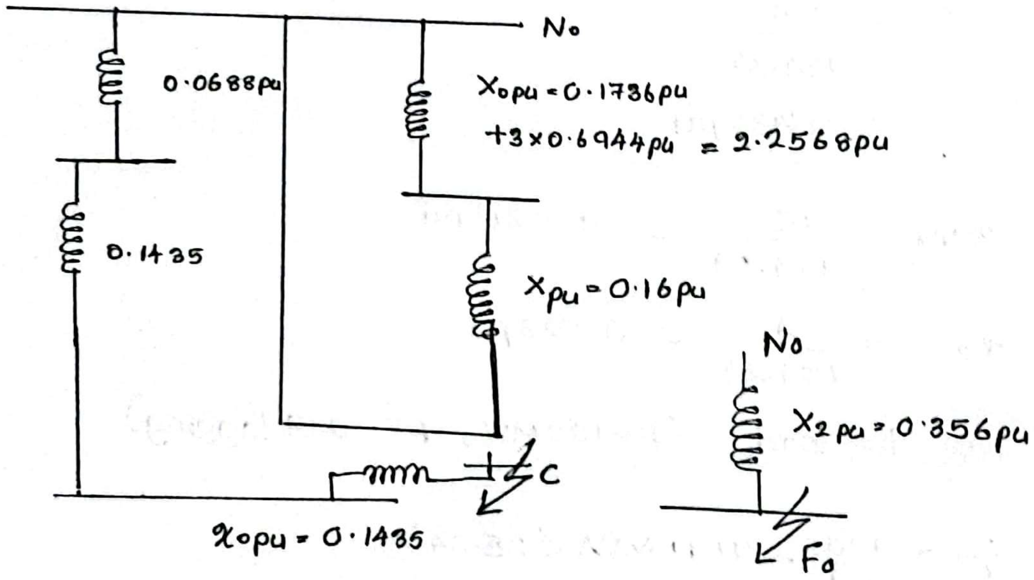
$S = 50$ MVA $\quad V = 12.5$ kV , 1.03 pu

$x_1(pu) = 0.12 \times \left(\frac{12.5}{12}\right)^2 \times 2 = 0.2604$ pu

$x_2(pu) = 0.10 \times \left(\frac{12.5}{12}\right)^2 \times 2 = 0.2170$ pu

$x_0(pu) = 0.08 \times \left(\frac{12.5}{12}\right)^2 \times 2 = 0.1736$ pu

$x_{gn}(pu) = 1 \times \left(\frac{100}{12}\right)^2 = 0.6944$ pu



Neutral is connected in seiries.

total impedence $= 0.153 + 0.154 + 0.356$

$= 0.663$ pu

$I_b = I_c = 0 \qquad I_a = 3I_a = 3 \times \frac{1}{0.663}$

$= 4.52$ pu

PRACTICAL WORK

A. SIMULATION USING MATLAB

1.

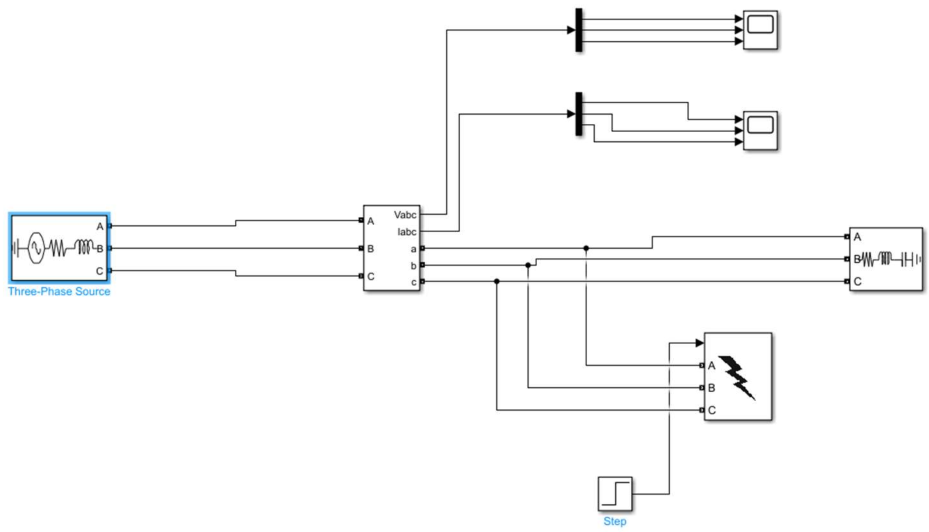


Figure 01: Model to analyze line faults

2. All 3 phases of the system short circuited to each other

a)

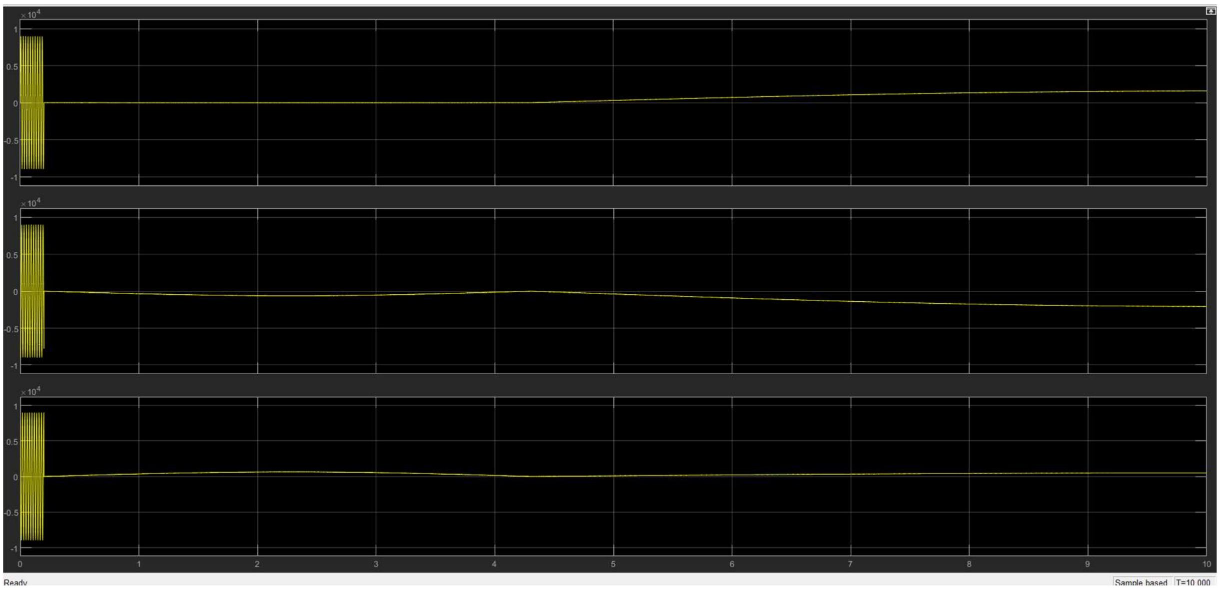


Figure 02: voltage output from scope

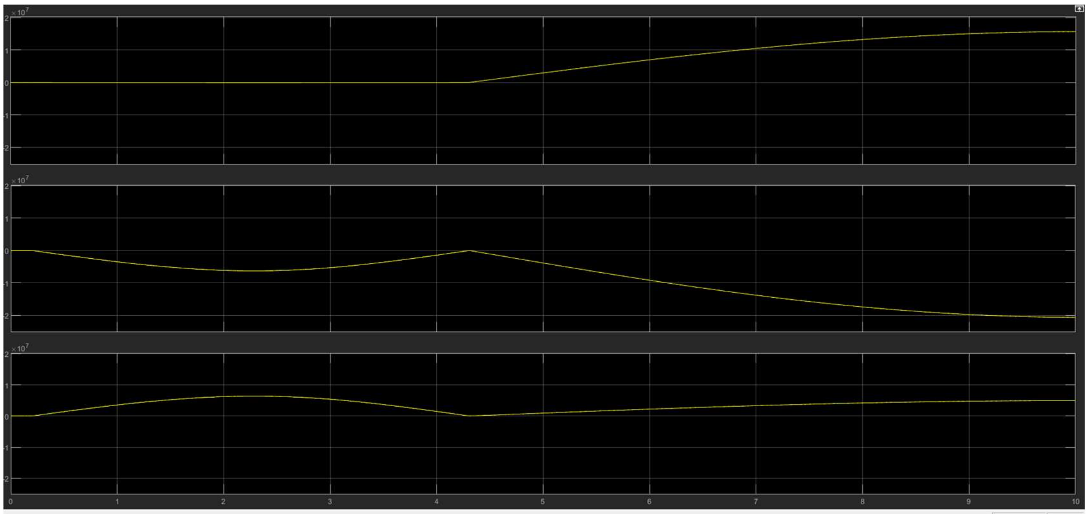


Figure 03: Current output from scope 1

b) Before the fault (Figure 02) the voltage waves are smooth and sinusoidal but when the fault happens the voltage drops to zero. In the current output (Figure 03) the current starts at zero in each line and then increases in either the positive or negative direction.

c) When a fault happens in the system the current increases significantly and the voltage drops. Since all three phases are equally affected by the fault the voltage and current behave the same in all three phases.

3. Phase A to Ground fault

a)

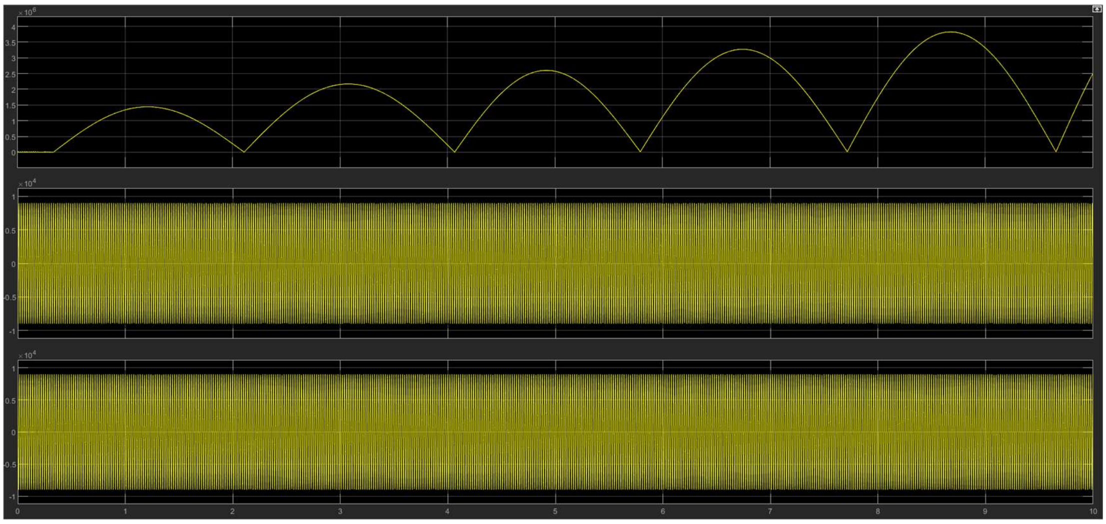


Figure 04:voltage output from scope

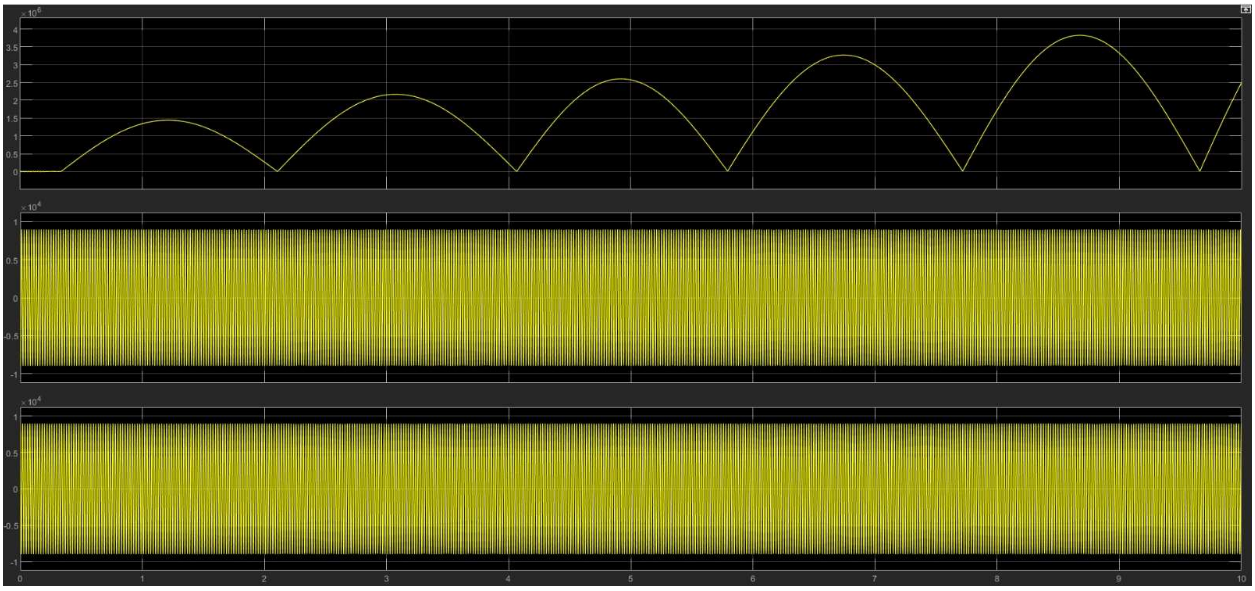


Figure 05: Current output from scope 1

b) In Figure 04 the voltages of phases B and C are not affected by the fault but the voltage in phase A is and its waveform changes. In Figure 05 the currents in phases B and C stay normal but the current in phase A is affected and its waveform changes.

c) In this case only phase A is affected and the voltages and currents in phases B and C remain unchanged. Normally during a fault current should increase and voltages should decrease. In Figures 04 and 05 the voltage and current waveforms look similar.

4. Fault between phase B and Phase C

a)

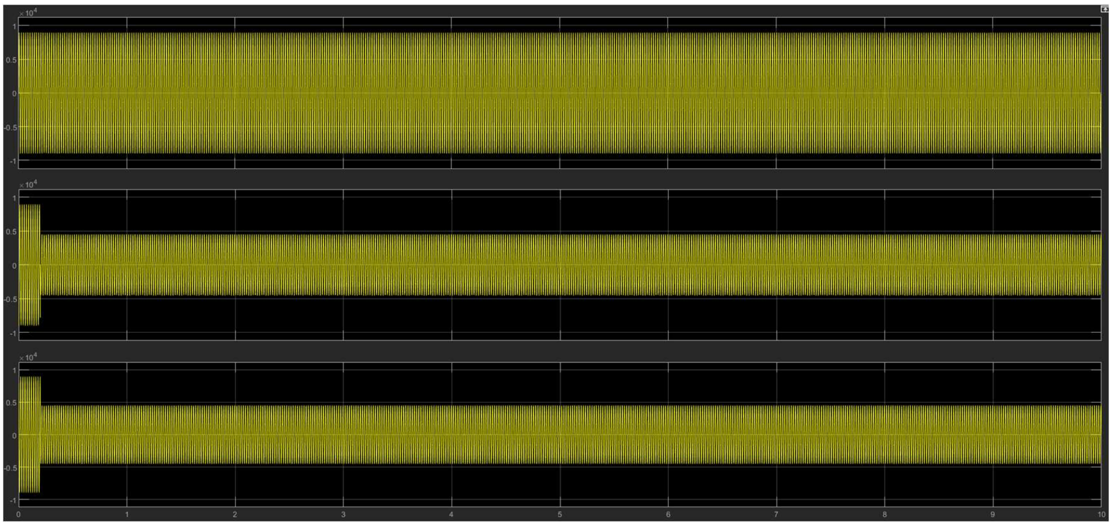
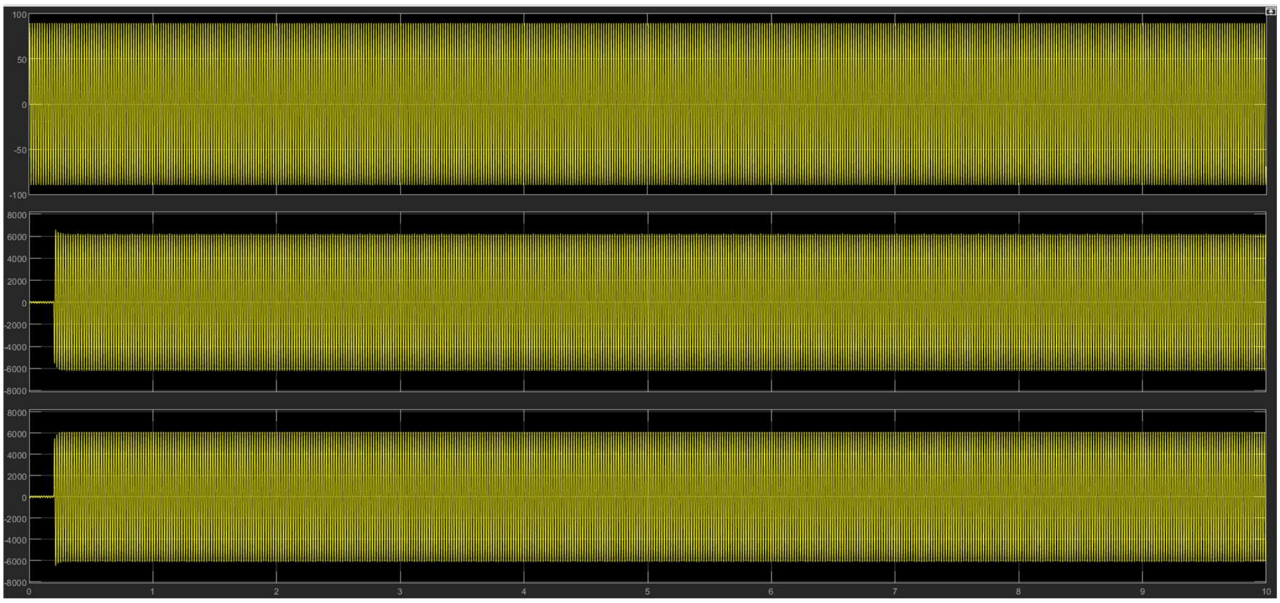


Figure 06: Voltage outputs from scope



b) Phase B and C change and phase A is not changed. In voltage graph phase B magnitude will changes after fault occurred. That magnitude is less than previous magnitude of the phase B. Before fault in current graph, it shows higher value than previous state.

c) The outputs are approximately similar to the results gained by symmetrical component analysis.

DISSCUSSION

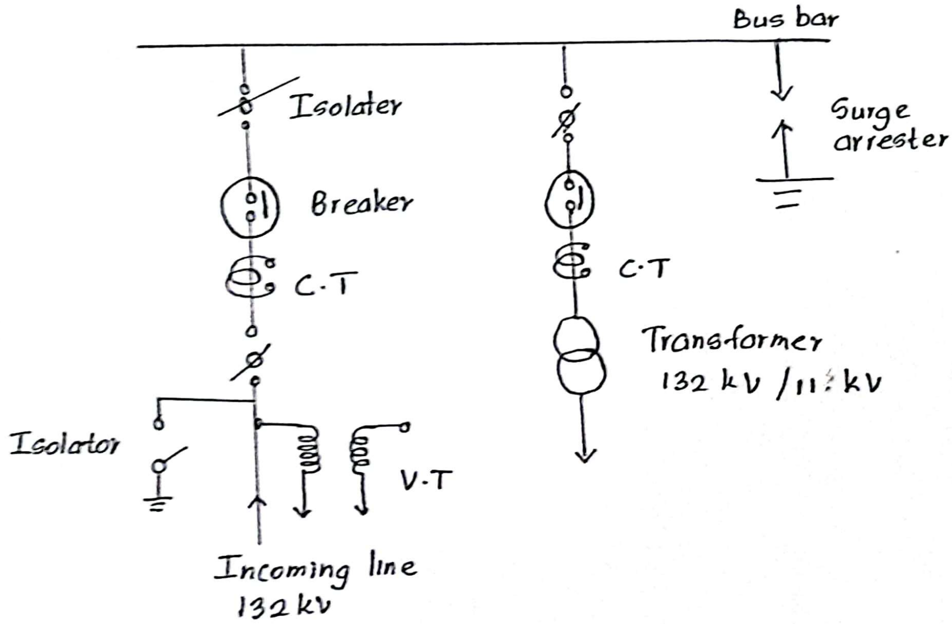
1. Reduces energy losses.
   Shorten the response time.
   It is scalable and flexible in adding additional resources.

2. The short circuit capacity of a system is designed to withstand the fault currents that flow during a short circuit. It is equally important to understand the capacity of the short circuit protective reactors, as they play a role in controlling these fault currents and ensuring the protection system functions correctly. If reactors with a higher short circuit capacity are used, the system may not disconnect properly during a fault, as the fault current might remain too high for the protection system to trigger the necessary disconnection.

3.
   Table01: advantages and disadvantages of breaker and a half scheme and double bus bar single breaker scheme

Breaker and a half scheme	Double bus bar single breaker scheme
Advantage	
• High reliability • All switching is done with breakers. • Simple operation • Flexible • Bus failure does not remove any feeder circuits from service.	• Reliable • Flexible • With only one bus coupler only one circuit breaker can be isolated for maintenance at a time without affecting the load.
Disadvantages	
• One and half circuit breaker is required by each circuit. • The central circuit must be designed to respond effectively to faults occurring on any circuit breaker in the system.	• An additional circuit breaker is required to perform bus coupling in the system.

4.



5. Fault Detection & Isolation
   Identify Faulted Busbar
   Transfer Feeders to Healthy Busbar
   Isolate Faulted Busbar
   Investigate & Clear Fault
   Re-energize Faulted Busbar
   Restore Normal Operation

6. Material -copper

   - Better electricity conductor
   - It has good corrosion resistance

7. There are some issues can be happened in a power system due to the impact of the inverter based power generation. Inverter-based power systems often change output quickly and don't maintain a steady voltage level. This causes instability in the system and makes voltage control difficult. There for voltage fluctuations occur. Due to voltage output from inverter based systems constantly changes traditional protection systems may not work well. Special protection systems are needed to match the characteristics of inverter based generation and keep the system stable. Therefor it impacts for the protection. Voltage dips and flickers can happen with inverter based systems leading to equipment damage and reduced performance in the power system. These issues affect the quality of power being supp