Fault Analysis

Prof. M VENKATESWARA RAO

Dept. of EEE,

JNTUA College of Engineering, Kalikiri

Chittoor District, A P, India

Outline of Presentation

- ❖ Introduction
- ❖ Types of Faults
- ❖ Symmetrical Fault Analysis
- ❖ Sequence components
- ❖ Sequence Networks
- ❖ Zero sequence Impedance of Transformers
- ❖ Unsymmetrical Fault Analysis
- ❖ Previous years GATE questions

Introduction

- A fault in a power system or circuit is a failure which interferes with the normal flow of current
- The faults are associated with abnormal change in current, voltage and frequency of the power system
- In general faults occur in power system networks due to insulation failure of equipments, flashover of lines initiated by a lightning stroke, or due to accidental faulty operation

Need for fault calculation

- ❖ When the fault occur in a part of power system, heavy current flows in that part of circuit which may cause permanent damage to the equipments

- ❖ The selection of the circuit breaker depends on the current flowing immediately after the fault occurs

- ❖ The estimation of these currents for various types of faults at various locations in the system is called fault calculation

- ❖ The data obtained from fault calculations are also used to determine the settings of the relay which control the circuit breakers

Types of Faults

- The faults can be broadly classified into

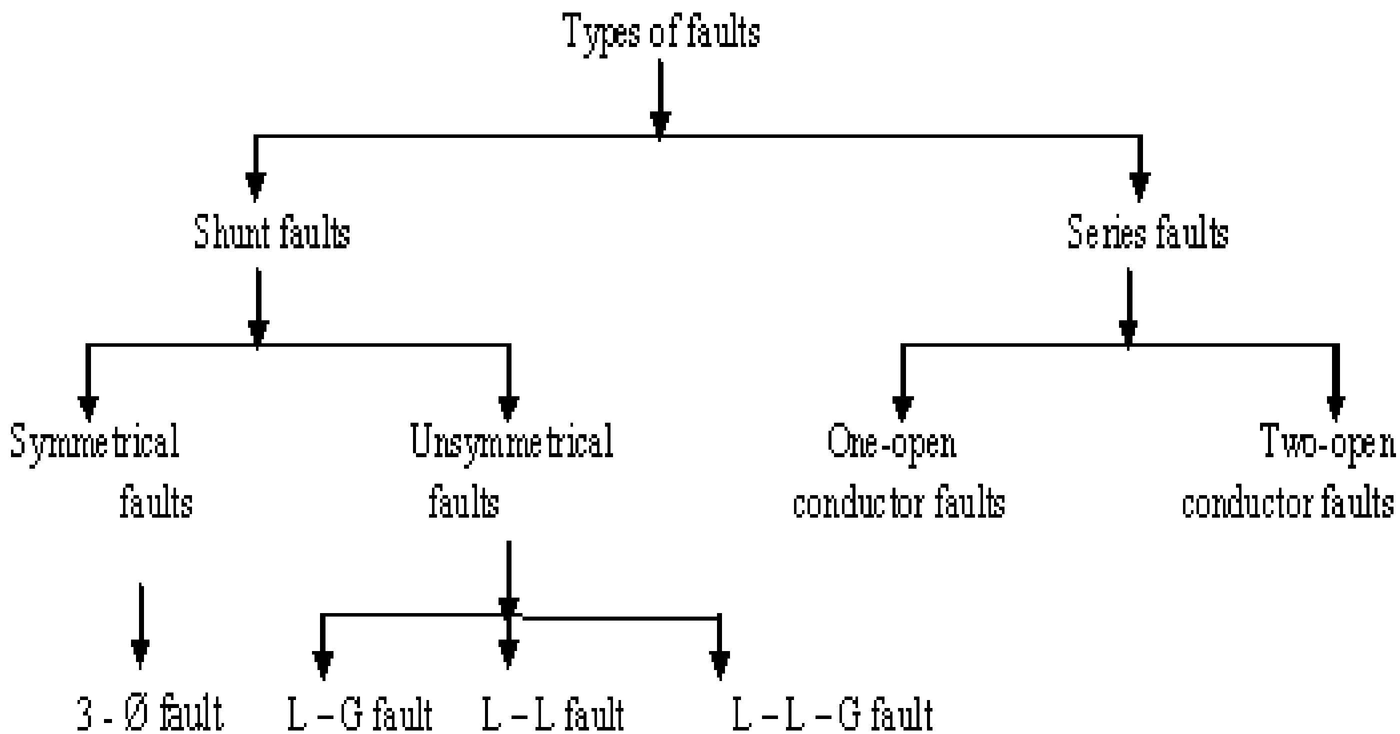
  a) Shunt faults (short circuit)

  b) Series faults (open conductors)

- The shunt type of faults involves short circuit between conductor and ground or short circuit between two or more conductors. *The shunt faults are characterized by increase in current and fall in voltage and frequency*

- The series faults may occur with one or two broken conductors which creates open circuits. *The series faults are characterized by increase in voltage and frequency and fall in current in the faulty phase*

Types of Faults (contd...)



Types of Faults (contd...)

- Occurrence of faults in the power systems in the order of increasing is as follows:

  - 3-Phase fault - 5%
  - Double line to ground fault - 10%
  - Line to line fault - 15%
  - Single line to ground fault - 70%

Types of Faults (contd...)

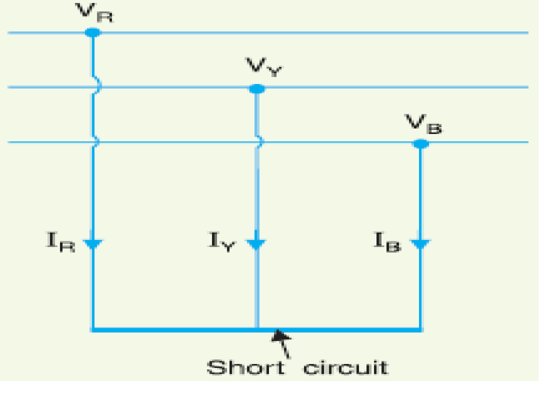
❖ The various faults in the order of increasing severity are as follows:

- Open conductor fault
- L-G fault
- L-L fault
- L-L-G fault
- 3-Ø fault

Symmetrical Fault Analysis

❖ That fault on the power system which gives rise to symmetrical current (i.e. equal fault currents in the lines with 120^0 displacement) is called a symmetrical fault.

❖ The symmetrical fault occurs when all the three conductors of a 3-Ø line are brought together simultaneously into a short circuit condition as shown in the Fig.



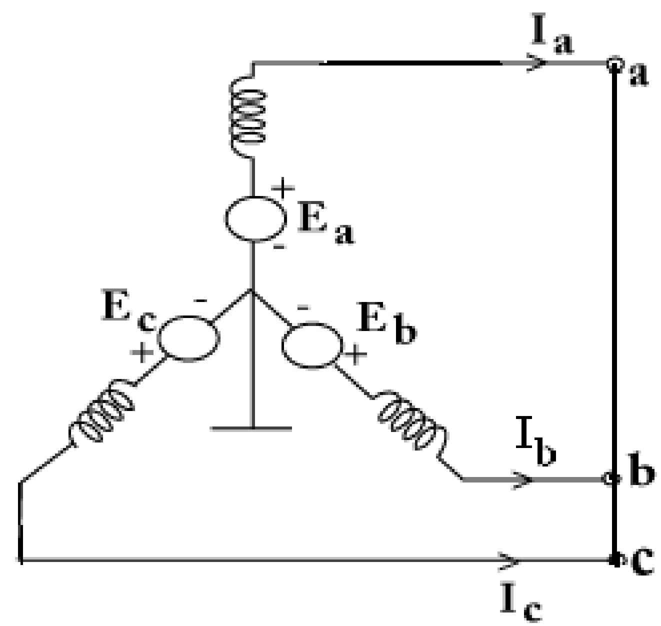
Symmetrical Fault Analysis (contd…)

3-phase Fault :

❖ The boundary conditions are

$$V_a = V_b = V_c$$

$$I_a + I_b + I_c = 0$$



❖ The Symmetrical fault conditions are analyzed on per phase basis using Thevenin's Theorem or Bus Impedance Matrix

Sequence Components

❖ An unbalanced system of ‘n’ related vectors can be resolved into ‘n’ system of balanced vectors called Symmetrical components of original vectors

❖ In a Three phase system, the three unbalanced vectors either Va, Vb, Vc or Ia, Ib, Ic can be resolved into three balanced system of vectors. The vectors of the balanced system are called Symmetrical components of the original system

❖ The symmetrical components of Three Phase system are as follows:

Positive Sequence Components

Negative Sequence Components

Zero Sequence Components

Sequence Components (contd...)

1. **Positive sequence components:**
   - ✓ Equal in magnitude
   - ✓ 120 degrees phase angle exists with same phase sequence of original vectors
   - ✓ occurs before and after fault

   Importance: Relay and circuit breaker operates on positive sequence components

2. **Negative sequence components:**
   - ✓ Equal in magnitude
   - ✓ 120 degrees phase angle exists with opposite phase sequence of original vectors
   - ✓ Occurs only during fault

   Importance: Synchronous Generator is protected from unbalanced condition by using negative sequence relay

Sequence Components (contd...)

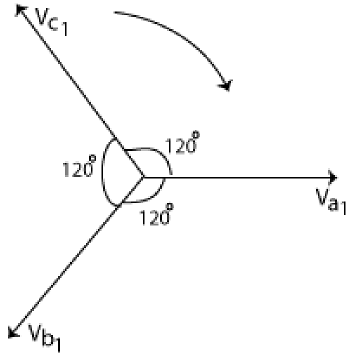
3. Zero sequence components:

- ✓ Equal in magnitude, No phase difference
- ✓ Occurs only when neutral is grounded and fault occurred with grounded

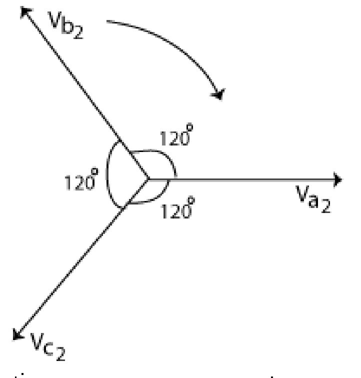
Importance:

zero sequence components are used in the calculation of leakage Flux.

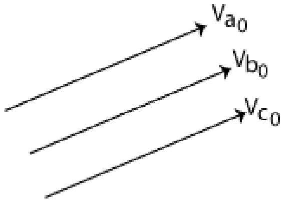
Sequence Components (contd...)



Positive sequence component



Negative sequence component



Zero sequence component

The operator ' a ' is defined as

$$a = Cos\,120° + j\,Sin\,120° \;\; = -0.5 + j0.8666$$

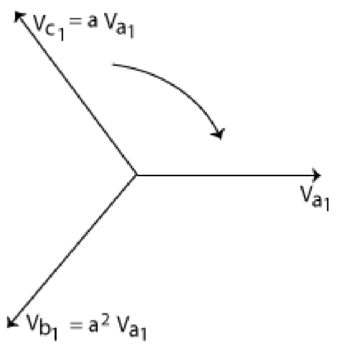
$$a^2 = Cos\,120° - j\,Sin\,120° \;\; = -0.5 - j0.8666$$

$$a^3 \; = 1$$

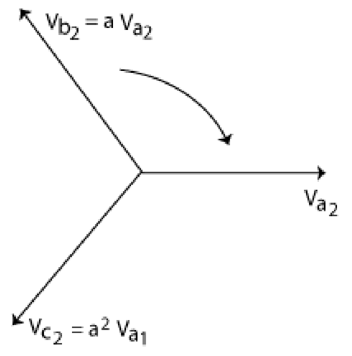
$$1 + a + \; a^2 = 0$$

Sequence Components (contd…)

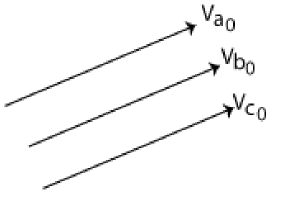
The symmetrical components for voltages are derived as follows :



Positive sequence component



Negative sequence component



Zero sequence component

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} . \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix}$$

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

Sequence Components (contd...)

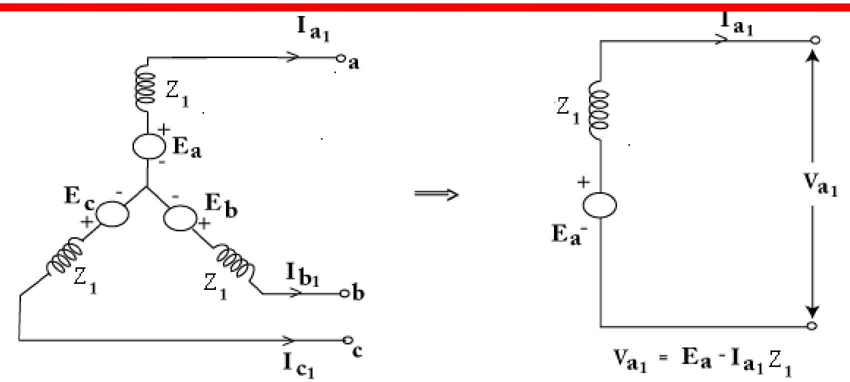
The symmetrical components for currents can be expressed as follows:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} . \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

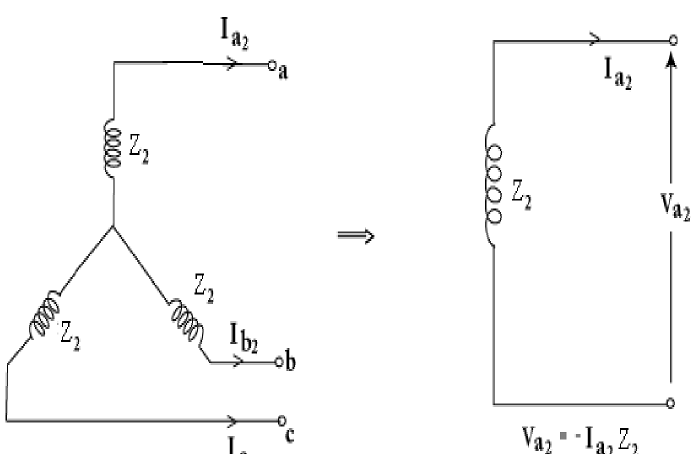
$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

Sequence Networks

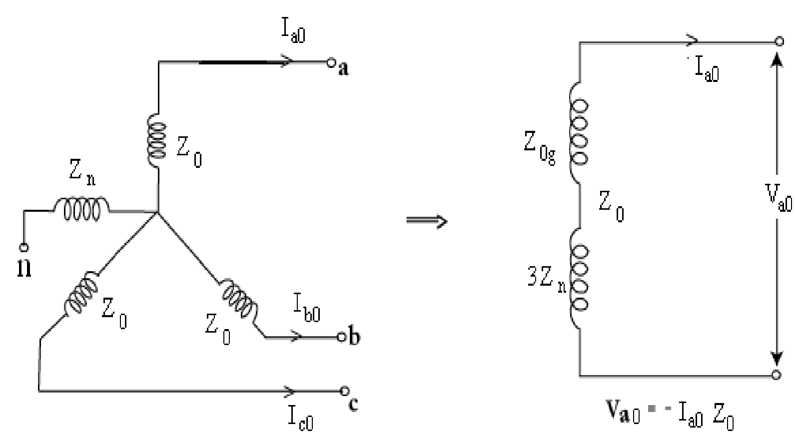
$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$



(a) Positive sequence network



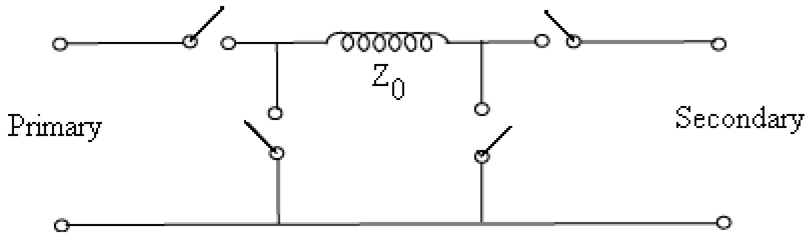
(b) Negative sequence network



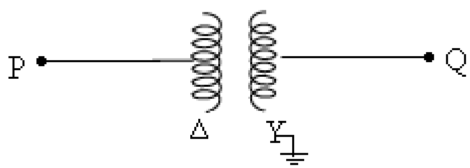
(c) Zero sequence network

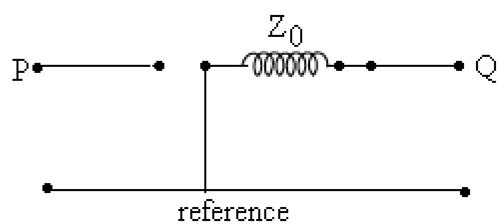
Zero Sequence Networks of Transformer

❖Series and Shunt switch connections for Delta and Star windings of Transformers are represented as follows:



❖consider a Δ/Y Transformer connected with star grounded as shown in the following Fig.

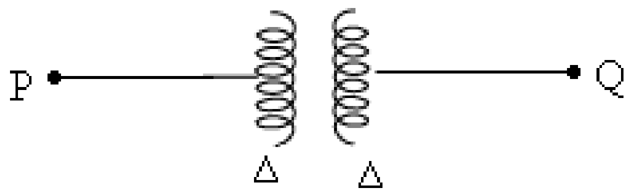
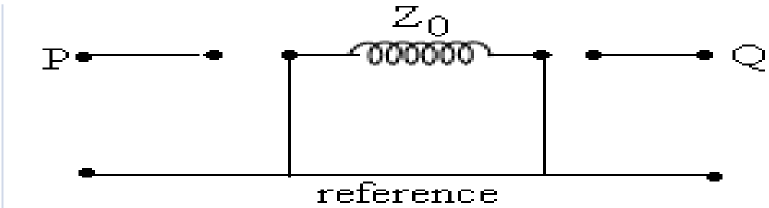
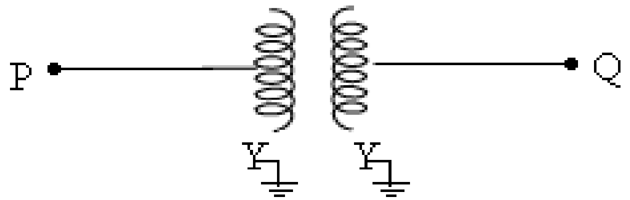
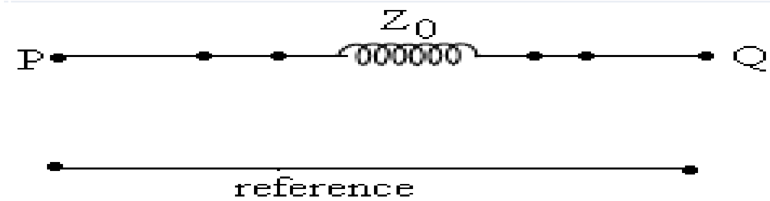
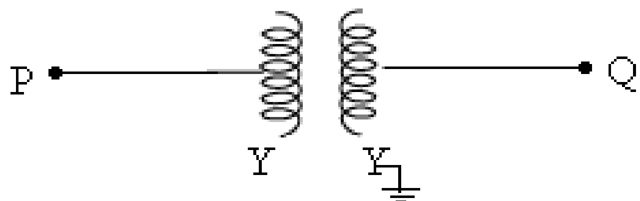
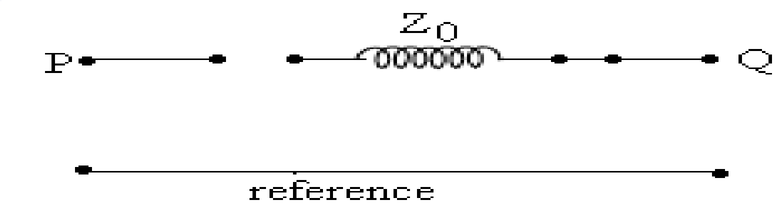
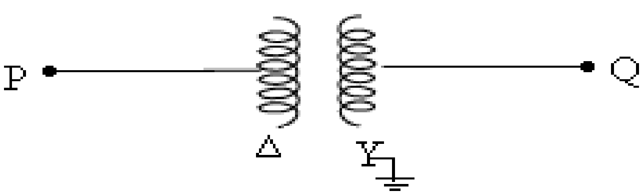
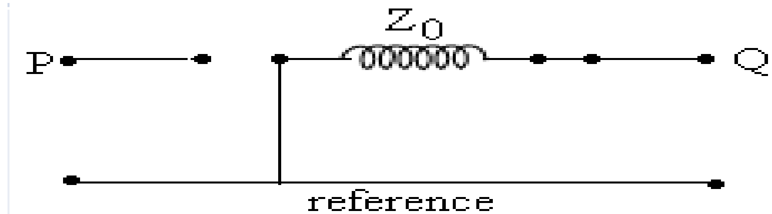
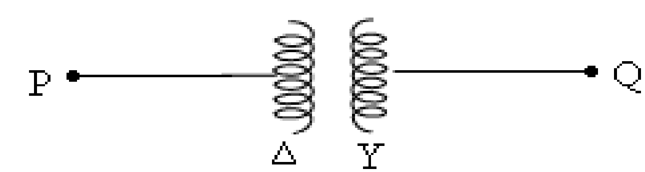
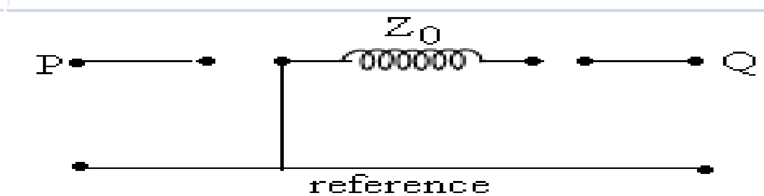




❖Since, the primary is delta connected, the shunt switch of primary side is closed and the series switch is left open

❖Secondary is star grounded, therefore the series switch is closed and the shunt switch is left open.

Zero Sequence Networks of Transformer (contd…)

S.No	Winding symbol	Zero sequence equivalent circuit
1.		
2.		
3.		
4.		
5.		

Unsymmetrical Fault Analysis

❖ The faults on the power system which give rise to unsymmetrical fault currents (i.e. unequal fault currents in the lines with unequal phase displacement) are known as unsymmetrical faults.

❖On the occurrence of an unsymmetrical fault, the currents in the three lines become unequal and so there is a phase displacement among them.

❖ There are three ways in which unsymmetrical faults may occur in a power system

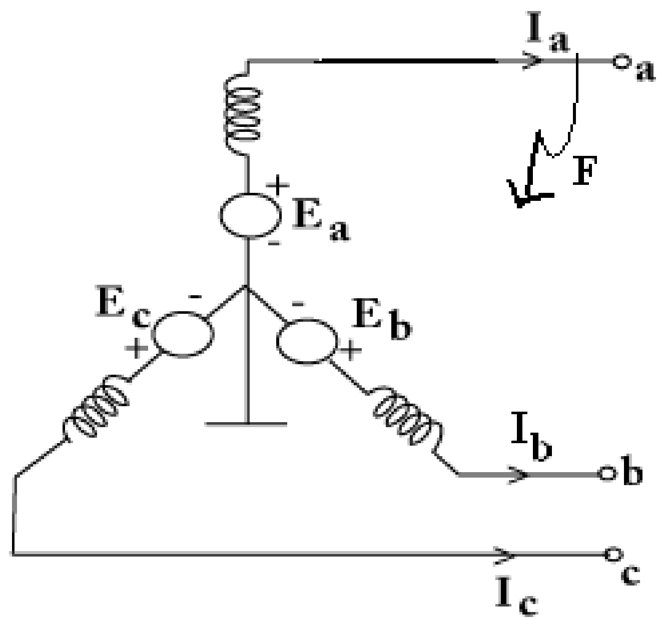
- ➢Single line-to-ground fault (L-G)
- ➢Line-to-line fault (L-L)
- ➢Double line-to-ground fault (L-L-G)

Unsymmetrical Fault Analysis (contd.)

Line to Ground Fault(L-G) :

Case (a): Without fault impedance

Let us assume an L-G fault occurs on phase-a as shown below



The boundary conditions are

$V_a = 0$; $I_b = 0$; $I_c = 0$

The fault current is

$I_f = I_a$

Unsymmetrical Fault Analysis (contd...)

❖ The fault current is given by

$$I_f = I_a = 3I_{a1} = \frac{3E_a}{Z_0 + Z_1 + Z_2}$$

❖ The sequence network equations are given by,

$$V_{a0} = -I_{a0}Z_0$$
$$V_{a1} = E_a - I_{a1}Z_1$$
$$V_{a2} = -I_{a2}Z_2$$

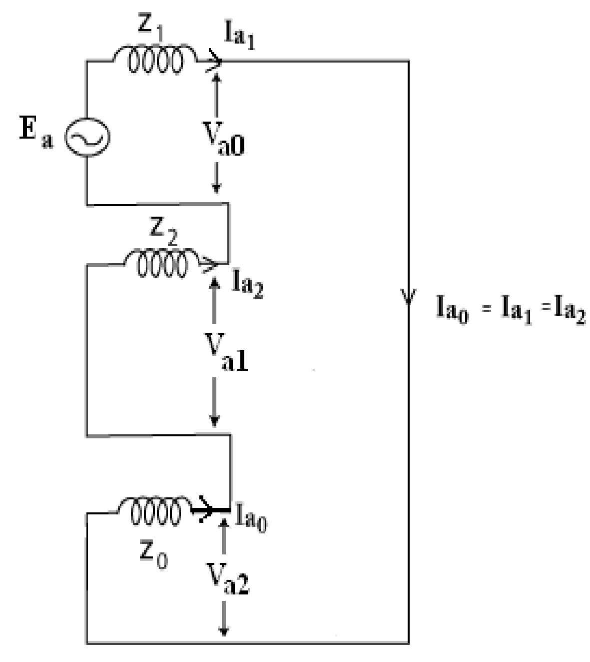
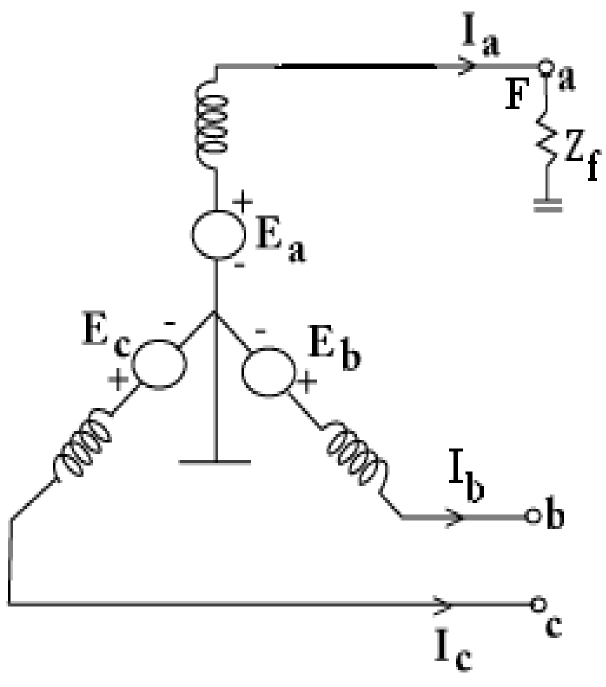


Fig: The equivalent circuit of generator during L-G fault

Unsymmetrical Fault Analysis (contd...)

Case (b): With fault impedance (Z_f) :

Let us assume an L-G fault occurs on phase-a as shown below



The boundary conditions are

$V_a = I_a Z_f$; $I_b = 0$; $I_c = 0$

The fault current is

$I_f = I_a$

Unsymmetrical Fault Analysis (contd...)

❖ The fault current is

$I_f = I_a = I_{a0}+I_{a1}+I_{a2}=3I_{a1}$

$$I_f = I_a = 3I_{a1} = \frac{3E_a}{Z_0 + Z_1 + Z_2 + 3Z_f}$$

❖ The sequence network equations are given by

$$V_{a0} = -I_{a0}Z_0$$
$$V_{a1} = E_a - I_{a1}Z_1$$
$$V_{a2} = -I_{a2}Z_2$$

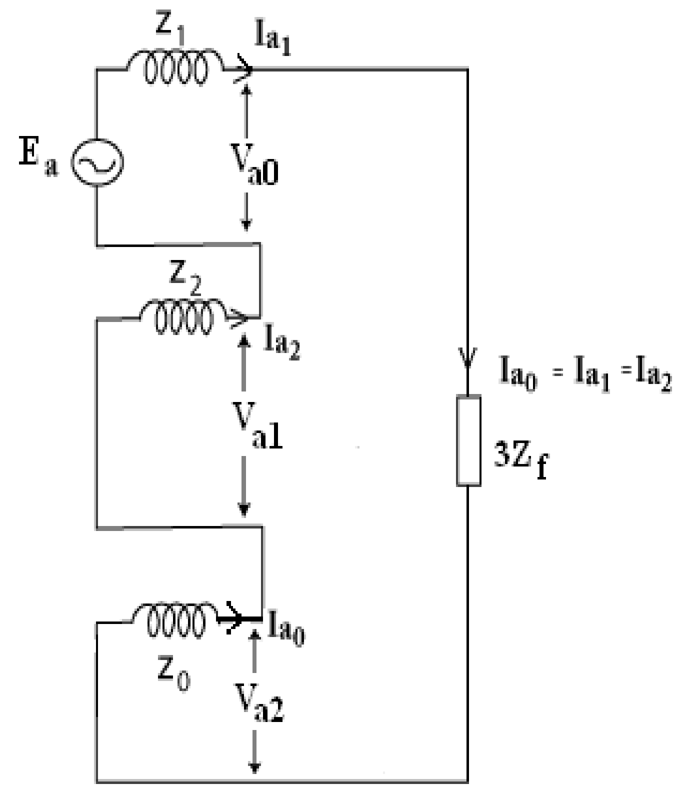


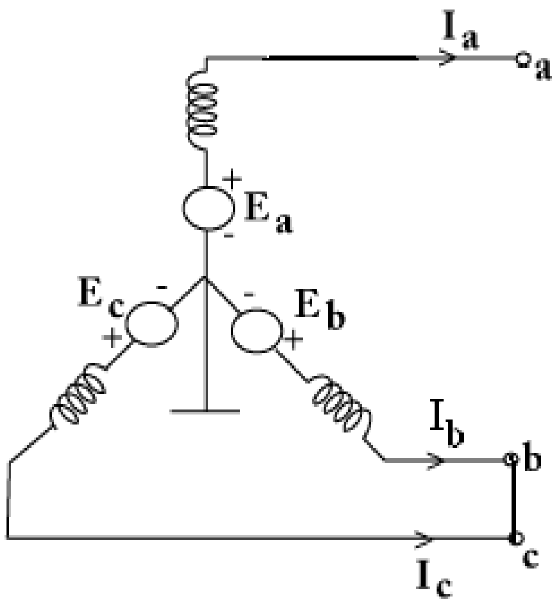
Fig: Equivalent circuit of generator during L-G fault with fault impedance

Unsymmetrical Fault Analysis (contd...)

Line to line Fault (L-L) :

Case (a): Without fault impedance

Let us assume an L-L fault occurs on phase-b and phase-c as shown below



The boundary conditions are

$$V_b = V_c, \quad I_a = 0$$

$$I_b + I_c = 0 \Rightarrow I_b = -I_c$$

Unsymmetrical Fault Analysis (contd...)

❖ The fault current is given by

$$\Rightarrow I_f = I_b = -j\sqrt{3}I_{a1} = \frac{-j\sqrt{3}E_a}{Z_1+Z_2}$$

❖ The sequence network equations are given by

$$V_{a1}=V_{a2}$$

$$E_a - I_{a1}Z_1 = -I_{a2}Z_2$$

$$E_a = I_{a1}Z_1 - I_{a2}Z_2 = I_{a1}\left(Z_1+Z_2\right)$$

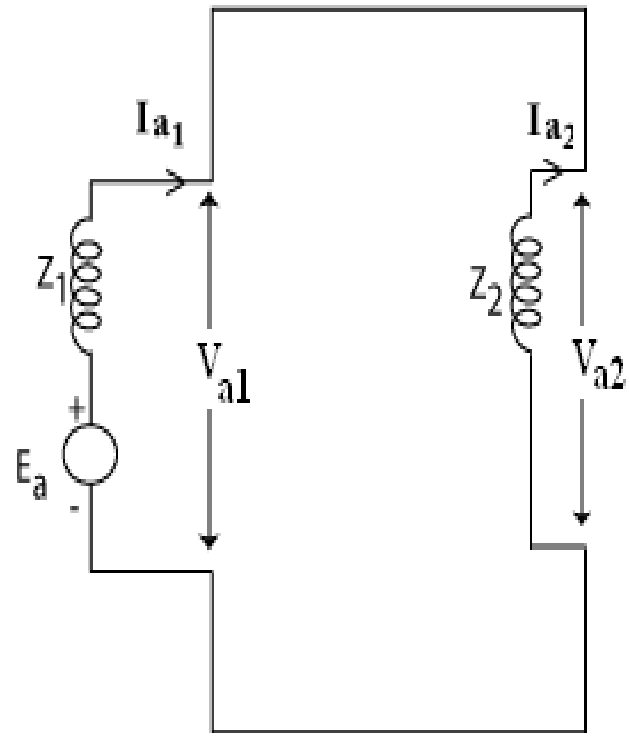
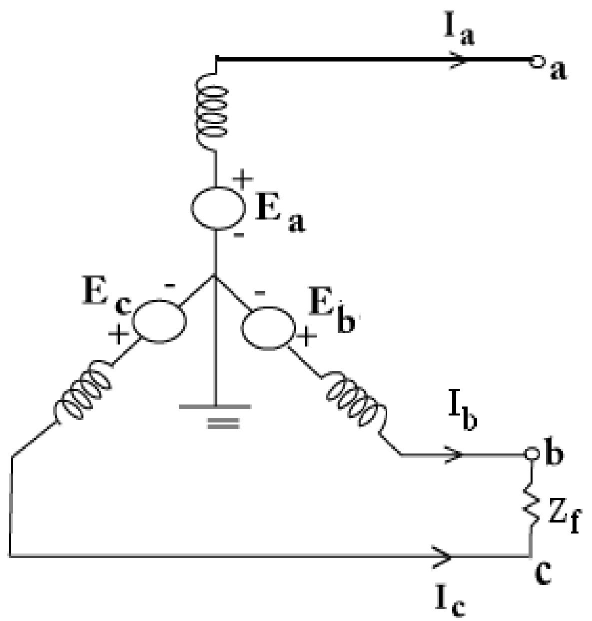


Fig: The equivalent circuit of generator during L-L fault without fault impedance

Unsymmetrical Fault Analysis (contd…)

Case (b): With fault impedance :

Let us assume an L – L fault occurs on phase-b and phase-c as shown below



The boundary conditions are

$$V_b = V_c + I_b Z_f, \quad I_a = 0$$

$$I_b + I_c = 0 \Rightarrow I_b = -I_c$$

Unsymmetrical Fault Analysis (contd.)

❖ The fault current is given by

$$\Rightarrow I_f = I_b = -j\sqrt{3}I_{a1} = \frac{-j\sqrt{3}E_a}{Z_1 + Z_2}$$

❖ The sequence network equations are given by

$$\Rightarrow V_{a1} - V_{a2} = I_{a1}Z_f$$

$$E_a - I_{a1}Z_1 + I_{a2}Z_2 = I_{a1}Z_f \;\left(\because \textit{From sequence network quations}\right)$$

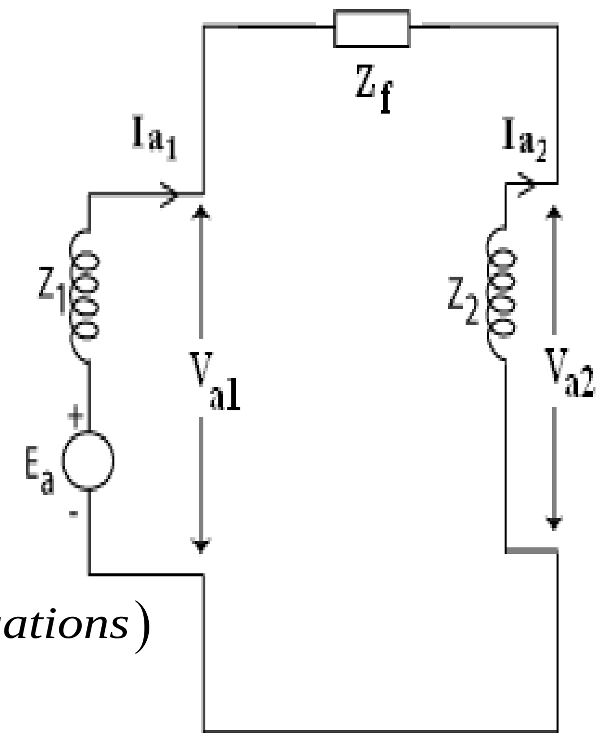
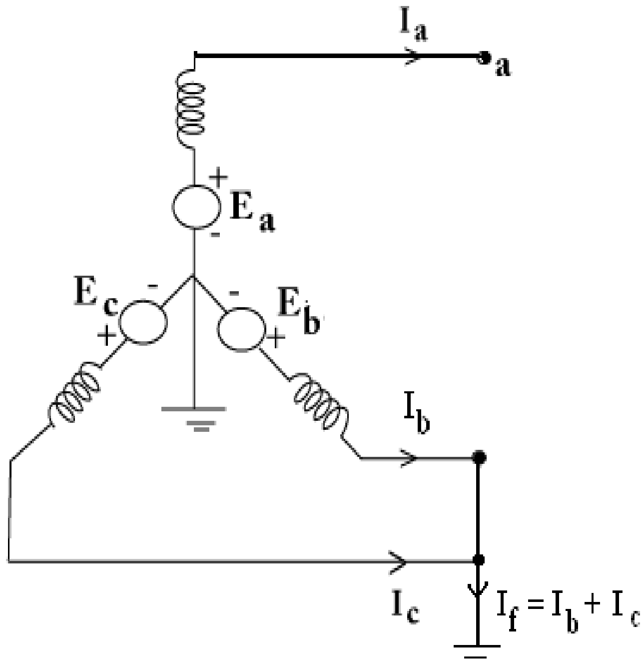


Fig: The equivalent circuit of generator during L-L fault with fault impedance

Double line to ground fault (L-L-G fault) :

Case (a): Without fault impedance



❖ The boundary conditions are given by

$$V_c = 0, V_b = 0, I_a = 0$$

❖ The fault current is

$$I_f = I_b + I_c$$

Unsymmetrical Fault Analysis (contd...)

❖ The fault current is given by

$$I_f = I_b + I_c$$

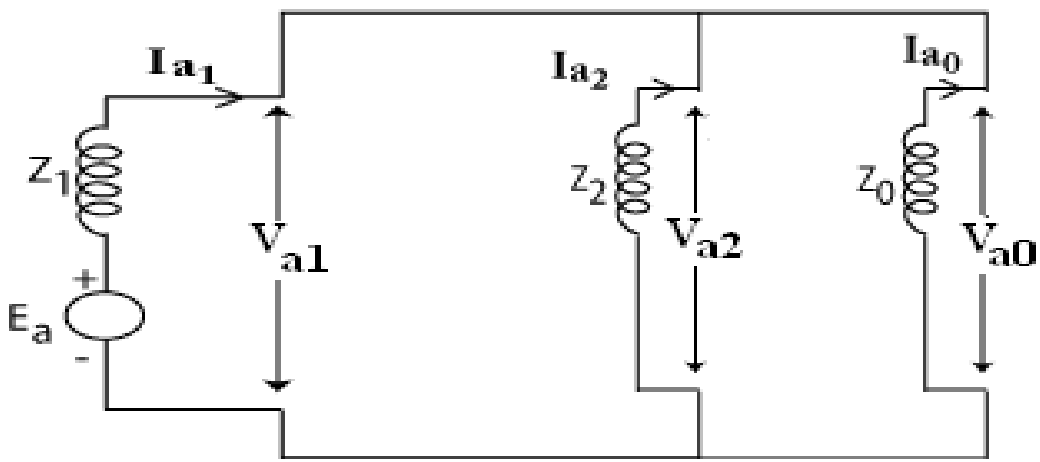
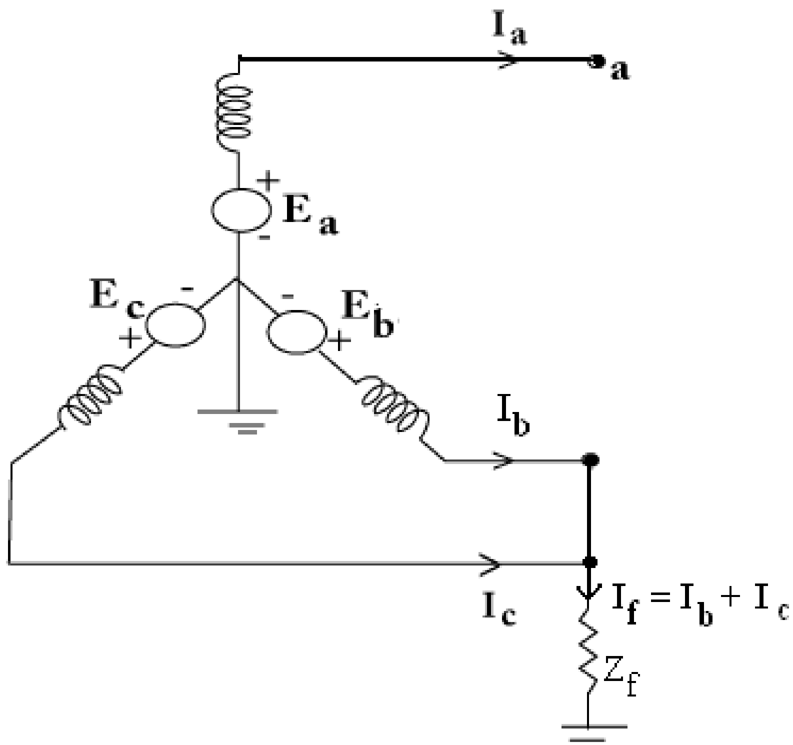


Fig: The equivalent circuit of generator during L-L-G fault without fault impedance

Unsymmetrical Fault Analysis (contd…)

Case(b): With fault impedance (Z_f)



❖ The boundary conditions are

$$I_a = 0$$

$$V_b = V_c = (I_b + I_c) Z_f = 3 I_{a0} Z_f$$

Prof. M Venkateswara Rao, Dept. of EEE, JNTUA College of Engineering, Kalikiri, Chittoor District, A P, India

Unsymmetrical Fault Analysis (contd...)

- The fault current is given by

$$I_f = I_b + I_c = 3I_{a0}$$

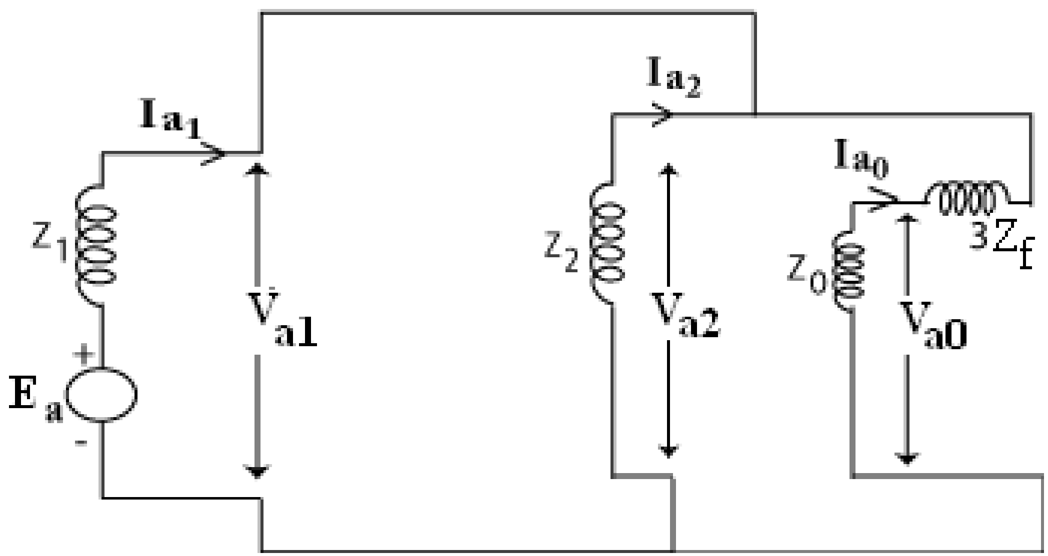


Fig: The equivalent circuit of generator during L-L-G fault with fault impedance

Previous years GATE questions

Q.No.1:

A Three-phase,50 Hz. 4-Pole Induction motor is supplied through an unbalanced source, the frequency of circulating currents that are induced in rotor due to negative sequence components flux is 98 Hz. Calculate the speed of Induction Motor

Sol:

Frequency of circulating current = Rotor frequency-(-Stator frequency)

98 = Rotor frequency + 50

Rotor frequency = 98-50

= 48 hz

Speed of Induction Motor = 120*48/4

= 144 RPM

Previous years GATE questions (contd...)

Q.No.2:

Four Generators are connected in parallel having rating of each generator is 100 MVA,11KV, Z_1=0.12 pu. A symmetrical fault takes place at common busbar. The short circuit MVA of fault is

Sol:

Short circuit MVA = MVA base/Z_1 eq.

Z_1 eq. = (0.12/4) =0.03

Hence Short circuit MVA = 100/0.03 = 3333.33

Previous years GATE questions (contd…)

Q.No. 3:

The sequence impedance of generator in pu are $Z_1=Z_2=0.15$, $Z_0=0.05$. The neutral of generator is grounded by impedance. The fault current of LG fault is same as that of LLL fault. The per unit impedance of neutral grounding is…..

Q. No. 3. Sol:-

$Z_1 = J0.15$, $Z_2 = J0.15$, $Z_0 = J0.05$

I_{fault} for L-G Fault $= \dfrac{3E_a}{Z_1 + Z_2 + Z_0 + 3Z_f}$

For LLL Fault (3-ϕ) $I_{fault} = \dfrac{E_a}{Z_1} = \dfrac{1}{J0.15}$

when both Fault currents are equal

$$\frac{(3)(1)}{J0.15 + J0.15 + J0.05 + 3(Z_f)} = \frac{1}{J0.15}$$

$\Rightarrow Z_f = 0.03$ pu

Q.No. 4:

The positive negative and zero sequence impedance of 125 MVA, Three phase, 15.5KV Star grounded, 50 Hz generator are j0.1 pu, j0.05pu, j0.01pu respectively on machine rating base. The machine is unloaded and working at rated terminal voltage. If grounding impedance of generator is j0.01pu, then calculate magnitude of fault current in KA, for a B-phase to ground.

Q.No.4 - Sol :-

$\sqrt{3}\, V_{R(L-L)}\, I_R = 125\times10^6$ VA

$$\Rightarrow I_R = \frac{125\times10^6}{\sqrt{3}\times 15.5\times10^3} = 4.656\text{ KA}$$

$Z_1 = j0.1,\ Z_2 = j0.05,\ Z_0 = j0.01,\ Z_f = j0.01$

For L-G Fault with impedance

$$I_{Fault} = 3I_{a1} = \frac{3E_a}{Z_0+Z_1+Z_2+3Z_f}$$

$$= \frac{3\times 1}{j0.1+j0.05+j0.01+3(0.01)}$$

$$= 15.79\text{ pu}$$

$\therefore$ Actual current $= (I_f \text{ in pu})(I_R)$

$= (4.656\text{ KA})(15.79\text{ pu})$

$= 73.51$ KA

Previous years GATE questions (contd...)

Q.No. 5:

The sub-transient current of an Alternator for a balanced fault is 20 pu. A Series Reactor is connected to the Alternator to reduce the sub-transient current is 5.0 pu. The Reactance of the Reactor in pu is...

Sol. for Q.No.5)

For Balanced (LLL Fault) $I_{Fault} = \frac{E_a}{Z_1} = \frac{1.0}{Z_1}$

$\Rightarrow Z_1 = \frac{1.0}{I_{Fault}} = \frac{1.0 \text{ pu}}{20 \text{ pu}} = 0.05$

Since the sub-transient current is limited to 5 pu

But $\therefore I_{Fault} = \frac{E_a}{Z_1 + \text{Reactance of Reactor}}$

$\Rightarrow 5 = \frac{1.0}{0.05 + \text{Reactance of Reactor}}$

$\Rightarrow$ Reactance of Reactor $= 0.15$ pu

Queries ???

Thank You