Nadar Saraswathi College of Engineering & Technology

NSCET E-LEARNING PRESENTATION

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ELECTRICAL AND ELCTRONICS ENGINEERING

III rd YEAR / V th SEMESTER

EE8501 – Power System Analysis

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UNIT 04 – Unsymmetrical Fault Analysis

Your positive action combined with positive thinking results in success.

-Shiv Khera

UNIT-4

- Symmetrical components
- Sequence impedances
- Sequence networks
- Analysis of Unsymmetrical faults at generator terminals : LG, LL and LLG
- Unsymmetrical fault occurring at any point in a power system.

Symmetrical Components

Symmetrical components of a 3 phase system

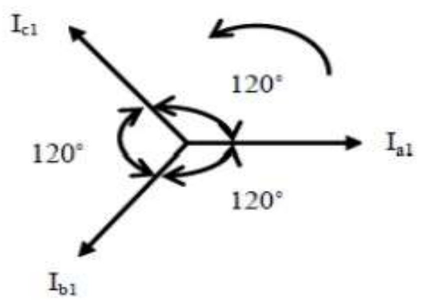
In a 3 phase system, the unbalanced vectors (either currents or voltage) can be resolved into three balanced system of vectors.

- Positive sequence components
- Negative sequence components
- Zero sequence components

Unsymmetrical fault analysis can be done by using symmetrical components.

Positive sequence components

It consists of three components of equal magnitude, displaced each other by 120˚ in phase and having the phase sequence abc .



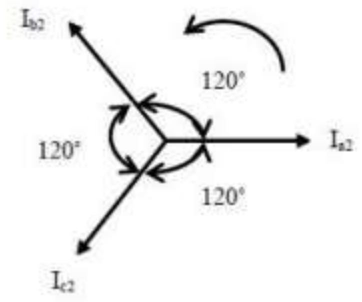
$$I_{a1} = I_{a1}\angle 0^\circ$$

$$I_{b1} = I_{a1}\angle 240^\circ = I_{a1}\angle -120^\circ$$

$$I_{c1} = I_{a1}\angle 120^\circ$$

Negative sequence components

It consists of three components of equal magnitude, displaced each other by 120˚ in phase and having the phase sequence acb .



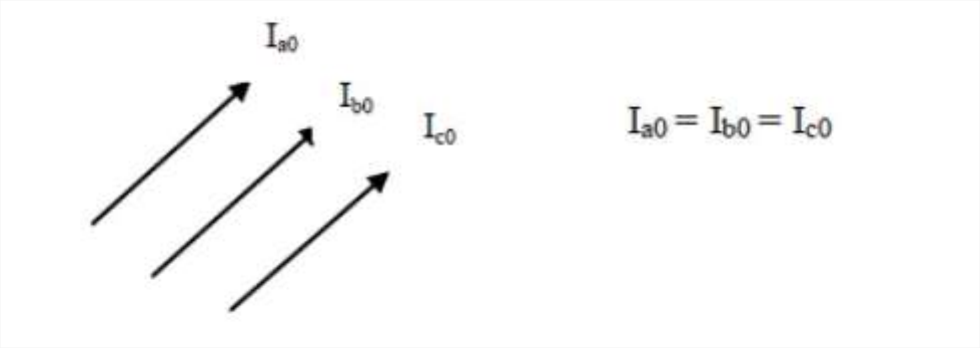
$$I_{a2} = I_{a2}\angle 0^\circ$$

$$I_{b2} = I_{a2}\angle 120^{\circ *}$$

$$I_{c1} = I_{a2}\angle 240^\circ = I_{a2}\angle -120^\circ$$

Zero sequence components

It consists of three phasors equal in magnitude and with zero phase displacement from each other.



Sequence operator

- In unbalanced problem, to find the relationship between phase voltages and phase currents, we use <u>sequence operator</u> ***'a'***.

$$a = 1\angle 120^{\circ} = -0.5 + j0.86$$

$$a^2 = 1\angle 240^{\circ} = -0.5 - j0.866$$

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

<u>Unbalanced currents from symmetrical currents</u>

Let, Ia, Ib, Ic be the unbalanced phase currents

Let, Ia0, Ia1, Ia2 be the symmetrical components of phase a

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

Determination of symmetrical currents from unbalanced currents.

Let, Ia, Ib, Ic be the unbalanced phase currents
Let, Ia0, Ia1, Ia2 be the symmetrical components of phase a

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

Sequence Impedances Sequence Networks

- The sequence impedances are the impedances offered by the power system components or elements to +ve, -ve and zero sequence current.

- The single phase equivalent circuit of power system consisting of impedances to current of any one sequence only is called sequence network.

Problem#1

The phase voltage across a certain load are given as

Va=(176-j132)volts

Vb=(-128-j96)volts

Vc=(-160+j100)volts

Compute positive, negative and zero sequence component of voltage

Solution:

$$V_{a1} = \frac{1}{3}\left(V_a + \beta V_b + \beta^2 V_c\right)$$

$$V_{a2} = \frac{1}{3}\left(V_a + \beta^2 V_b + \beta V_c\right)$$

$$V_{a0} = \frac{1}{3}\left(V_a + V_b + V_c\right)$$

$$V_{a1} = \frac{1}{3}\left\{176 - j132 + 1\angle 120^\circ \times (-128 - j96) + 1\angle 240^\circ (-160 + j100)\right\}$$

$$V_{a1} = (163.24 - j35.10) \text{ Volts}$$

$$V_{a2} = \frac{1}{3}\left\{176 - j132 + 1\angle 240^\circ (-128 - j96) + 1\angle 120^\circ (-160 + j100)\right\}$$

$$V_{a2} = (50.1 - j53.9) \text{ Volts}$$

$$V_{a0} = \frac{1}{3}(176 - j132 - 128 - j96 - 160 + j100) \text{ Volts}$$

Analysis of Unsymmetrical faults at generator terminals : LG, LL and LLG

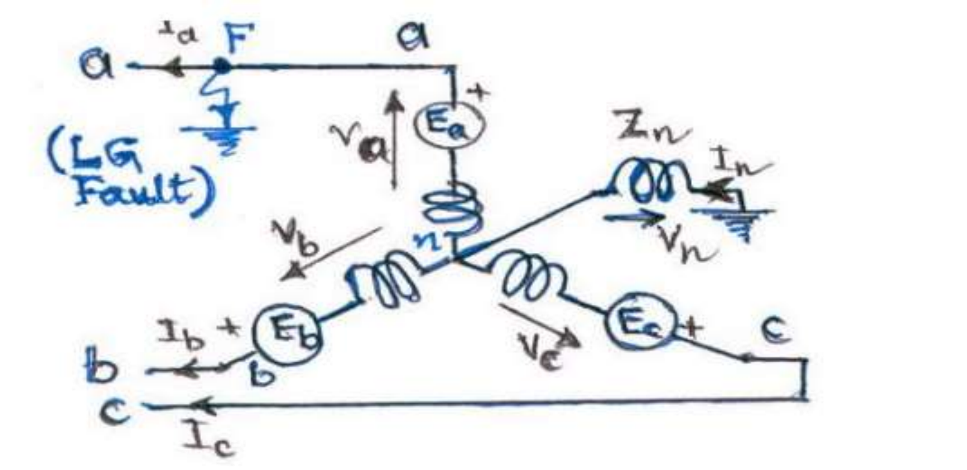
The unsymmetrical faults will have faulty parameters at random. They can be analyzed by using the symmetrical components. The standard types of unsymmetrical faults considered for analysis include the following (in the order of their severity):

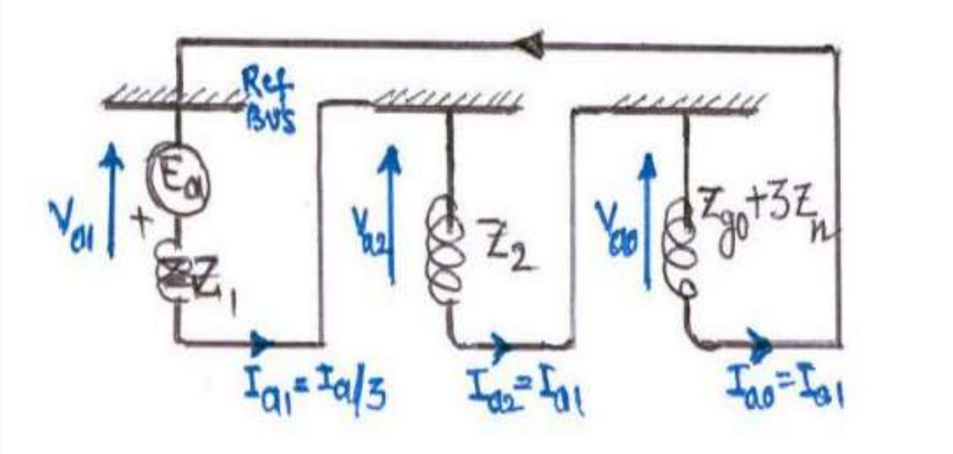
- Line–to–Ground (L-G) Fault
- Line–to–Line (L-L) Fault
- Double Line–to–Ground (L-L-G)Fault and
- Three-Phase–to–Ground (LLL-G) Fault.

SINGLE LINE TO GROUND FAULT ON A CONVENTIONAL (UNLOADED) GENERATOR

A conventional generator is one that produces only the balanced voltages. Let Ea, nd Ec be the internally generated voltages and Zn be the neutral impedance. The fault is assumed to be on the phase'a'.

Ia1 = [Ea/(Z1 + Z2 + Z0)]





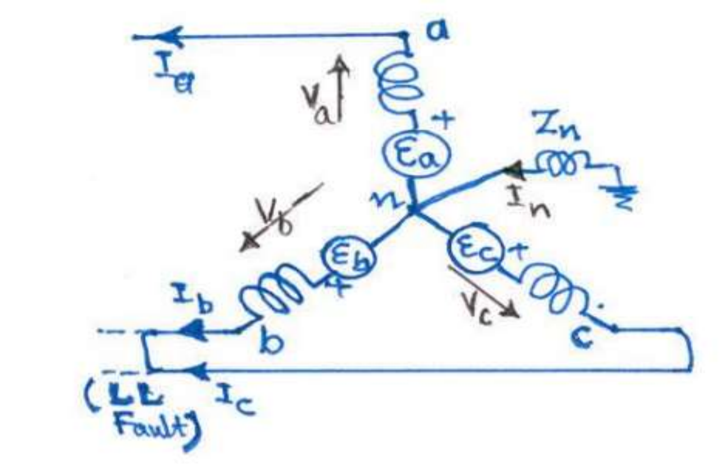
Connection of sequence networks for LG Fault on phase a of a Conventional Generator

- $I_{a1} = I_{a2} = I_{a0} = (I_a/3) = [E_a/(Z_1 + Z_2 + Z_0)]$
- Fault current $I_f = I_a = 3I_{a1} = [3E_a/(Z_1 + Z_2 + Z_0)]$
- $V_{a1} = E_a - I_{a1}Z_1 = E_a(Z_2+Z_0)/(Z_1+Z_2+Z_0)$
- $V_{a2} = - E_aZ_2/(Z_1+Z_2+Z_0)$
- $V_{a0} = - E_aZ_0/(Z_1+Z_2+Z_0)$
- Fault phase voltage $V_a = 0$,
- Sound phase voltages $V_b = a^2V_{a1}+aV_{a2}+V_{a0}$; $V_c = aV_{a1}+a^2V_{a2}+V_{a0}$
- Fault phase power: $V_aI_a^* = 0$, Sound pahse powers: $V_bI_b^* = 0$, and $V_cI_c^* = 0$,
- If $Z_n = 0$, then $Z_0 = Z_{g0}$,
- If Z_n =infinity, then Z_0 = infinity, i.e., the zero sequence network is open so that then, $I_f=I_a=0$

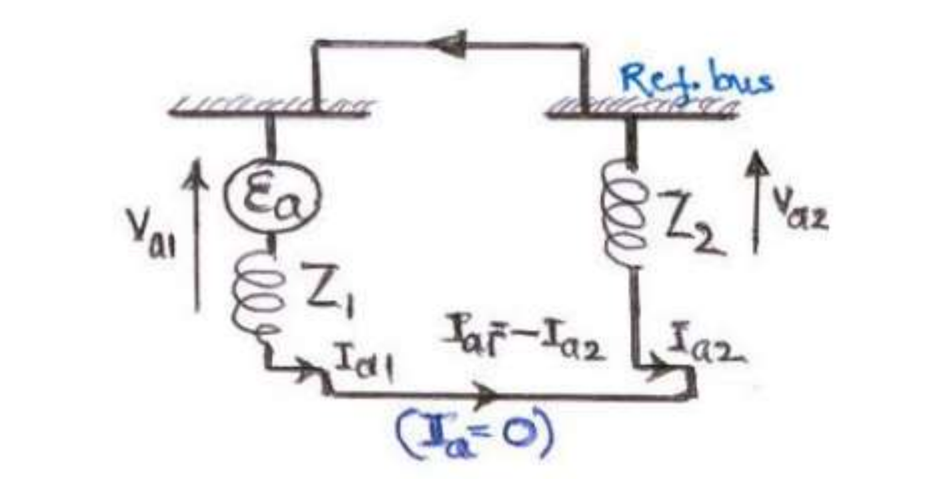
LINE TO LINE FAULT ON A CONVENTIONAL GENERATOR

Consider a line to line fault between phase ‘b’ and phase ‘c’ at the terminals of a conventional generator, whose neutral is grounded through a reactance.

$$I_{a1} = [E_a/(Z_1 + Z_2)]$$



LL fault on a conventional generator



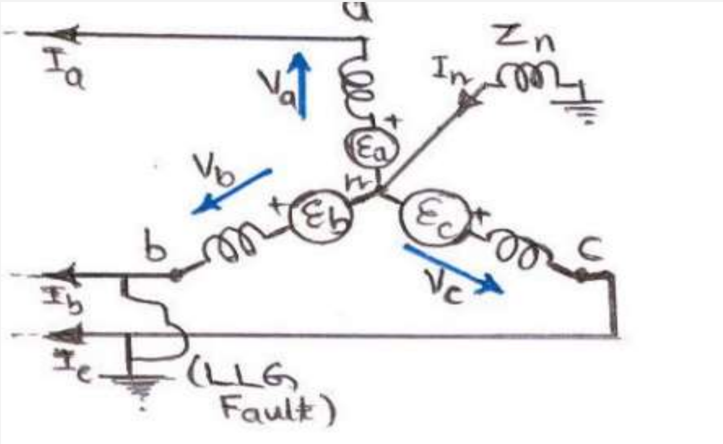
Connection of sequence networks for LL Fault on phase a of a Conventional Generator

- $I_{a1} = - I_{a2} = [E_a/(Z_1 + Z_2)]$ and $I_{a0} = 0$,
- Fault current $I_f = I_b = - I_c = [\sqrt{3}E_a/(Z_1 + Z_2)]$ (since $I_b = (a^2 - a)I_{a1} = \sqrt{3}I_{a1}$)
- $V_{a1} = E_a - I_{a1}Z_1 = E_aZ_2/(Z_1+Z_2)$
- $V_{a2} = V_{a1} = E_aZ_2/(Z_1+Z_2)$ 5. $V_{a0} = 0$,
- Fault phase voltages; $V_b = V_c = aV_{a1}+a^2V_{a2}+V_{a0} = (a+a^2)V_{a1} = - V_{a1}$
- Sound phase voltage; $V_a = V_{a1}+V_{a2}+V_{a0} = 2V_{a1}$
- Fault phase powers are $V_bI_b^*$ and $V_cI_c^*$,
- Sound phase power: $V_aI_a^* = 0$,
- Since $I_{a0}=0$, the presence of absence of neutral impedance does not make any difference in the analysis.

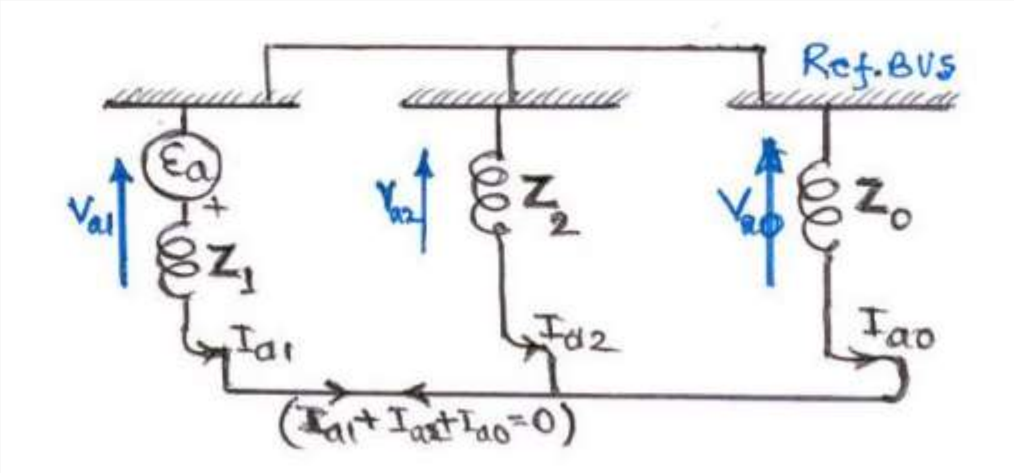
DOUBLE LINE TO GROUND FAULT ON A CONVENTIONAL GENERATOR

Consider a double-line to ground fault at the terminals of a conventional unloaded generator, whose neutral is grounded through a reactance, between phase ‘b’ and phase ‘c’

$$I_{a1} = \{ E_a / [Z_1 + Z_2 Z_0/(Z_2+Z_0)] \}$$



LLG Fault on a Conventional Generator

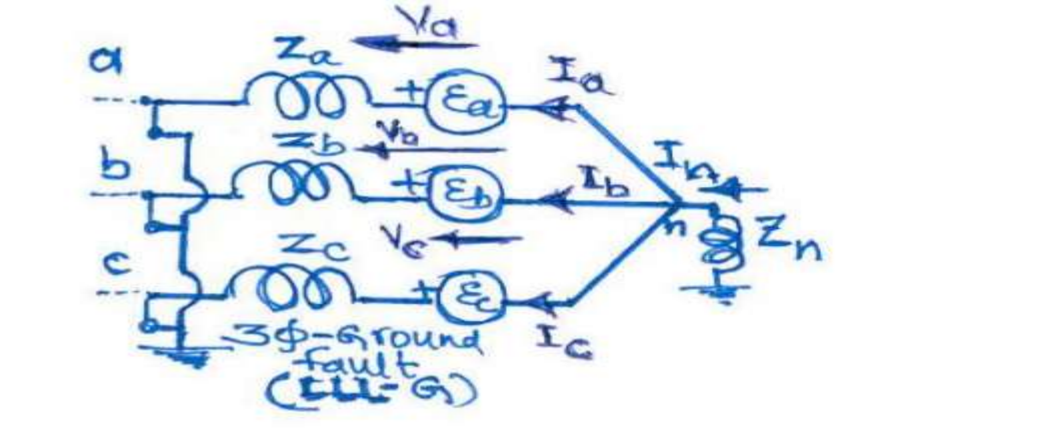


Connection of sequence networks for LLG Fault on phases b and c of a Conventional Generator

- $I_{a1} = \{E_a / [Z_1+Z_2Z_0/(Z_2+Z_0)]\}$; $I_{a2}= -I_{a1}Z_0/(Z_2 + Z_0)$ and $I_{a0} = -I_{a1}Z_2/(Z_2 + Z_0)$,
- Fault current If: $I_{a0}=(1/3)(I_a+I_b+I_c) = (1/3)(I_b+I_c) = I_f/$
- Hence $I_f = 3I_{a0}$ 3. $I_a = 0$, $V_b=V_c=0$ and hence $V_{a1}=V_{a2}=V_{a0}=V_a/3$
- Fault phase voltages;$V_b = V_c = 0$
- Sound phase voltage; $V_a = V_{a1}+V_{a2}+V_{a0} = 3V_{a1}$;
- Fault phase powers are $V_bI_b^* = 0$, and $V_cI_c^* = 0$, since $V_b=V_c=0$
- Healthy phase power: $V_aI_a^* = 0$, since $I_a=0$
- If Z_0=infinity, (i.e., the ground is isolated), then $I_{a0}=0$, and hence the result is the same as that of the LL fault [with Z_0=infinity]

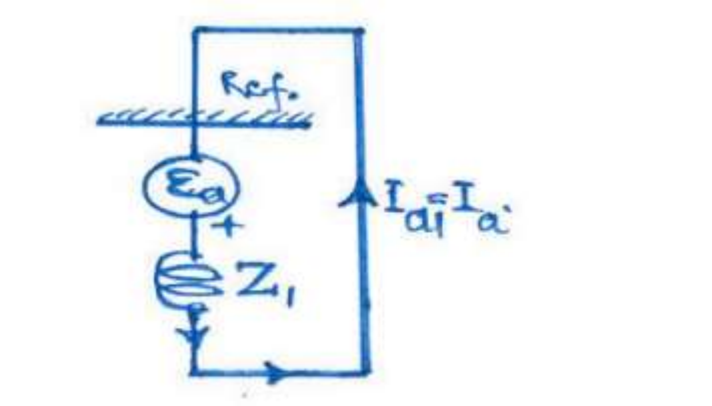
THREE PHASE TO GROUND FAULT ON A CONVENTIONAL GENERATOR

Consider a three phase to ground (LLLG) fault at the terminals of a conventional unloaded generator, whose neutral is grounded through a reactance, between all its three phases a, b and c.



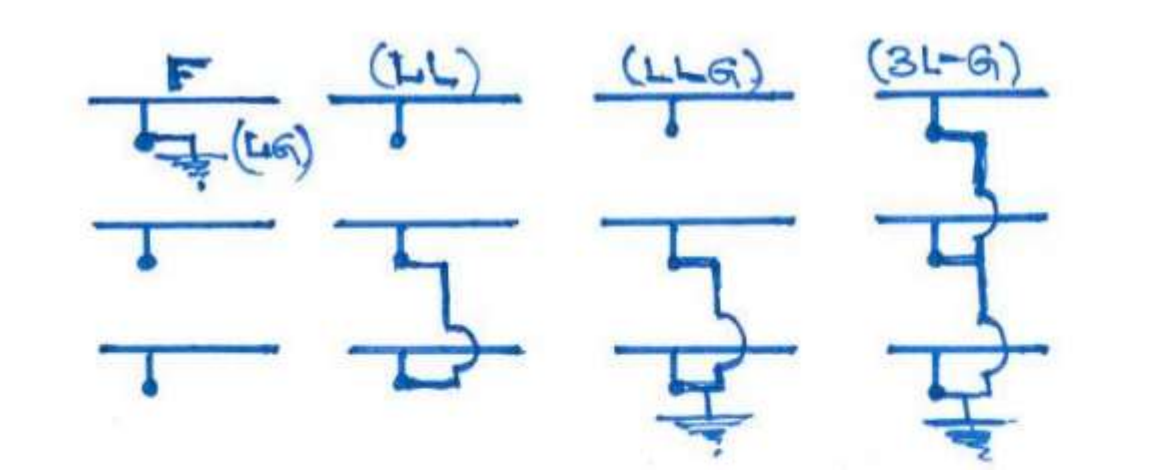
Three phase ground Fault on a Conventional Generator

$I_f = I_{a1} = I_a = (E_a/Z_1)$



Connection of sequence networks for 3-phase ground Fault on phases b and c of a Conventional Generator

UNSYMMETRICAL FAULTS ON POWER SYSTEMS



Unsymmetrical faults in Power Systems

- <u>LG Fault at any point F of a given Power system</u>

Let phase ‘a’ be on fault at F so that then, the c.u.f. would be:

$I_b = 0$; $I_c = 0$; and $V_a = 0$.

Hence the derived conditions under fault would be:

$I_{a1} = I_{a2} = I_{a0} = (I_a/3)$ $I_{a1} = [V_f / (Z_1 + Z_2 + Z_0)]$ and $I_f = 3I_{a1}$

- <u>LL Fault at any point F of a given Power system</u>

Let phases ‘b’ and ‘c’ be on fault at F so that then, the c.u.f. would be:

$I_a = 0$; $I_b = - I_c$; and $V_b = V_c$

Hence the derived conditions under fault would be:

$V_{a1} = V_{a2}$; $I_{a0} = 0$; $I_{a2} = -I_{a1}$ $I_{a1} = [V_f / (Z_1 + Z_2)]$ and $I_f = I_b = - I_c$ $= [\square 3 V_f / (Z_1 + Z_2)]$

- LLG Fault at any point F of a given Power system

Let phases ‘b’ and ‘c’ be on fault at F so that then, the c.u.f. would be:

Ia = 0 and Vb = Vc = 0 Hence the derived conditions under fault would be:

Va1 = Va2 = Va0 = (Va/3)

Ia1 = {Vf / [Z1+Z2Z0/(Z2+Z0)]} Ia2= -Ia1Z0/(Z2 + Z2);

Ia0 = -Ia1Z2/(Z2 + Z2) and

If = 3Ia0

- <u>Three Phase Fault at any point F of a given Power system</u>

Let all the 3 phases a, b and c be on fault at F so that then, the c.u.f. would be:

$V_a = V_b = V_c = 0$, $I_a + I_b + I_c = 0$

Hence the derived conditions under fault would be:

$V_{a1} = V_{a2} = V_{a0} = V_a/3$ $V_{a0} = V_{a1} = V_{a2} = 0$;

$I_{a0} = I_{a2} = 0$, $I_{a1} = [V_f / Z_1]$ and

$I_f = I_{a1} = I_a$

Problem#2:

A three phase generator with constant terminal voltages gives the following currents when under fault: 1400 A for a line-to-line fault and 2200 A for a line-to-ground fault. If the positive sequence generated voltage to neutral is 2 ohms, find the reactances of the negative and zero sequence currents.

Solution:

Case a) Consider the conditions w.r.t. the LL fault:

$$I_{a1} = [E_{a1}/(Z_1 + Z_2)]$$

$$I_f = I_b = - I_c = \sqrt{3}\, I_{a1}$$

$$= \sqrt{3}\, E_{a1} / (Z_1 + Z_2) \quad \text{or}$$

$$(Z_1 + Z_2) = \sqrt{3}\, E_{a1} / I_f$$

i.e., $2 + Z_2 = \sqrt{3}\, [2000/1400]$

Solving, we get, $Z_2 = 0.474$ ohms.

Case b) Consider the conditions w.r.t. a LG fault:

$$I_{a1} = [E_{a1}/(Z_1 + Z_2+Z_0)]$$

$$I_f = 3\ I_{a1}$$

$$= 3\ E_{a1} / (Z_1 + Z_2+Z_0) \quad \text{or}$$

$$(Z_1 + Z_2+Z_0) = 3\ E_{a1} / I_f$$

i.e., $2 + 0.474 + Z_0 = 3\ [2000/2200]$

Solving, we get, $Z_0 = 0.253$ ohms.

Thank you