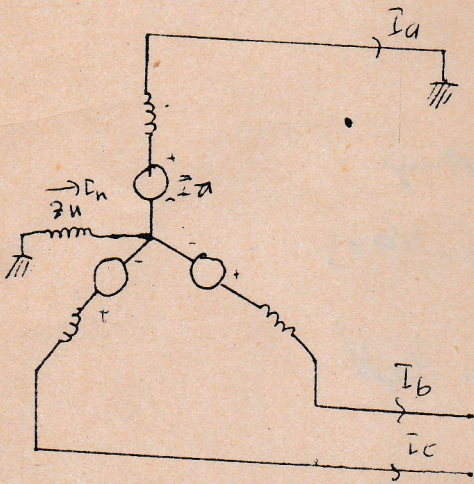


Contoh : II-1

Sebuah generator mempunyai rating 30 MVA, 15 kV, $x'' = x_2 = 10\%$, $x_0 = 5\%$. Generator terhubung Y dan ditanahkan melalui suatu impedansi realitas sebesar $0,4 \Omega$. Apabila terjadi gangguan salinan tunggal ke tanah.

Hitung arus-arus sebelum peralihan per fase yang mengalami gangguan.

Jawab.



$$E_a = 1 \text{ pu}$$

$$Z_1 = j0,1 \text{ pu}$$

$$Z_2 = j0,1 \text{ pu}$$

$$Z_0' = j0,05 \text{ pu}$$

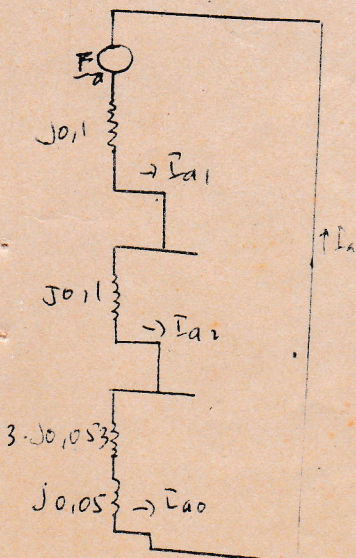
$$Z_n = 0,4 \Omega$$

$$Z_{\text{dasar}} = \frac{(15)^2 \text{ kV}^2}{30 \text{ MVA}} = 7,5 \Omega$$

$$Z_n = \frac{0,4}{7,5} = j0,053 \text{ pu}$$

$$Z_0 = Z_0' + 3Z_n = j0,05 + 3 \cdot j0,053 = j0,209 \text{ pu}$$

Untuk gangguan single line to ground :



$$I_{a0} = I_{a1} = I_{a2} = \frac{E_a}{Z_0 + Z_1 + Z_2}$$

$$= \frac{1}{j0,209 + j0,1 + j0,1}$$

$$= -j2,44 \text{ pu}$$

$$I_a = 3I_{a0} = 3 \cdot -j2,44 = -j7,32 \text{ pu}$$

$$I_b = 0$$

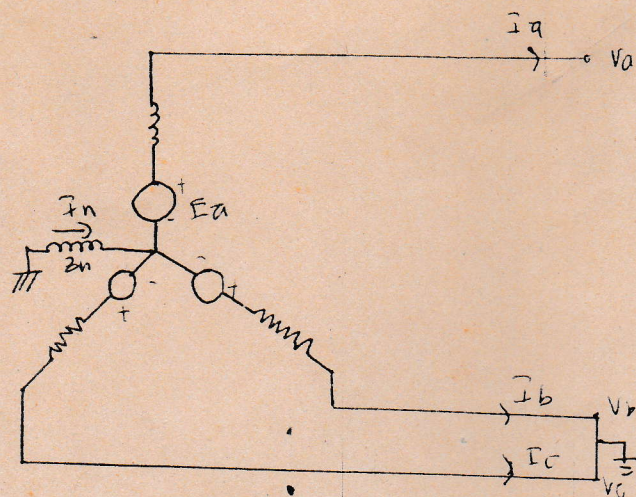
$$I_c = 0$$

$$I_{\text{dasar}} = \frac{30.000}{\sqrt{3} \cdot 15} = 1154 \text{ A}$$

$$I_a \text{ sebenarnya} = 7,32 \times 1154 = 8447,28 \text{ A}$$

1.2. GANGGUAN DUA SALURAN KE TANAH (DOUBLE LINE TO GROUND FAULT)

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Persamaan - persamaan
pada titik gangguan:

$$I_a = 0 \quad (1)$$

$$V_b = 0 \quad (2)$$

$$V_c = 0 \quad (3)$$

dan (2) dan (3) diperoleh:

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

$$V_{a1} = \frac{1}{3} (V_a + aV_b + a^2V_c) = \frac{1}{3} (V_a + 0 + 0) = \frac{V_a}{3}$$

$$V_{a2} = \frac{1}{3} (V_a + a^2V_b + aV_c) = \frac{1}{3} (V_a + 0 + 0) = \frac{V_a}{3}$$

$$V_{a1} = V_{a2} = V_{a0}$$

dan (1)

$$I_a = I_{a1} + I_{a2} + I_{a0} = 0$$

$$I_{a1} = -(I_{a2} + I_{a0})$$

dari persamaan umum:

$$V_{a0} = -I_{a0}Z_0 \Rightarrow I_{a0} = -\frac{V_{a0}}{Z_0} \rightarrow Z_0 = Z'_0 + 3Z_n$$

$$= -I_{a0}(Z'_0 + 3Z_n)$$

$$= -\frac{V_{a0}}{Z'_0 + 3Z_n} = -\frac{V_{a1}}{Z'_0 + 3Z_n}$$

$$V_{a2} = -I_{a2}Z_2 \Rightarrow I_{a2} = -\frac{V_{a2}}{Z_2} = -\frac{V_{a1}}{Z_2}$$

$$I_{a1} = -(I_{a2} + I_{a0}) = -\left(-\frac{V_{a1}}{Z_2} - \frac{V_{a1}}{Z_0}\right)$$

$$= -\left(-\frac{1}{Z_2} - \frac{1}{Z'_0 + 3Z_n}\right)V_{a1}$$

$$I_{a1} = \frac{Z_2 + Z'_0 + 3Z_n}{Z_2 Z'_0 + 3Z_2 Z_n} V_{a1}$$

$$V_{a1} = \frac{Z_2 Z'_0 + 3Z_2 Z_n}{Z_2 + Z'_0 + 3Z_n} I_{a1}$$

$$\frac{1}{Z_2} = \frac{Z'_0 + 3Z_n}{Z_2(Z'_0 + 3Z_n)}$$

$$\frac{1}{Z'_0 + 3Z_n} = \frac{Z_2}{Z_2(Z'_0 + 3Z_n)}$$

carana

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$$V_{a1} = E_a - I_{a1} z_1$$

selanjutnya

$$\frac{z_2 z_0' + 3 z_2 z_n}{z_2 + z_0' + 3 z_n} I_{a1} = E_a - I_{a1} z_1$$

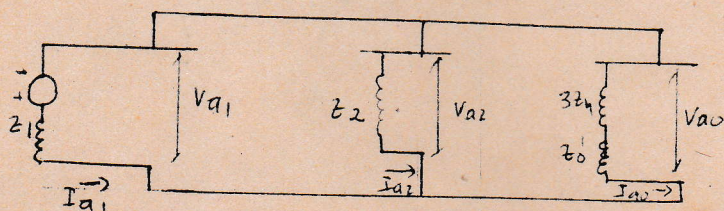
$$\left(\frac{z_2 z_0' + 3 z_2 z_n + z_1 (z_2 + z_0' + 3 z_n)}{z_2 + z_0' + 3 z_n} \right) I_{a1} = E_a$$

$$I_{a1} = \frac{(z_2 + z_0' + 3 z_n) E_a}{z_2 z_0' + 3 z_2 z_n + z_1 (z_2 + z_0' + 3 z_n)}$$

$$= \frac{(z_2 + z_0' + 3 z_n) E_a}{z_2 z_0' + 3 z_2 z_n + z_1 (z_2 + z_0' + 3 z_n)}$$

$$I_{a1} = \frac{E_a}{z_1 + \frac{z_2 z_0' + 3 z_2 z_n}{z_2 + z_0' + 3 z_n}} = \frac{E_a}{z_1 + \frac{z_2 (z_0' + 3 z_n)}{z_2 + z_0' + 3 z_n}}$$

Rangkaian ekvivalennya



$$I_{a2} = - \frac{3 z_n + z_0'}{z_1 + 3 z_n + z_0'} I_{a1}$$

$$= - \frac{(3 z_n + z_0') E_a}{z_1 (z_2 + 3 z_n + z_0') + z_2 (z_0' + 3 z_n)}$$

$$I_{a0} = - \frac{z_2}{z_1 + 3 z_n + z_0'} I_{a1}$$

$$= - \frac{(z_2) E_a}{z_1 (z_2 + 3 z_n + z_0') + z_2 (z_0' + 3 z_n)}$$

arus gangguan :

$$I_f = I_b + I_c$$

$$= (a^2 I_{a1} + a I_{a2} + I_{a0}) + (a I_{a1} + a^2 I_{a2} + I_{a0})$$

$$= I_{a1} (a^2 + a) + I_{a2} (a + a^2) + 2 I_{a0}$$

$$= -I_{a1} - I_{a2} + 2 I_{a0}$$

$$= \frac{-z_2 - 3 z_n - z_0' + 3 z_n - z_0' - 2 z_2}{z_1 z_2 + 3 z_1 z_n + z_1 z_0' + z_2 z_0' + z_2 3 z_n} E_a$$

$$I_f = -3 \frac{z_2}{z_1 z_2 + z_1 (3 z_n + z_0') + z_2 (3 z_n + z_0')} E_a$$

Tegangan - tegangan urutan

$$\begin{aligned}
 V_{a1} &= E_a - I_{a1} z_1 \\
 &= E_a - (z_2 + z_0' + 3z_n) I_{a1} \\
 &= \frac{z_1 z_2 + z_1 (z_0' + 3z_n) + z_2 (z_0' + 3z_n)}{z_1 z_2 + z_1 (z_0' + 3z_n) + z_2 (z_0' + 3z_n)} E_a
 \end{aligned}$$

$$V_{a1} = \frac{z_2 (z_0' + 3z_n)}{z_1 z_2 + z_1 (z_0' + 3z_n) + z_2 (z_0' + 3z_n)} E_a$$

$$V_{a2} = -I_{a2} z_2 = \frac{z_2 (z_0' + 3z_n)}{z_1 z_2 + z_1 (z_0' + 3z_n) + z_2 (z_0' + 3z_n)} E_a$$

$$V_{a0} = -I_{a0} z_0 = \frac{z_2 (z_0' + 3z_n)}{z_1 z_2 + z_1 (z_0' + 3z_n) + z_2 (z_0' + 3z_n)} E_a$$

$$V_{a1} = V_{a2} = V_{a0}$$

Tegangan - tegangan saluran

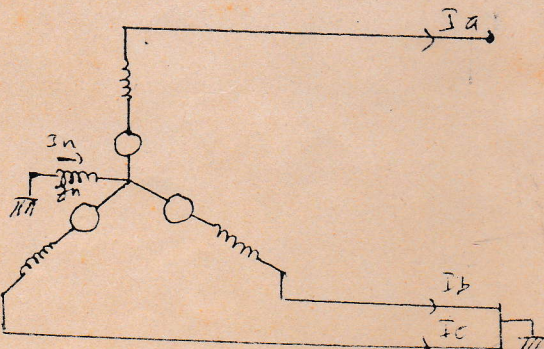
$$\begin{aligned}
 V_a &= V_{a1} + V_{a2} + V_{a0} \\
 &= \frac{3 z_2 (z_0' + 3z_n)}{z_1 z_2 + z_1 (z_0' + 3z_n) + z_2 (z_0' + 3z_n)} E_a
 \end{aligned}$$

$$V_b = 0$$

$$V_c = 0$$

Contoh : II.2

Hitunglah arus gangguan untuk jenis gangguan dua saluran ke tanah juga tegangan - tegangan saluran dari generator pada contoh II.1.



$$E_a = 1 \text{ pu}$$

$$z_1 = j0,1 \text{ pu}$$

$$z_2 = j0,1 \text{ pu}$$

$$z_0' = j0,05 \text{ pu}$$

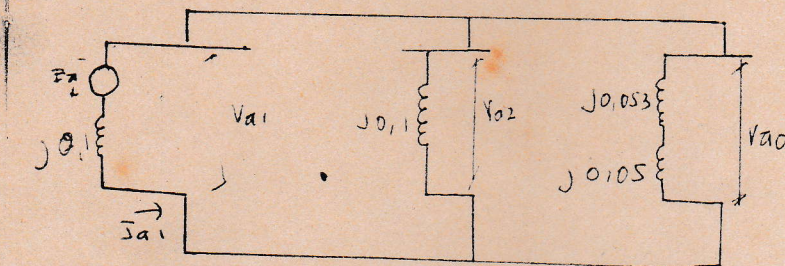
$$z_n = 0,4 \Omega$$

$$Z_{\text{dasar}} = \frac{(15)^2 (kV)^2}{30 \text{ MVA}} = 7,5 \Omega$$

$$Z_n = \frac{0,4}{7,5} = j0,053 \text{ pu}$$

$$Z_0 = Z_0' + 3Z_n = j0,05 + 3 \cdot j0,053 = j0,209 \text{ pu}$$

gangguan dua saluran ke tanah.



$$I_{a1} = \frac{E_a}{Z_1 + \frac{Z_2(Z_0' + 3Z_n)}{Z_2 + Z_0' + 3Z_n}} = \frac{1}{j0,1 + \frac{j0,1 \cdot j0,209}{j0,1 + j0,209}} = j5,97 \text{ pu}$$

$$I_{a2} = - \frac{3Z_n + Z_0'}{Z_1 Z_2 + Z_1(3Z_n + Z_0') + Z_2(3Z_n + Z_0')} E_a$$

$$= - \frac{j0,209}{j0,1 \cdot j0,1 + j0,1 \cdot j0,209 + j0,1 \cdot j0,209} \cdot 1 = j4,03 \text{ pu}$$

$$I_{a0} = - \frac{Z_2}{Z_1 Z_2 + Z_1(3Z_n + Z_0') + Z_2(3Z_n + Z_0')} E_a$$

$$= - \frac{j0,1}{j0,1 \cdot j0,1 + j0,1 \cdot j0,209 + j0,1 \cdot j0,209} \cdot 1 = j1,93 \text{ pu}$$

arus gangguan

$$I_f = I_b + I_c$$

$$= (a^2 I_{a1} + a I_{a2} + I_{a0}) + (a I_{a1} + a^2 I_{a2} + I_{a0})$$

$$= I_{a1}(a^2 + a) + I_{a2}(a + a^2) + 2I_{a0}$$

$$= -3 \frac{Z_2}{Z_1 Z_2 + Z_1(3Z_n + Z_0') + Z_2(3Z_n + Z_0')} E_a$$

$$= -3 \frac{j0,1}{j0,1 \cdot j0,1 + j0,1 \cdot j0,209 + j0,1 \cdot j0,209} \cdot 1$$

$$= j5,79 \text{ pu}$$

arus dasar

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$$I_{\text{dasar}} = \frac{30.000 \text{ kVA}}{\sqrt{3} \cdot 15 \text{ kV}} = 1154 \text{ A}$$

arus gangguan sebenarnya :

$$I_f = 5,79 \times 1154 = 6681,66 \text{ A}$$

Voltage. Voltage urutan

$$\begin{aligned} V_{a1} &= \frac{Z_2 (3Z_1 + j0)}{2Z_2 + Z_1 (3Z_1 + j0) + Z_2 (3Z_1 + j0)} E_a \\ &= \frac{j0,1 \cdot j0,209}{j0,1 \cdot j0,1 + j0,1 \cdot j0,209 + j0,1 \cdot j0,209} \cdot 1 = 0,4 \text{ pu} \end{aligned}$$

$$V_{a2} = V_{a0} = V_{a1} = 0,4 \text{ pu}$$

Voltage saluran :

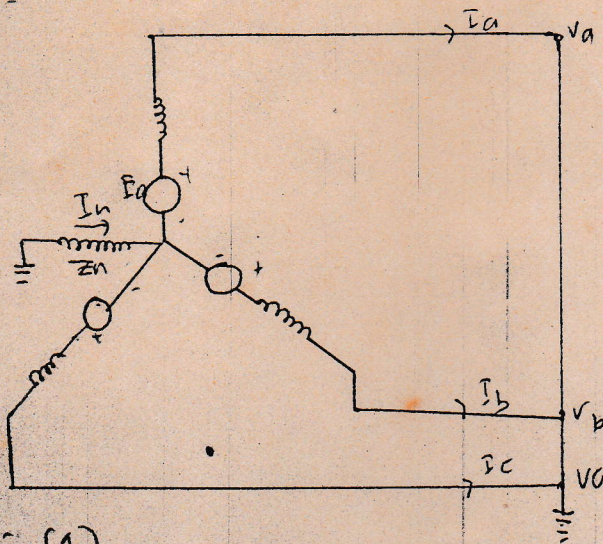
$$V_a = V_{a0} + V_{a1} + V_{a2} = 3 \cdot 0,4 = 1,2 \text{ pu}$$

$$V_b = 0$$

$$V_c = 0$$

$$\text{Voltage phase a sebenarnya} = 1,2 \times 15 \text{ kV} = 18 \text{ kV}$$

I.3. GANGGUAN TIGA SALURAN KE TANAH (TRIPLE LINE TO GROUND FAULT)



Persamaan - persamaan
pada titik gangguan :

$$I_a + I_b + I_c = 0 \quad (1)$$

$$V_a = V_b = V_c = 0 \quad (2)$$

dari (1)

$$I_{a0} = \frac{1}{3} (I_a + I_b + I_c) = 0$$

dari (2)

$$V_{a0} = \frac{1}{3} (V_a + V_b + V_c) = 0$$

$$V_{a1} = \frac{1}{3} (V_a + aV_b + a^2V_c) = 0$$

$$V_{a2} = \frac{1}{3} (V_a + a^2V_b + aV_c) = 0$$

dari persamaan umum :

$$V_{a1} = E_a - I_{a1} z_1 = 0$$

$$E_a = I_{a1} z_1$$

$$I_{a1} = \frac{E_a}{z_1}$$

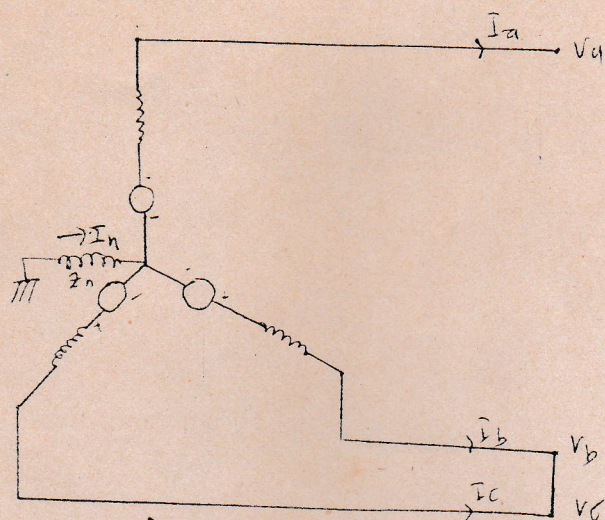
$$V_{a2} = -I_{a2} z_2 = 0 \cdot z_2 = 0 \rightarrow I_{a2} = 0$$

$$V_{a0} = -I_{a0} z_0 = 0 \cdot z_0 = 0 \rightarrow I_{a0} = 0$$

arus gangguan :

$$\left\| I_f = I_a = \frac{E_a}{z_1} \right\|$$

II. 4. SAMPULAN ANTARA DUA SALURAN, PHASE B & C (LINE TO LINE FAULT)



Persamaan - persamaan pada titik gangguan:

$$I_a = 0 \quad (1)$$

$$I_b = -I_c \quad (2)$$

$$V_b = V_c \quad (3)$$

dan (1) dan (2)

$$I_{a0} = \frac{1}{3} (I_a + I_b + I_c) = \frac{1}{3} (0 - I_c + I_c) = 0$$

$$I_{a1} = \frac{1}{3} (I_a + aI_b + a^2I_c) = \frac{1}{3} (0 + I_b(a - a^2)) = \frac{a - a^2}{3} I_b$$

$$I_{a1} = j \frac{I_b}{\sqrt{3}}$$

$$I_{a2} = \frac{1}{3} (I_a + a^2I_b + aI_c) = \frac{1}{3} (0 + I_b(a^2 - a))$$

$$I_{a2} = \frac{a^2 - a}{3} I_b = -j \frac{I_b}{\sqrt{3}}$$

$$I_{a0} = 0 \quad I_{a1} = -I_{a2}$$

dan (3)

$$V_b = V_c$$

$$a^2V_{a1} + aV_{a2} + V_{a0} = aV_{a1} + a^2V_{a2} + V_{a0}$$

$$(a^2 - a)V_{a1} = (a^2 - a)V_{a2}$$

dan persamaan umum

$$E_a - I_{a1}z_1 = -I_{a2}z_2$$

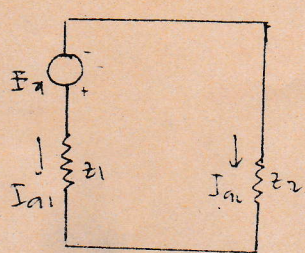
$$= I_{a1}z_2$$

$$E_a = I_{a1}(z_1 + z_2)$$

$$I_{a1} = \frac{E_a}{z_1 + z_2} = -I_{a2}$$

$$I_{a0} = 0$$

rangkainan ekuivalen



$$V_{a1} = V_{a2} = -I_{a2} z_2$$

$$= \frac{z_2}{z_1 + z_2} E_a$$

$$V_{a0} = -I_{a0} z_0 = 0$$

tegangan - tegangan saluran

$$V_a = V_{a0} + V_{a1} + V_{a2} = \frac{2z_2}{z_1 + z_2} E_a$$

$$V_b = V_{a0} + a^2 V_{a1} + a V_{a2} = (a^2 + a) V_{a1} = -\frac{z_2}{z_1 + z_2} E_a$$

$$V_c = V_{a0} + a V_{a1} + a^2 V_{a2} = (a + a^2) V_{a1} = -\frac{z_2}{z_1 + z_2} E_a$$

arus gangguan

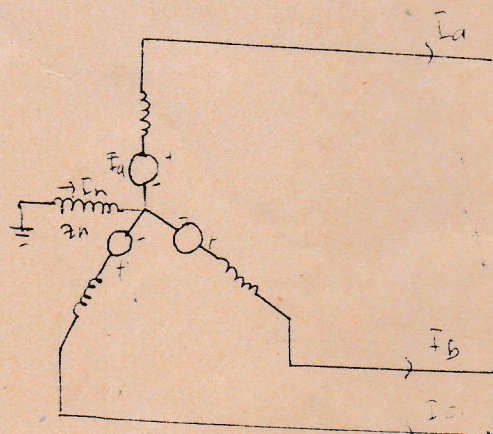
$$I_f = I_b = -I_c = a^2 I_{a1} + a I_{a2} + I_{a0}$$

$$= (a^2 - a) I_{a1}$$

$$= -j\sqrt{3} \frac{E_a}{z_1 + z_2}$$

Contoh : II. 4.

Hitunglah arus gangguan dan tegangan - tegangan saluran untuk jenis gangguan line to line dari generator pada contoh II. 1.



$$E_a = 1 \text{ pu}$$

$$z_1 = j0,1 \text{ pu}$$

$$z_2 = j0,1 \text{ pu}$$

$$z'_0 = j0,05 \text{ pu}$$

$$z_n = 0,4 - j2$$