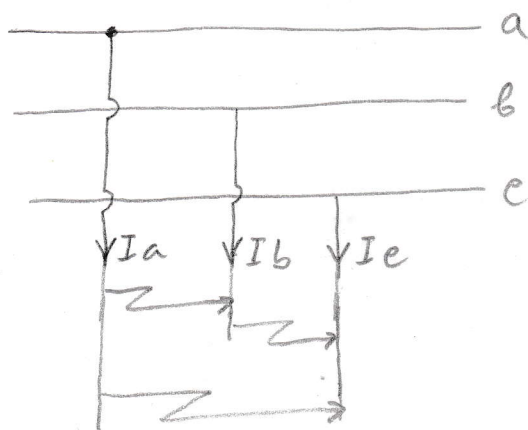


#### 4. Gangguan tiga fase :



Kondisi awal terjadi gangguan hubung singkat tiga fase :

$$I_a + I_b + I_c = 0$$

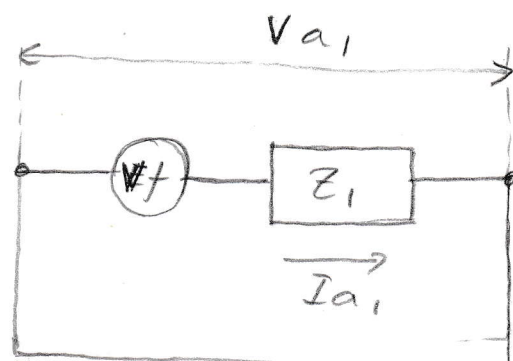
$$I_n = 0$$

$$V_a = V_b = V_c$$

Karena sistemnya simbalis maka urutan negatif dan nol tidak ada.

$$V_a = V_f - I_{a1} \cdot Z_1 = 0$$

$$I_f = I_a = \frac{V_f}{Z_1}$$

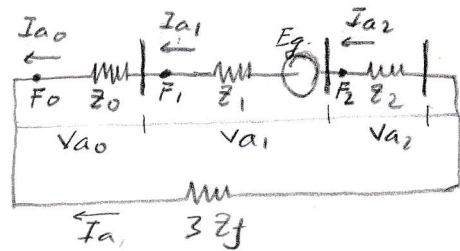
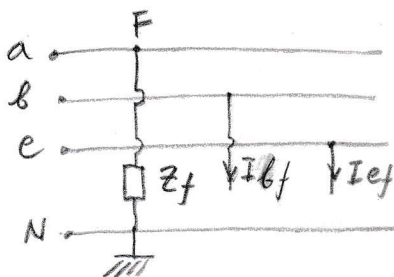


### 5. Gangguan melalui impedansi.

Dalam kenyataannya pada arus gangguan yg mengalir adalah melalui impedansi, baik impedansi pada saluran itu sendiri dan ataupun tahanan pentanahan.

Impedansi gangguan  $Z_f$  didefinisikan sebagai impedansi yg mengalirkan arus gangguan dan sebesar  $I_f$ .

#### a. Gangguan satu fase ke tanah melalui impedansi:



Pada keadaan gangguan ini:

$$I_b = 0; I_e = 0 \text{ dan } V_a = I_f \cdot V_f$$

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

$$I_{a1} = \frac{1}{3}(I_a + a^2 I_b + a I_e) = \frac{1}{3} I_a$$

$$\text{jadi: } I_{a0} = I_{a1} = I_{a2} = \frac{1}{3} I_a$$

$$V_a = I_f \cdot V_f = I_a \cdot Z_f \rightarrow I_a = I_f$$

$$V_{a0} + V_{a1} + V_{a2} = (I_{a0} + I_{a1} + I_{a2}) Z_f$$

$$(V_{a0} - I_{a0} \cdot Z_f) + (V_{a1} - I_{a1} \cdot Z_f) + (V_{a2} - I_{a2} \cdot Z_f) = 0$$

$$(-I_{a0} Z_0 - I_{a0} Z_f) + (E_g - I_{a1} Z_1 - I_{a1} Z_f) + (-I_{a2} Z_2 - I_{a2} Z_f) = 0$$

$$E_g = I_{a1} (Z_0 + Z_1 + Z_2 + 3Z_f)$$

$$I_{a1} = \frac{E_g}{(Z_0 + Z_1 + Z_2 + 3Z_f)} = I_{a2} = I_{a0}$$

$$I_f = I_a = \frac{3E_g}{(Z_0 + Z_1 + Z_2 + 3Z_f)}$$

selanjutnya:

$$V_a = I_a \cdot Z_f = \left\{ \frac{3 E_g}{(Z_0 + Z_1 + Z_2 + 3 Z_f)} \right\} \cdot E_g$$

$$\begin{aligned} V_b &= V_{a0} + a^2 V_{a1} + a V_{a2} = (-I_{a0} Z_0) + a^2 (E_g - I_{a1} Z_1) + a (-I_{a2} Z_2) \\ &= a^2 E_g - I_{a1} (Z_0 + a^2 Z_1 + a Z_2) \end{aligned}$$

$$V_b = E_g \left\{ \frac{a^2 (Z_0 + Z_1 + Z_2 + 3 Z_f) - (Z_0 + a^2 Z_1 + a Z_2)}{(Z_0 + Z_1 + Z_2 + 3 Z_f)} \right\}$$

$$V_b = E_g \left\{ \frac{(a^2 - 1) Z_0 + (a^2 - a) Z_2 + 3 a^2 Z_f}{(Z_0 + Z_1 + Z_2 + 3 Z_f)} \right\}$$

$$\begin{aligned} V_c &= V_{a0} + a V_{a1} + a^2 V_{a2} = (-I_{a0} Z_0) + a (E_g - I_{a1} Z_1) + a^2 (-I_{a2} Z_2) \\ &= a E_g - I_{a1} (Z_0 + a Z_1 + a^2 Z_2) \end{aligned}$$

$$E_g = \left\{ \frac{a (Z_0 + Z_1 + Z_2 + 3 Z_f) - (Z_0 + a Z_1 + a^2 Z_2)}{(Z_0 + Z_1 + Z_2 + 3 Z_f)} \right\}$$

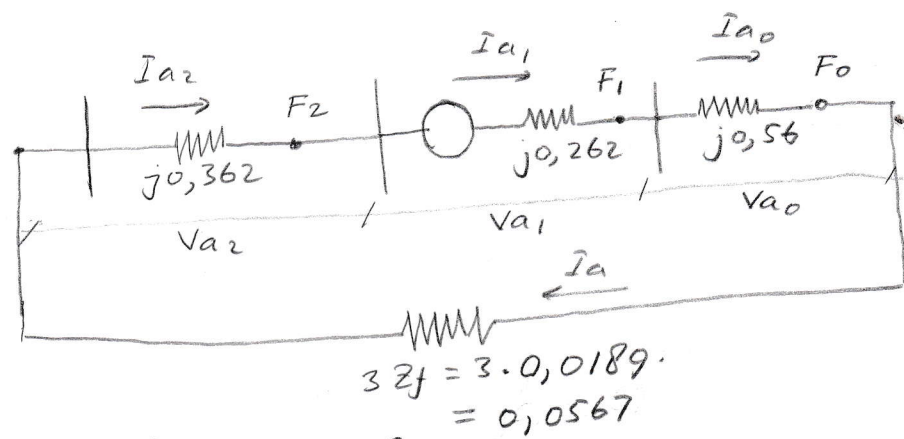
$$V_c = E_g \left\{ \frac{(a - 1) Z_0 + (a - a^2) Z_2 + 3 a Z_f}{(Z_0 + Z_1 + Z_2 + 3 Z_f)} \right\}$$

Contoh:

Jalur sistem tenaga listrik terjadi gangguan satu fase  
 saluran (fase a) melalui impedansi  $Z_f = 5 + j0,01 \text{ ohm}$ ,  
 mempunyai  $Z_1 = j0,262 \text{ pu}$ ;  $Z_2 = j0,56 \text{ pu}$  dan  
 $Z_0 = j0,362 \text{ pu}$ , tegangan  $E_g = 1 \text{ pu}$  pada dasar  $\text{KV}$   
 $230 \text{ KV}$  dan  $\text{MVA}$  dasar  $200 \text{ MVA}$ .

Tentukan: Arus dan tegangan urutan serta tegangan  
 antar fase.

jawab :



$$Z_{\text{dasar}} = \frac{1000^2}{\text{MVA}_B} = \frac{(230)^2}{200} = 264,5 \, \Omega$$

$$Z_f = \frac{5 + j0}{264,5} = 0,0189 \, \text{pu}$$

$$\begin{aligned}
 I_{a0} = I_{a1} = I_{a2} &= \frac{E}{Z_0 + Z_1 + Z_2 + 3Z_f} \\
 &= \frac{1 + j0}{j0,56 + j0,262 + j0,362 + 0,0567} \\
 &= \frac{1 + j0}{0,0567 + j1,184} = 0,04 - j0,843 \\
 &= 0,844 \angle -87,3^\circ
 \end{aligned}$$

$$\begin{aligned}
 I_a &= I_{a0} + I_{a1} + I_{a2} \\
 &= 3I_{a0} = 3(0,04 - j0,843) \\
 &= 0,12 - j2,531
 \end{aligned}$$

$$I_a = 2,531 \angle -87,3^\circ$$

$$\begin{aligned}
 V_{a0} &= -I_{a0}Z_0 = (0,04 - j0,843)j0,56 \\
 &= 0,47 + j0,022 = 0,472 \angle -177,3^\circ
 \end{aligned}$$

$$\begin{aligned}
 V_{a1} &= 1 - (0,22 + j0,1) = 0,771 - j0,1 \\
 &= 0,779 \angle -0,8^\circ
 \end{aligned}$$



$$V_{a2} = -I_{a2} \cdot Z_2 = -(0,09 - j0,843) \cdot j0,362$$

$$= -0,305 + j0,019 = 0,305 \angle -177,3^\circ.$$

$$V_{a2} = 0,305 \angle -177,3^\circ.$$

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

$$= 0,47 + j0,022 + 0,779 - j0,1 + 0,305 + j0,019.$$

$$V_a = 0,949 - j0,064 = 0,945 \angle -87^\circ.$$

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

$$= 0,472 \angle -177,30 + 0,779 \angle -0,8 \angle 240^\circ + 0,305 \angle -177,3 \angle 120^\circ$$

$$V_b = 0,472 \angle -177,30 + 0,779 \angle 239,2 + 0,305 \angle 2,7^\circ$$

$$V_b = 0,751 \angle -160^\circ.$$

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

$$= 0,472 \angle -177,3^\circ + 0,779 \angle -0,8 \angle 120^\circ + 0,305 \angle -177,3 \angle 240^\circ$$

$$= 0,472 \angle -177,3^\circ + 0,779 \angle 179,2^\circ + 0,305 \angle 16,7^\circ$$

$$V_e = 0,738 \angle 16,7^\circ.$$

$$V_{ab} = V_{af} - V_{bf} = 0,945 \angle -87,3^\circ - 0,751 \angle -180^\circ.$$

$$V_{be} = V_{bf} - V_{ef}$$

$$= 0,751 \angle -160^\circ - 0,738 \angle 16,7^\circ$$

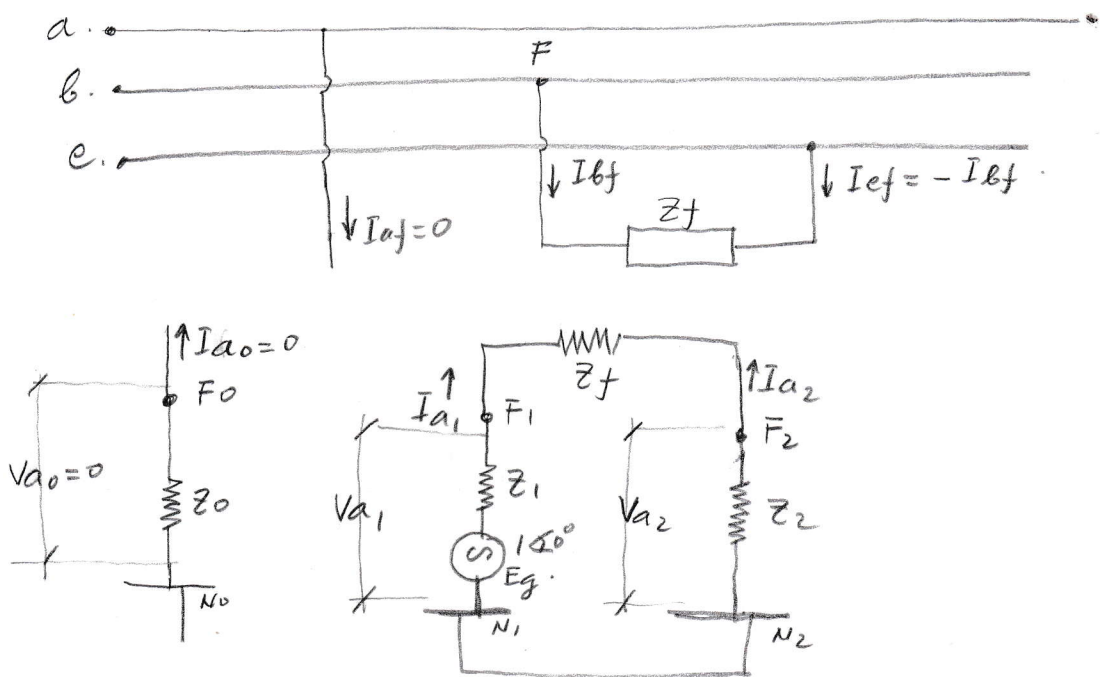
$$= 0,782 \angle 155,6^\circ.$$

$$V_{ea} = V_e - V_a$$

$$= 0,738 \angle 160,5^\circ - 0,945 \angle -87,3^\circ$$

$$V_{ea} = 0,754 \angle 163,5^\circ$$

b. gangguan dua saluran fase melalui impedansi



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

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

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

jadi:  $I_{a1} = -I_{a2}$

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

$$= \frac{1}{3}\{V_a + aV_b + a^2(V_b - I_b Z_f)\}$$

$$V_{a1} = \frac{1}{3}(V_a - V_b - a^2I_b Z_f)$$

$$= \frac{1}{3}(V_a - V_b) - \frac{1}{3}a^2(a^2I_{a1} + aI_{a2})Z_f$$

$$= \frac{1}{3}(V_a - V_b) - \frac{1}{3}(aI_{a1} - I_{a1})Z_f$$

$$V_{a1} = \frac{1}{3}(1 - a)I_{a1}Z_f = \frac{1}{3}(V_a - V_b)$$

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

$$= \frac{1}{3}(V_a - V_b - aI_b Z_f)$$

$$= \frac{1}{3}(V_a - V_b) - \frac{1}{3}a(a^2I_{a1} + aI_{a2})Z_f$$

$$\text{jadi: } V_{a2} - \frac{1}{3}(1-a^2) \bar{I}_{a2} z_f = \frac{1}{3}(V_a - V_b)$$

$$V_{a1} - \frac{1}{3}(-a) \bar{I}_{a1} z_f = V_{a2} - \frac{1}{3}(1-a^2) \bar{I}_{a2} z_f$$

$$V_{a1} - \frac{1}{3}(1 + \frac{1}{2} - j\frac{\sqrt{3}}{2}) \bar{I}_{a1} z_f = V_{a2} - \frac{1}{3}(1 + \frac{1}{2} + j\frac{\sqrt{3}}{2}) \bar{I}_{a2} z_f$$

$$V_{a1} - \frac{1}{2} \bar{I}_{a1} z_f = V_{a2} - \frac{1}{2} \bar{I}_{a2} z_f - \{j\frac{1}{2}\sqrt{3} \cdot \bar{I}_{a2} z_f + j\frac{1}{2}\sqrt{3} \cdot \bar{I}_{a1} z_f\}$$

$$V_{a1} - \frac{1}{2} \bar{I}_{a1} z_f = V_{a2} - \frac{1}{2} \bar{I}_{a2} z_f - 0$$

$$V_{a1} - \frac{1}{2} \bar{I}_{a1} z_f = V_{a2} - \frac{1}{2} \bar{I}_{a2} z_f, \text{ karena } \bar{I}_{a1} = -\bar{I}_{a2}$$

maka:

$$V_{a1} = V_{a2} + \bar{I}_{a1} z_f$$

$$(E_g - \bar{I}_{a1} z_1) - \frac{1}{2} \bar{I}_{a1} z_f = -\bar{I}_{a2} z_2 - \frac{1}{2} \bar{I}_{a2} z_f$$

$$E_g = \bar{I}_{a1} (z_1 + z_2 + z_f)$$

$$\text{maka } \bar{I}_{a1} = -\bar{I}_{a2} = \frac{E_g}{(z_1 + z_2 + z_f)}$$

selanjutnya:

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

$$= (a^2 - a) \bar{I}_{a1}$$

$$I_f = \frac{(a^2 - a) E_g}{(z_1 + z_2 + z_f)}$$

$$\begin{aligned} V_a &= V_{a1} + V_{a2} = (E_g - \bar{I}_{a1} z_1) + (-\bar{I}_{a2} z_2) = E_g - \bar{I}_{a1} (z_1 - z_2) \\ &= E_g \left\{ \frac{(z_1 + z_2 + z_f) - (z_1 - z_2)}{(z_1 + z_2 + z_f)} \right\} \end{aligned}$$

$$V_a = E_g \left\{ \frac{z_f + 2z_2}{(z_1 + z_2 + z_f)} \right\}$$

$$\begin{aligned} V_b &= a^2 V_{a1} + a V_{a2} = a^2 (E_g - \bar{I}_{a1} z_1) + a (-\bar{I}_{a2} z_2) \\ &= a^2 E_g - \bar{I}_{a1} (a^2 z_1 - a z_2) \\ &= E_g \left\{ \frac{(a^2 z_1 + z_2 + z_f) - (a^2 z_1 - a z_2)}{(z_1 + z_2 + z_f)} \right\} \end{aligned}$$

Maka:

$$V_b = E_g \left\{ \frac{-z_2 + a^2 z_f}{z_1 + z_2 + z_f} \right\}$$

$$V_e = E_g \left\{ \frac{-z_2 + a z_f}{z_1 + z_2 + z_f} \right\}$$

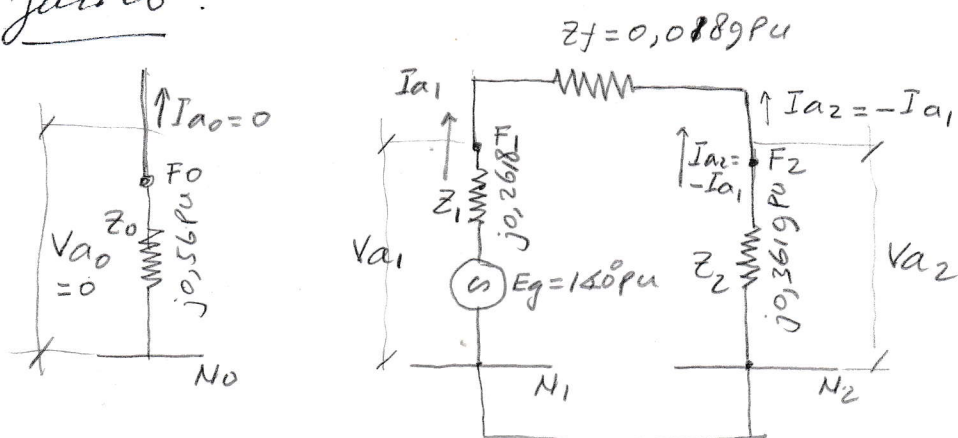
$$V_b - V_e = I_f \cdot V_f = \left\{ \frac{(a^2 - a) z_f}{z_1 + z_2 + z_f} \right\} E_g$$

Contoh:

Juata sistem tenaga listrik mempunyai impedansi urutan positif, negatif dan nol ( $z_1$ ,  $z_2$  dan  $z_0$ )  
 sistem terjadi gangguan dua fase (antar fase) melalui impedansi  $z_f = 0,0189 \text{ pu}$ , dan  $z_1 = j0,2618 \text{ pu}$ ,  $z_2 = j0,3619 \text{ pu}$  dan  $z_0 = j0,56 \text{ pu}$  pada tegangan  $E_g = 1 \angle 0^\circ \text{ pu}$ .

Tentukan: Arus dan tegangan urutan dan tegangan antar  
 Solusi:

Jawab:



$$I_{a0} = 0$$

$$I_{a1} = -I_{a2} = \frac{1,0 \angle 0^\circ}{z_1 + z_2 + z_f}$$

$$= \frac{1,0 \angle 0^\circ}{j0,2618 + j0,3619 + 0,0189} = 1,6026 \angle -88,3^\circ \text{ pu}$$

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

$$I_{a0} = 0$$



$$I_a = 0 + 1,602 \angle -88,3^\circ + 1,602 \angle 91,7^\circ$$

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

$$= 0 + 1,602 \angle -88,3^\circ \cdot 1 \angle 240^\circ + 1,602 \angle 91,7^\circ \cdot 1 \angle 120^\circ$$

$$= 2,776 \angle -178,3^\circ$$

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

$$= 0 + 1,602 \angle -88,3^\circ \cdot 1 \angle 120^\circ + 1,602 \angle 91,7^\circ \cdot 1 \angle 240^\circ$$

$$I_c = 2,776 \angle 1,7^\circ$$

$$V_{a0} = -I_{a0} \cdot Z_0 = 0$$

$$V_{a1} = 1 - I_{a1} \cdot Z_1$$

$$= 1 - 1,602 \angle 91,7^\circ \cdot 0,262 \angle 90^\circ$$

$$V_{a1} = 0,581 \angle -1,2^\circ$$

$$V_{a2} = -I_{a2} \cdot Z_2$$

$$= -1,602 \angle 91,7^\circ \cdot 0,362 \angle 90^\circ$$

$$V_{a2} = 0,581 \angle 1,7^\circ$$

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

$$= 0 + 0,581 \angle -1,2^\circ + 0,581 \angle 1,7^\circ$$

$$V_a = 1,166 \angle 0,2^\circ \text{ pu}$$

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

$$= 0 + 0,581 \angle -1,2^\circ \cdot 1 \angle 240^\circ + 0,581 \angle 1,7^\circ \cdot 1 \angle 120^\circ$$

$$V_b = 0,606 \angle -0,3^\circ \text{ pu}$$

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

$$= 0 + 0,581 \angle -1,2^\circ \cdot 1 \angle 120^\circ + 0,581 \angle 1,7^\circ \cdot 1 \angle 240^\circ$$

$$V_c = 0,555 \angle -0,2^\circ \text{ pu}$$

$$V_{ab} = V_a - V_b$$

$$= 1,160 \angle 0,2^\circ - 0,606 \angle -0,3^\circ$$

$$= 0,555 + j0,007 \text{ pu}$$

$$V_{ob} = 0,555 \angle 0,8^\circ \text{ pu}$$

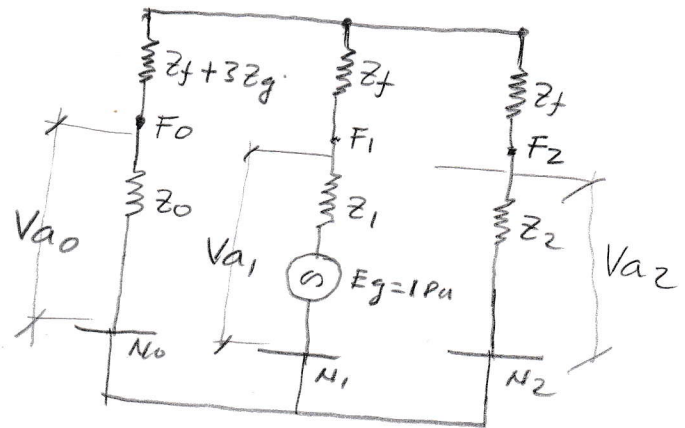
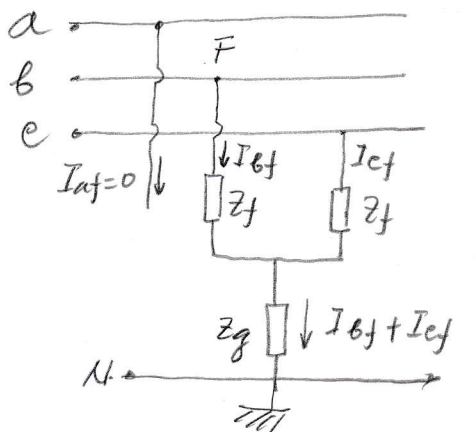
$$V_{be} = V_b - V_c$$

$$= 0,606 \angle -0,3^\circ - 0,555 \angle -0,2^\circ$$

$$= 0,051 \angle -1,5^\circ \text{ pu}$$

$$\begin{aligned}
 V_{ea} &= V_a - V_e \\
 &= 1,160 \angle 0,2^\circ - 0,555 \angle -0,2^\circ \\
 &= 0,605 \angle 18,96^\circ.
 \end{aligned}$$

c. gangguan dua saluran/dua fase kutanah melalui impedansi ( $Z_f$ ) dan impedansi tanah ( $Z_g$ ) yaitu fase b dan e.



$$I_a = 0; I_b + I_e = I_f \text{ dan } V_b = V_e = I_f \cdot Z_f$$

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

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

$$V_{a0} = \frac{1}{3}(V_a + 2 I_f \cdot Z_f) = \frac{1}{3}(V_a + 3 I_f Z_f) - \frac{1}{3}(I_f \cdot Z_f)$$

$$\text{jadi: } (V_{a0} - I_f \cdot Z_f) = \frac{1}{3}(V_a - I_f \cdot Z_f)$$

$$V_{a1} = \frac{1}{3}(V_a + a V_b + a^2 V_e) = \frac{1}{3}(V_a - V_b)$$

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

$$\text{maka: } (V_{a0} - I_f \cdot Z_f) = V_{a1} = V_{a2}$$

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

$$\text{jadi: } I_f = 3 I_{a0}$$

$$\text{maka: } (V_{a0} - 3 I_{a0} Z_f) = V_{a1} = V_{a0}$$

$$\text{jadi: } V_{a0} - 3 I_{a0} Z_f = V_{a1}$$

$$- I_{a0} \cdot Z_0 - 3 I_{a0} Z_f = E_g - I_{a1} Z_1$$

$$I_{a0} = - \left\{ \frac{E_g - I_{a1} Z_1}{(Z_0 + 3 Z_f)} \right\}$$

maka :  $V_{a2} = V_{a1}$

$$-I_{a2} \cdot Z_2 = E_g - I_{a1} \cdot Z_1$$

dan :  $I_{a2} = - \left( \frac{E_g - I_{a1} \cdot Z_1}{Z_2} \right)$

Dari persamaan di atas didapat :

$$- \left( \frac{E_g - I_{a1} \cdot Z_1}{Z_0 + 3Z_f} \right) + I_{a1} \cdot \left( \frac{E_g - I_{a1} \cdot Z_1}{Z_2} \right) = 0$$

$$I_{a1} = \left\{ \frac{Z_0 + Z_2 + 3Z_f}{Z_1 \cdot Z_2 + Z_2 \cdot Z_0 + Z_0 \cdot Z_1 + 3Z_f(Z_1 + Z_2)} \right\} \cdot E_g$$

$$I_{a0} = -E_g \left\{ \frac{Z_2}{Z_1 \cdot Z_2 + Z_2 \cdot Z_0 + Z_0 \cdot Z_1 + 3Z_f(Z_1 + Z_2)} \right\}$$

$$I_{a2} = -E_g \left\{ \frac{Z_0 + 3Z_f}{Z_1 \cdot Z_2 + Z_2 \cdot Z_0 + Z_0 \cdot Z_1 + 3Z_f(Z_1 + Z_2)} \right\}$$

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

$$V_a = V_{a0} + V_{a1} + V_{a2} = -I_{a0}Z_0 + (E_g - I_{a1}Z_1) - I_{a2}Z_2$$

$$V_a = E_g \frac{Z_0 Z_2}{D} + E_g - I_{a1} Z_1 \frac{(Z_0 + Z_2 + 3Z_f)}{D} + \frac{E_g - Z_2(Z_0 + 3Z_f)}{D}$$

dengan :

$$D = Z_1 \cdot Z_2 + Z_2 \cdot Z_0 + Z_0 \cdot Z_1 + 3Z_f(Z_1 + Z_2)$$

$$V_a = \left\{ \frac{Z_2 Z_0 + 2Z_f Z_2}{Z_1 Z_2 + Z_2 Z_0 + Z_0 Z_1 + 3Z_f(Z_1 + Z_2)} \right\}$$

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

$$= -I_{a0}Z_0 + a^2(E_g - I_{a1}Z_1) + a(-I_{a2}Z_2)$$

$$= a^2 E_g + \frac{E_g Z_2 Z_0}{D} - \frac{a^2 E_g (Z_2 + Z_0 + 3Z_f) Z_1}{D} + \frac{a E_g (Z_0 + 3Z_f) Z_2}{D}$$

$$= \left( \frac{3Z_2}{D} \right) E_g Z_f$$

jadi :  $V_b = 3I_{a0} Z_f = I_f \cdot Z_f$

$$V_e = I_f \cdot Z_f$$

Contoh :

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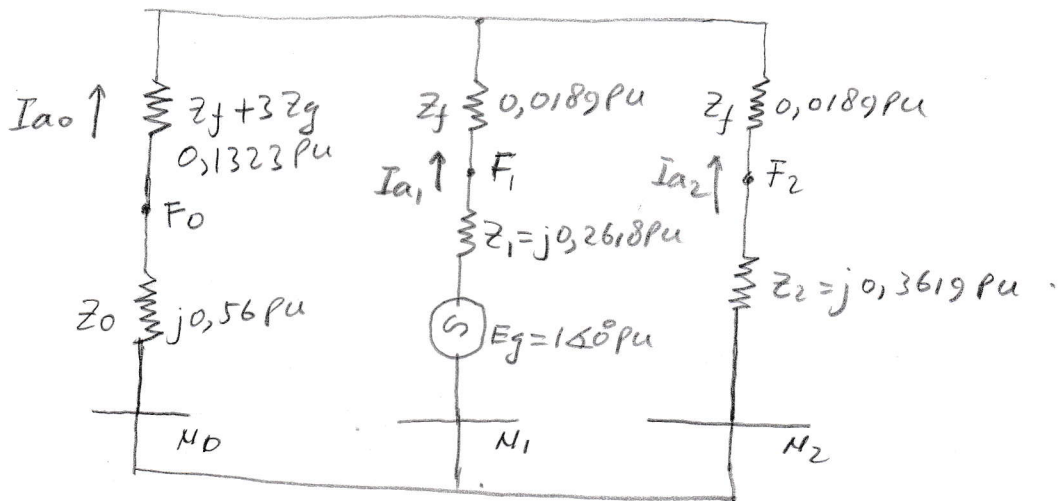
Juatu sistem tenaga listrik mempunyai  $Z_1 = j0,2618 \text{ pu}$   
 $Z_2 = j0,3619 \text{ pu}$  dan  $Z_0 = j0,56 \text{ pu}$ , impedansi gangguan kapad  
 $Z_f = 5 \text{ ohm}$  dan impedansi ketanah  $Z_g = 10 \text{ ohm}$ .

Jika terjadi gangguan dua saluran fasa ketanah ( fasa b dan  
 e) dan dg kV dasar 230 kV dan MVA dasar 200 MVA

Tentukan : Arus dan tegangan urutan rta tegangan saluran.  
 jawab :

$$Z_{\text{dasar}} = \frac{KV_b^2}{MVA_b} = \frac{230^2}{200} = 264,5 \Omega$$

$$Z_f + 3Z_g = \frac{5 + 3 \cdot 10}{264,5} = 0,1323 \text{ pu} ; Z_f = \frac{5}{264,5} = 0,0189 \text{ pu}$$



$$I_{a1} = \frac{1,0 \angle 0^\circ}{(Z_f + Z_1) + \frac{(Z_2 + Z_f)(Z_0 + Z_f + 3Z_g)}{Z_0 + Z_2 + 2Z_f + 3Z_g}}$$

$$I_{a1} = \frac{1,0 \angle 0^\circ}{(j0,2618 + 0,0189) + \frac{(j0,3619 + 0,0189)(j0,56 + 0,1323)}{(j0,3619 + 0,0189)(j0,56 + 0,1323)}}$$

$$= 2,0597 \angle -89,5^\circ \text{ pu}$$



$$I_{a2} = - \left[ \frac{z_0 + z_f + 3z_g}{(z_0 + z_f + 3z_g) + (z_1 + z_f)} \right] I_{a1}$$

$$= - \left[ \frac{0,5754 \angle 76,7^\circ}{0,9342 \angle 80,7^\circ} \right] [2,0597 \angle -84,5^\circ]$$

$$= -1,2686 \angle -88,5^\circ \text{ pu}$$

$$I_{a0} = - \left[ \frac{z_1 + z_f}{(z_1 + z_f) + (z_0 + z_f + 3z_g)} \right] \cdot I_{a1}$$

$$= - \left[ \frac{0,3624 \angle 87^\circ}{0,9342 \angle 80,7^\circ} \right] [2,0597 \angle -84,5^\circ]$$

$$= -0,799 \angle -78,2^\circ \text{ pu}$$

Arus? fasa adalah.

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

$$= -0,799 \angle -78,2^\circ + 2,059 \angle -84,5^\circ = 1,287 \angle -84,15^\circ$$

$$I_{a0} = 0$$

$$I_b = I_{a0} + a^1 I_{a1} + a I_{a2}$$

$$= -0,799 \angle -78,2^\circ + 2,059 \angle -84,5^\circ \cdot 1 \angle 240^\circ + 1 \angle 120^\circ \cdot 0,287 \angle -84,5^\circ$$

$$I_b = 3,268 \angle 162,7^\circ$$

$$I_c = I_{a0} + a I_{a1} + a^1 I_{a2}$$

$$= -0,799 \angle -78,2^\circ + 2,059 \angle -84,5^\circ + 120^\circ + 1,287 \angle -84,15^\circ + 240^\circ$$

$$I_c = 2,965 \angle 27,6^\circ$$

Tegangan - Tegangan.

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

$$= -0,56 \angle 90^\circ (-0,799 \angle -78,2^\circ)$$

$$= 0,447 \angle 11,8^\circ$$

$$V_{a1} = 1 - I_{a1} \cdot z_1 = 1 - 2,059 \angle -84,5^\circ \cdot 0,262 \angle 90^\circ$$

$$V_{a1} = 0,466 \angle -6,4^\circ$$

$$V_{a2} = -I_{a2} \cdot Z_2$$

$$= -(-1,2874 - 88,5^\circ \cdot 0,362 \angle 90^\circ)$$

$$V_{a2} = 0,459 \angle 1,5^\circ$$

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

$$= 0,497 \angle 11,8^\circ + 0,4964 \angle -6,4^\circ + 0,459 \angle 1,5^\circ$$

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

$$= 0,497 \angle 11,8^\circ + 0,4964 \angle -6,4^\circ + 240^\circ + 0,459 \angle 1,5^\circ + 120^\circ$$

$$= 0,133 \angle 126,1^\circ$$

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

$$= 0,497 \angle 11,8^\circ + 0,4964 \angle -6,4^\circ + 120^\circ + 0,459 \angle 1,5^\circ + 240^\circ$$

$$= 0,119 \angle 74,9^\circ$$

$$V_{ab} = V_a - V_b = 1,361 \angle 2,2^\circ - 0,133 \angle 126^\circ$$

$$= 1,439 \angle -2,2^\circ$$

$$V_{be} = V_b - V_e = 0,133 \angle 120^\circ - 0,119 \angle 74,9^\circ$$

$$= 0,111 \angle 184^\circ$$

$$V_{ea} = V_e - V_a = 0,119 \angle 74,9^\circ - 1,361 \angle 2,2^\circ$$

$$= 1,32 \angle 177,3^\circ$$

d. gangguan tiga fase melalui impedansi

Gangguan tiga saluran/tiga fase melalui impedansi bila impedansi gangguan ( $Z_f$ ) yang sama terdapat pada masing-masing ketiga saluran fasanya ataupun juga melalui impedansi pentanahan ( $Z_g$ ), maka dalam hal ini berlaku juga perhitungan sebagai mana gangguan tiga saluran/fase simetris, maka baik arus maupun tegangannya adalah simetris jadi tidak ada komponen urutan nol ataupun negatif.

