Komponen Simetris dan Tidak Simetris

-Review Materi-

Analisis Sistem Yang Tidak Seimbang

Penyebab :

- Beban pada setiap fasa tidak sama
- Konstruksi saluran yang tidak simetris dan tidak ditransposisikan.

Pengaruhnya :

- Tegangan pada setiap fasa tidak seimbang.
- Perpindahan daya pada generator dan trafo tidak merata sehingga menimbulkan getaran
- Meningkatkan rugi daya
- Memperburuk kinerja motor listrik

Analisis :

- Komponen simetris
- Impedansi urutan dan jaringan urutan

ANALISIS SISTEM 3 FASA TAK SEIMBANG

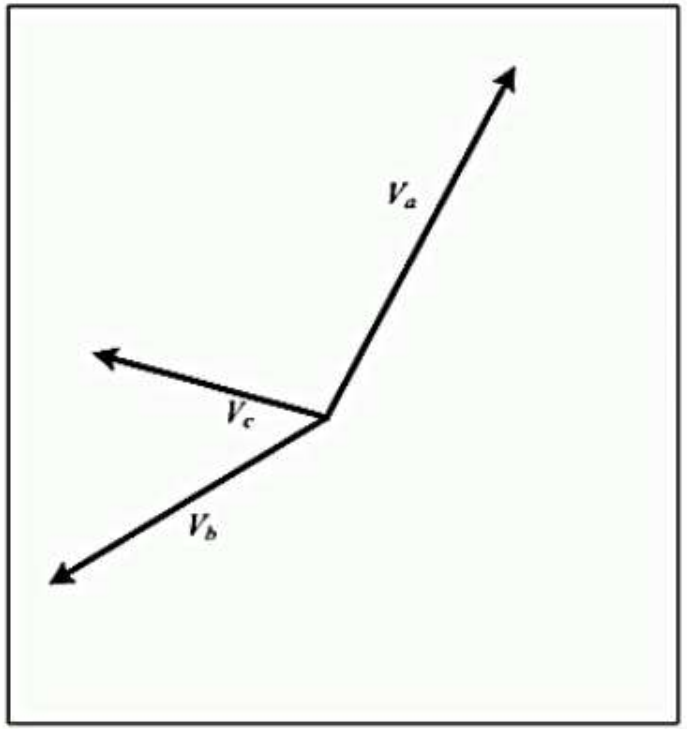
Sistem tidak seimbang dapat dianalisis dengan persamaan simpul atau persamaan jerat, tetapi ukuran matriks akan semakin besar karena perhitungan harus dilakukan pada setiap fasa.

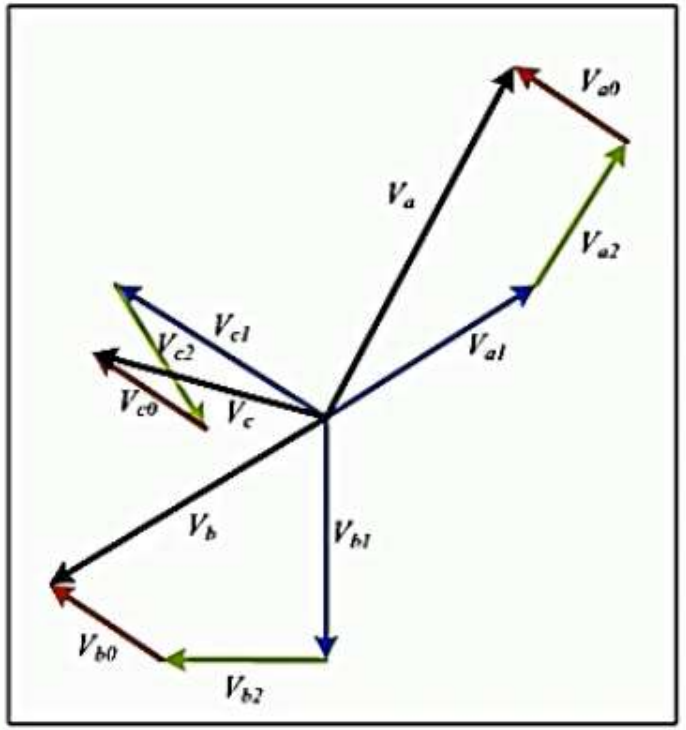
Perhitungan dapat disederhanakan dengan menggunakan komponen simetris

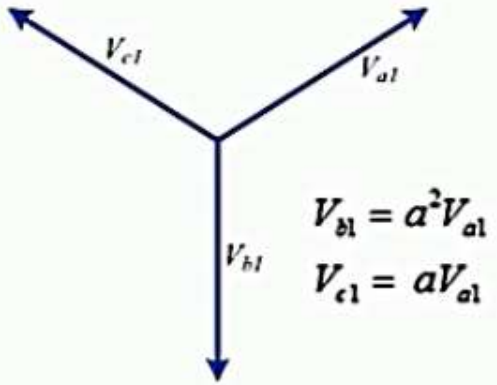
Sistem tiga fasa tidak seimbang lebih mudah dianalisis dengan menguraikan sistem tersebut menjadi tiga komponen simetris. Ketiga komponen tersebut adalah :

- Komponen urutan positif terdiri dari tiga fasor yang sama besarnya, berbeda fasa 120° dan mempunyai urutan fasa yang sama dengan fasor aslinya.
- Komponen urutan negatif terdiri dari tiga fasor yang sama besarnya, berbeda fasa 120° dan mempunyai urutan fasa yang berlawanan dengan fasor aslinya.
- Komponen urutan nol terdiri dari tiga fasor yang sama besarnya dan memiliki sudut fasa yang sama.

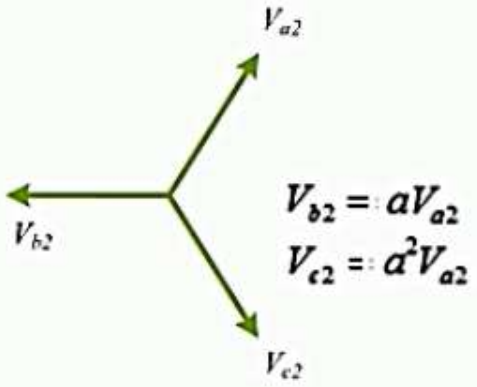
KOMPONEN SIMETRIS



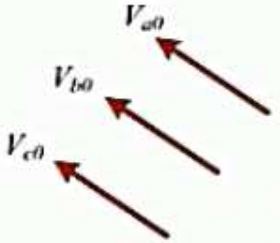




$$V_{b1} = a^2 V_{a1}$$
$$V_{c1} = a V_{a1}$$



$$V_{b2} = a V_{a2}$$
$$V_{c2} = a^2 V_{a2}$$



$$V_{b0} = V_{a0}$$
$$V_{c0} = V_{a0}$$

$$a = 1\angle 120 = \cos(120) + j\sin(120)$$

KOMPONEN SIMETRIS TEGANGAN DAN ARUS

$$V_{b1} = a^2 V_{a1}$$
$$V_{b2} = a V_{a2}$$
$$V_{c1} = a V_{a1}$$
$$V_{c2} = a^2 V_{a2}$$
$$V_{a0} = V_{b0} = V_{c0}$$

$$\rightarrow \quad \begin{aligned} V_a &= V_{a1} + V_{a2} + V_{a0} \\ V_b &= V_{b1} + V_{b2} + V_{b0} \\ V_c &= V_{c1} + V_{c2} + V_{c0} \end{aligned}$$

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

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

$$[V_{abc}] = [A][V_{120}]$$
$$[V_{120}] = [A^{-1}][V_{abc}]$$

$$[A] = \begin{bmatrix} 1 & 1 & 1 \\ a^2 & a & 1 \\ a & a^2 & 1 \end{bmatrix}$$

$$[A]^{-1} = \frac{1}{3} \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix}$$

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

$$V_{a1} = \frac{1}{3}(V_a + a V_b + a^2 V_c)$$
$$V_{a2} = \frac{1}{3}(V_a + a^2 V_b + a V_c)$$
$$V_{a0} = \frac{1}{3}(V_a + V_b + V_c)$$

$$I_{b1} = a^2 I_{a1} \qquad I_{c1} = a I_{a1}$$
$$I_{b2} = a I_{a2} \qquad I_{c2} = a^2 I_{a2}$$

$$I_{a0} = I_{b0} = I_{c0}$$

$$[I_{abc}] = [A][I_{120}]$$
$$[I_{120}] = [A^{-1}][I_{abc}]$$

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

$$I_{a1} = \frac{1}{3}(I_a + a I_b + a^2 I_c)$$
$$I_{a2} = \frac{1}{3}(I_a + a^2 I_b + a I_c)$$
$$I_{a0} = \frac{1}{3}(I_a + I_b + I_c)$$

PERSENTASE KETIDAKSEIMBANGAN

Phase Voltage Unbalance Rate (PVUR) :

$$\%PVUR = \frac{\text{Selisih maksimum tegangan fasa ke netral terhadap rata - rata tegangan fasa ke netral}}{\text{rata - rata tegangan fasa ke netral}}$$

Line Voltage Unbalance rate (LUVR) :

$$\%LVUR = \frac{\text{Selisih maksimum tegangan fasa ke fasa terhadap rata - rata tegangan fasa ke fasa}}{\text{rata - rata tegangan fasa ke fasa}}$$

Berdasarkan komponen simetris :

$$V_2(\%) = \frac{V_2}{V_1} x100\% \qquad V_0(\%) = \frac{V_0}{V_1} x100\%$$

Contoh 1

$V_a = 180\angle 0 \quad V_b = 250\angle -90 \quad V_c = 220\angle 100$

- Berapa komponen urutan positif, negatif dan nol nya ?
- Berapa persen ketidaksembangan tegangannya berdasarkan tegangan fasa ke fasa (LVUR) ?
- Berapa persen ketidakseimbangan berdasarkan komponen simetrisnya ?

$$V_{a1} = \frac{1}{3}\left(V_a + aV_b + a^2V_c\right) \qquad V_{a1} = \frac{1}{3}\left(180\angle 0 + \left(1\angle 120 x 250\angle -90\right) + \left(1\angle 240 x 220\angle 100\right)\right) = 201{,}8\angle 4{,}7$$

$$V_{a2} = \frac{1}{3}\left(V_a + a^2V_b + aV_c\right) \qquad V_{a2} = \frac{1}{3}\left(180\angle 0 + \left(1\angle 240 x 250\angle -90\right) + \left(1\angle 120 x 220\angle 100\right)\right) = 68{,}6\angle -175{,}4$$

$$V_{a0} = \frac{1}{3}\left(V_a + V_b + V_c\right) \qquad V_{a0} = \frac{1}{3}\left(180\angle 0 + 250\angle -90 + 220\angle 100\right) = 48{,}6\angle -13{,}2$$

$$\%LVUR = \frac{\text{Selisih maksimum tegangan fasa ke fasa terhadap rata - rata tegangan fasa ke fasa}}{\text{rata - rata tegangan fasa ke fasa}}$$

$V_{ab} = V_a - V_b = 180\angle 0 - 250\angle -90 \qquad |V_{ab}| = 308.0584 \text{ V}$

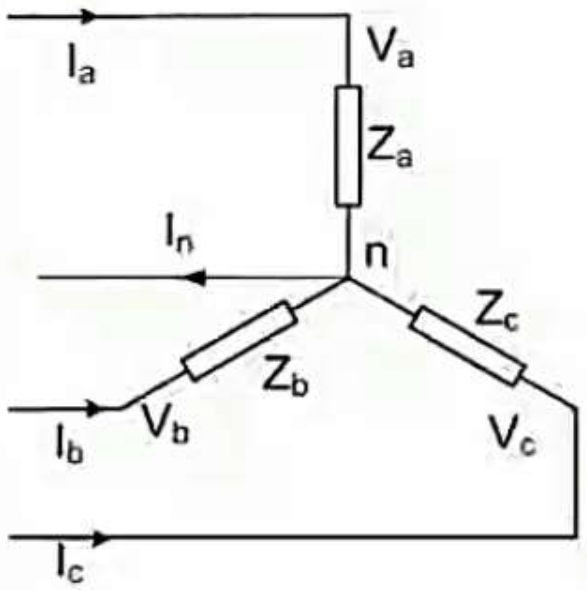
$V_{bc} = V_b - V_c = 250\angle -90 - 220\angle 100 \qquad |V_{bc}| = 468.2188 \text{ V}$

$V_{ca} = V_c - V_a = 20\angle 100 - 180\angle 0 \qquad |V_{ca}| = 307.4946$

rata - rata $= 361.2573$ V

$$\%LVUR = \frac{468.2188 - 361.2573}{361.2573} = 29.61\% \qquad V_2(\%) = \frac{68.6}{201.8} = 34\% \qquad V_0(\%) = \frac{48.6}{201.8} = 24.1\%$$

KOMPONEN SIMETRIS IMPEDANSI HUBUNGAN Y



$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} Z_a & 0 & 0 \\ 0 & Z_b & 0 \\ 0 & 0 & Z_c \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$[V_{abc}] = [Z_{abc}][I_{abc}]$$

$$[V_{abc}] = [A][V_{120}]$$

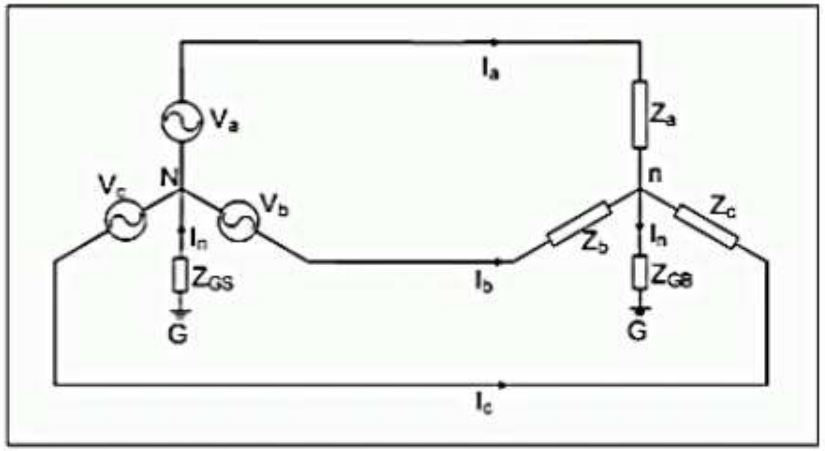
$$[I_{abc}] = [A][I_{120}]$$

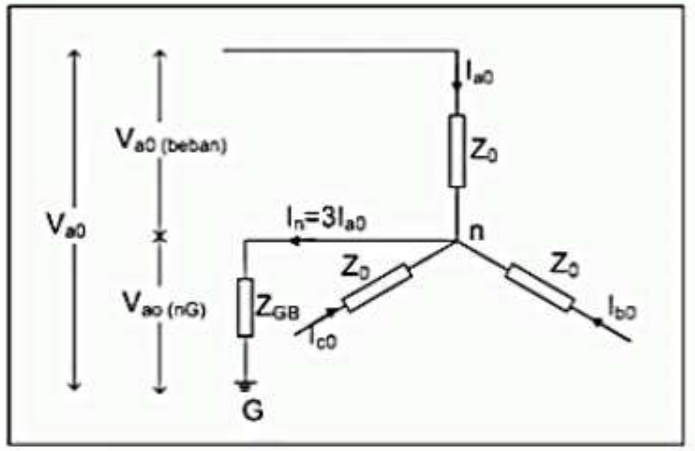
$$AV_{120} = Z_{abc}AI_{120}$$

$$V_{120} = A^{-1}Z_{abc}AI_{120}$$

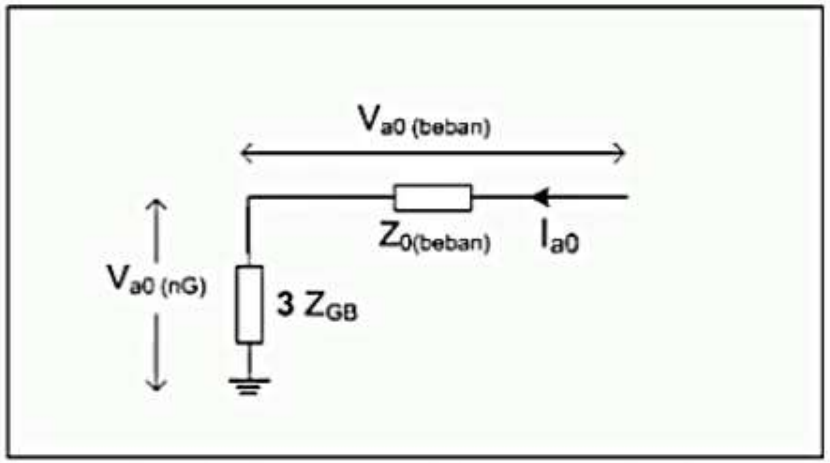
$$Z_{120} = A^{-1}Z_{abc}A$$

KOMPONEN URUTAN NOL

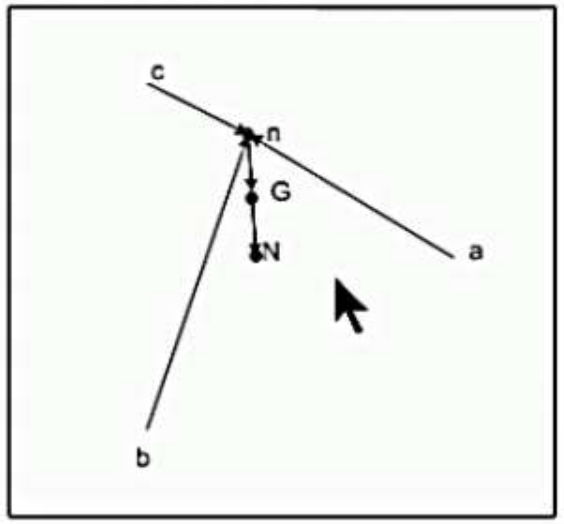




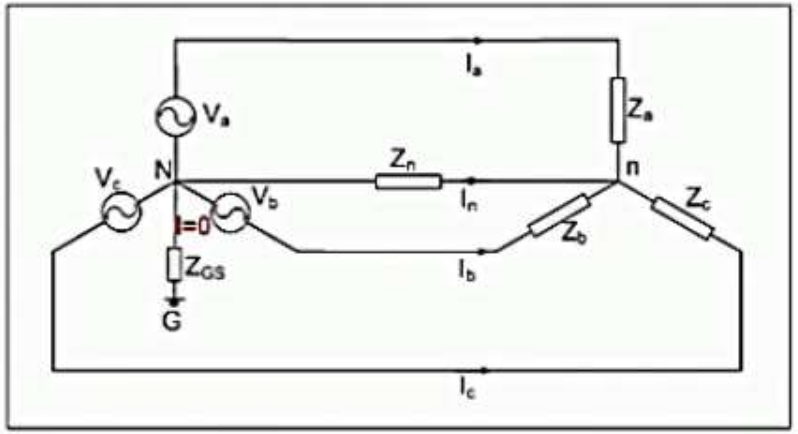
$$I_{a0} = \frac{1}{3}(I_a + I_b + I_c) \qquad I_{a0} = \frac{1}{3} I_n \qquad I_n = 3I_{a0}$$



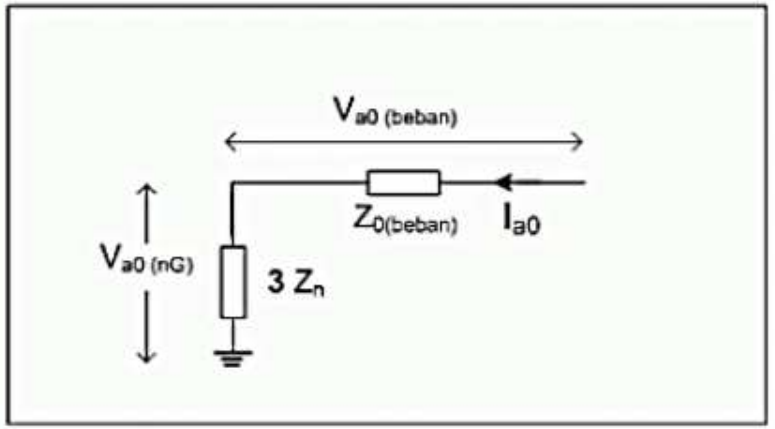
$$V_{nG} = V_{a0(nG)} = Z_{GB} I_n = 3 Z_{GB} I_{a0}$$



KOMPONENN URUTAN NOL

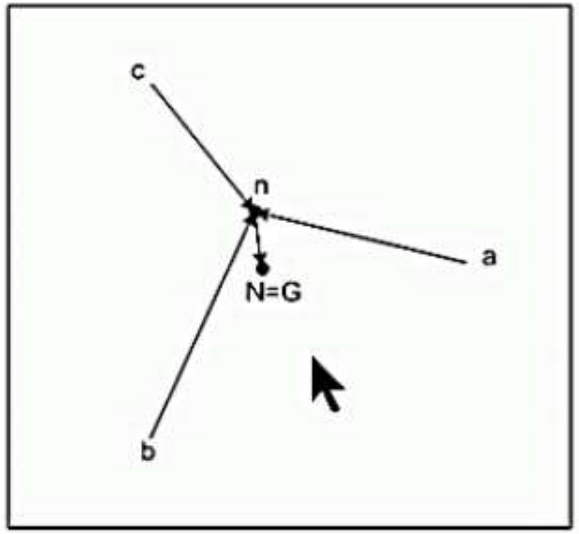


$$V_{NG} = 0$$

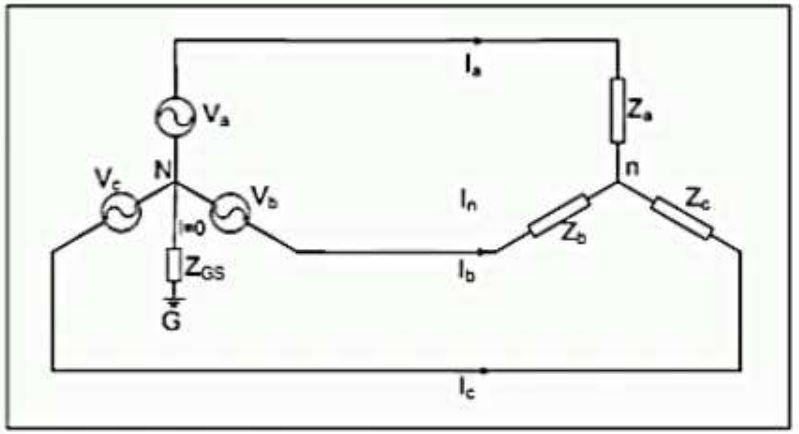


$$V_{nG} = V_{nN} + V_{NG}$$

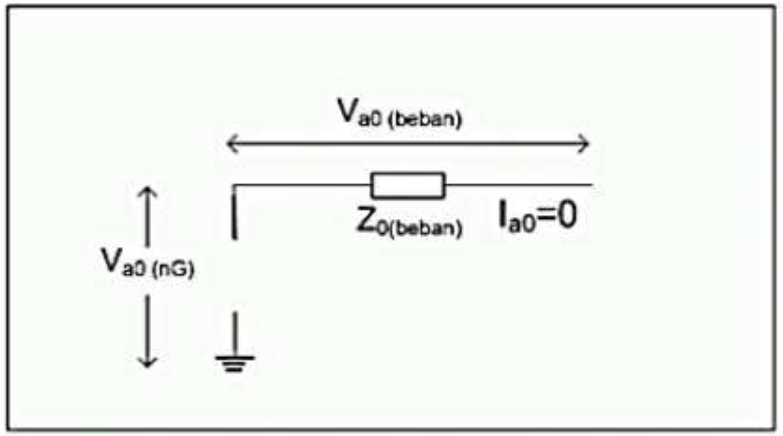
$$V_{nG} = V_a - Z_a I_a = V_b - Z_b I_b = V_c - Z_c I_c = Z_n I_n = 3 Z_n I_0$$



KOMPONEN URUTAN NOL

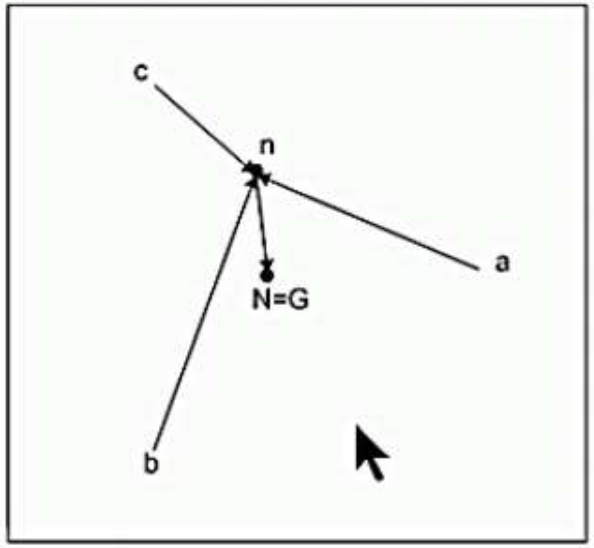


$$V_{NG} = 0$$

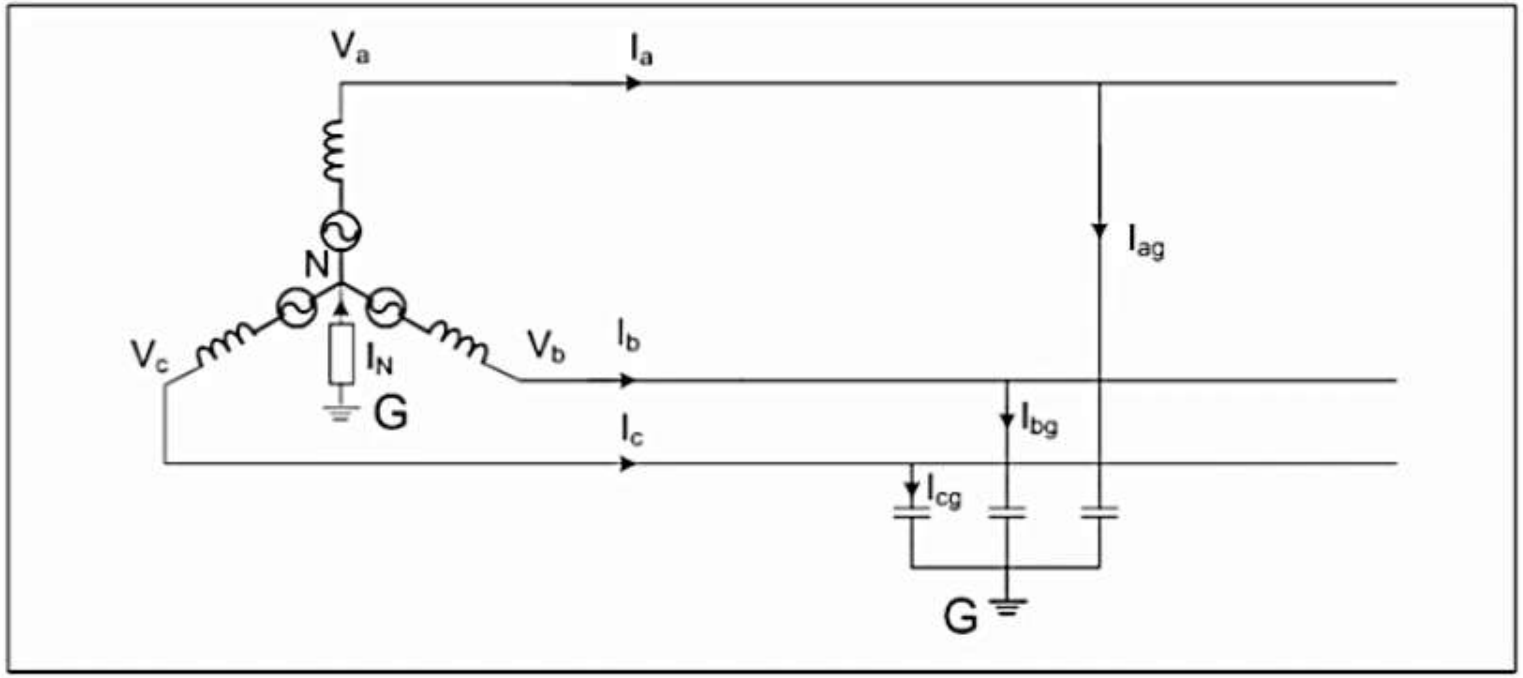


$$V_{nG} = V_{nN} + V_{NG}$$

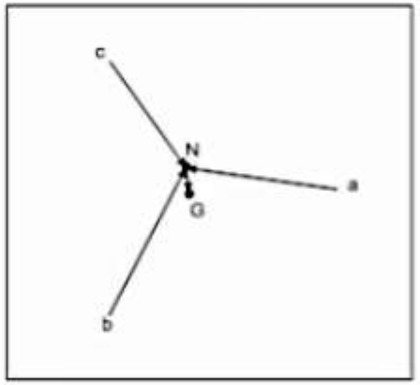
$$V_{nG} = V_a - Z_a I_a = V_b - Z_b I_b = V_c - Z_c I_c$$



KOMPONEN URUTAN NOL

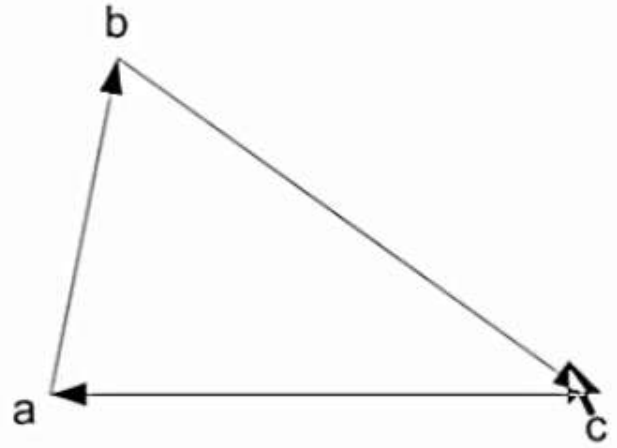


Va, Vb dan Vc tidak seimbang



KOMPONEN URUTAN NOL

- Jumlah fasor tegangan antara saluran selalu bernilai nol, sehingga komponen urutan nol tidak pernah terdapat pada tegangan antar saluran.



$$V_{ab0} = \frac{1}{3}\left(V_{ab} + V_{bc} + V_{ca}\right) = 0$$

$$V_{bc0} = 0$$

$$V_{ca0} = 0$$

DAYA BERDASARKAN KOMPONEN SIMETRIS

- Daya pada sistem yang tidak seimbang dihitung berdasarkan daya pada setiap fasa

$$S_{3fasa} = V_a I_a^* + V_b I_b^* + V_c I_c^*$$

$$S_{3fasa} = \begin{bmatrix} V_a & V_b & V_c \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}^*$$

$$S_{3fasa} = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}^T \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}^*$$

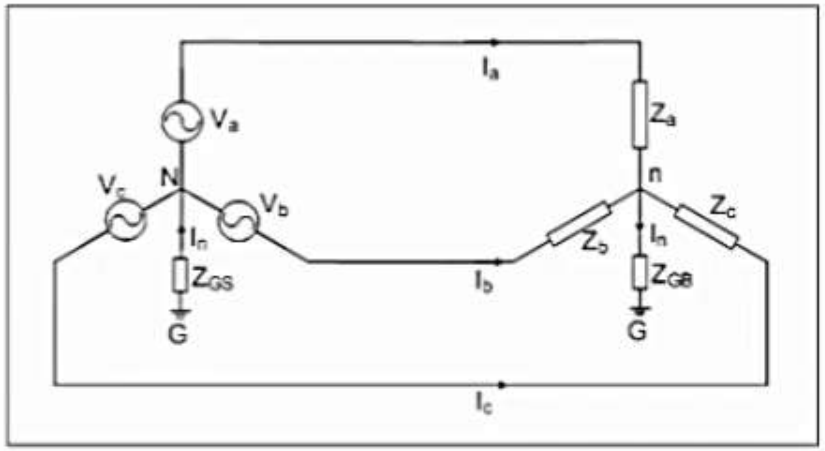
Berdasarkan nilai komponen simetrisnya :

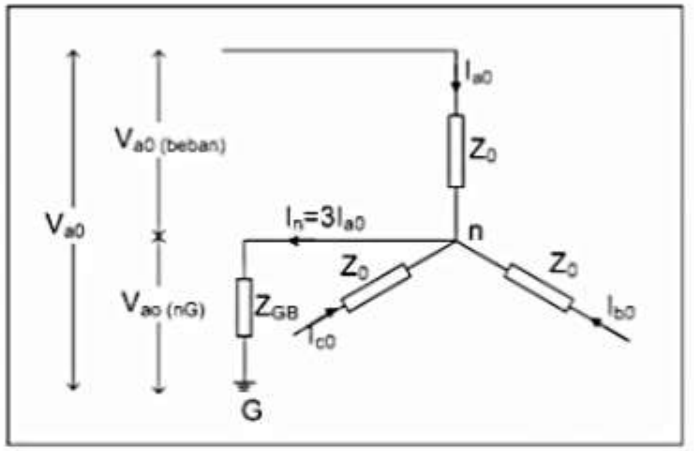
$$S_{3fasa} = [AV]^T [AI]^*$$

Dengan menggunakan aturan matriks diperoleh :

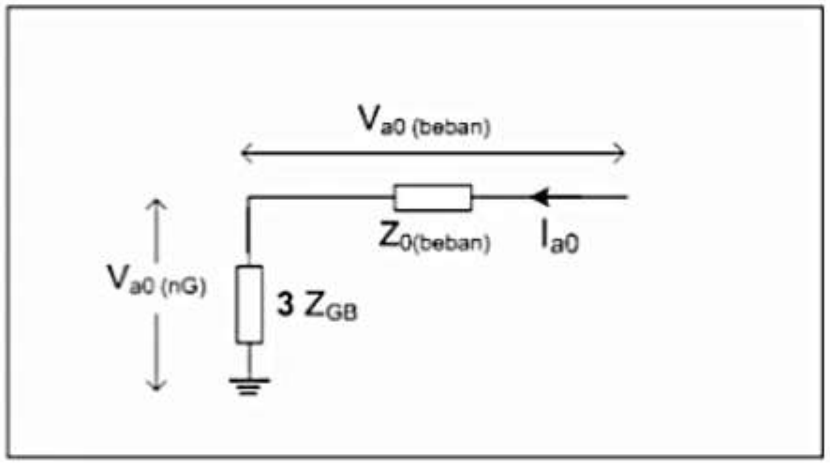
$$S_{3fasa} = 3V_{a1} I_{a1}^* + 3V_{a2} I_{a2}^* + 3V_{a0} I_{a0}^*$$

KOMPONEN URUTAN NOL

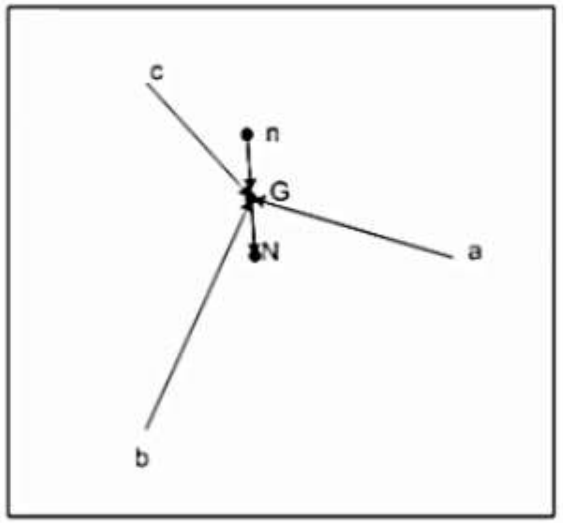




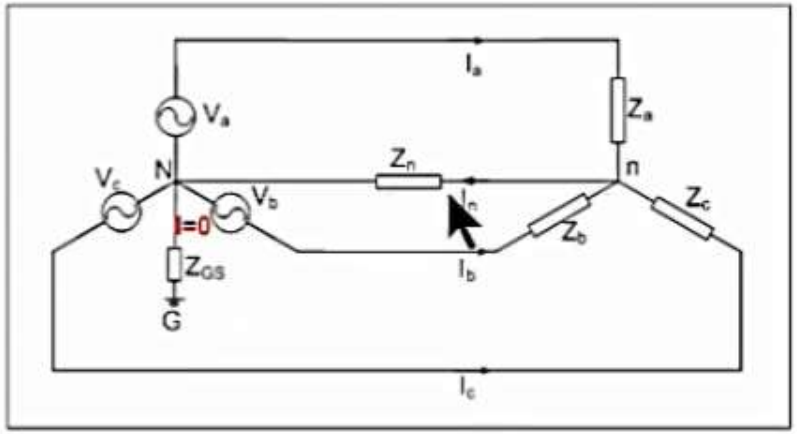
$$I_{a0} = \frac{1}{3}(I_a + I_b + I_c) \qquad I_{a0} = \frac{1}{3} I_n \qquad I_n = 3I_{a0}$$



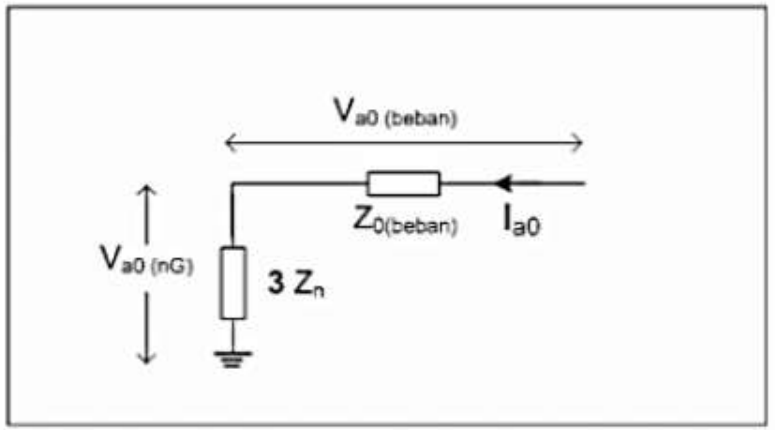
$$V_{nG} = V_{a0(nG)} = Z_{GB} I_n = 3 Z_{GB} I_{a0}$$



KOMPONEN URUTAN NOL

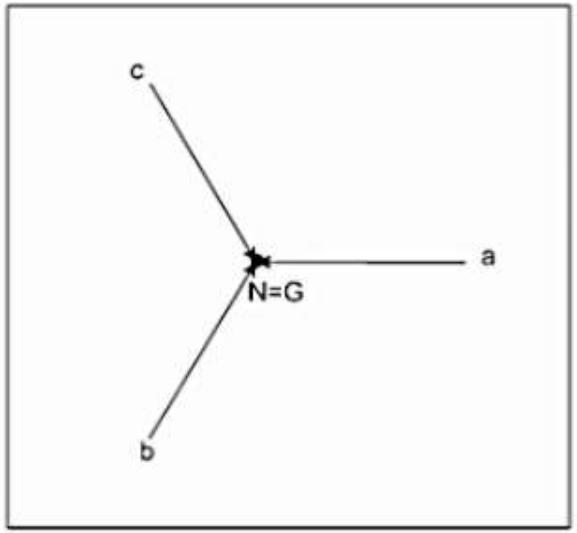


$$V_{NG} = 0$$

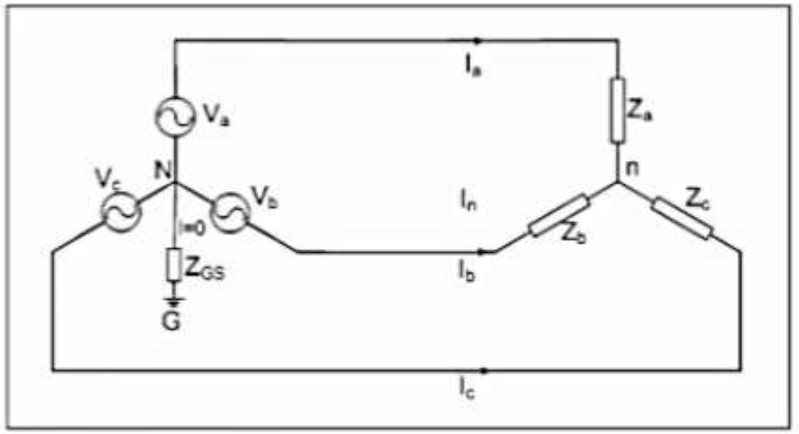


$$V_{nG} = V_{nN} + V_{NG}$$

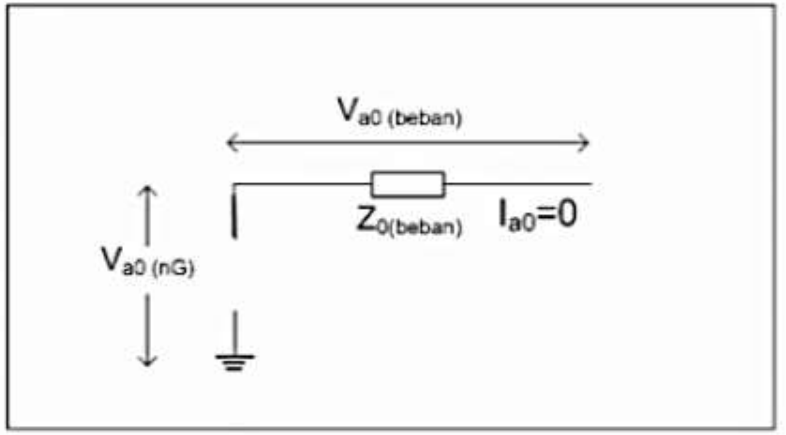
$$V_{nG} = V_a - Z_a I_a = V_b - Z_b I_b = V_c - Z_c I_c = Z_n I_n = 3 Z_n I_0$$



KOMPONEN URUTAN NOL

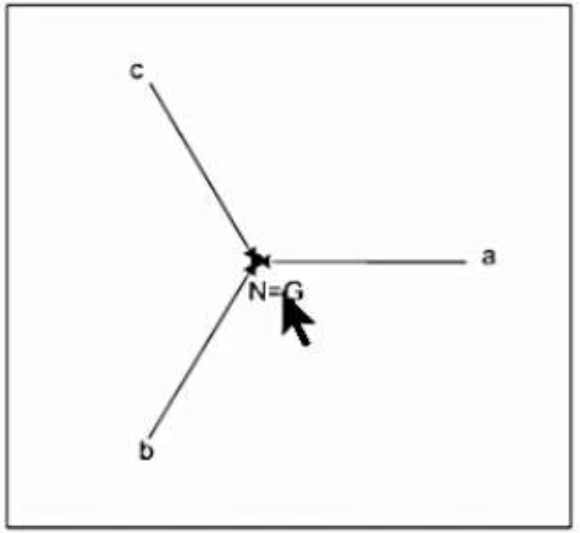


$$V_{NG} = 0$$

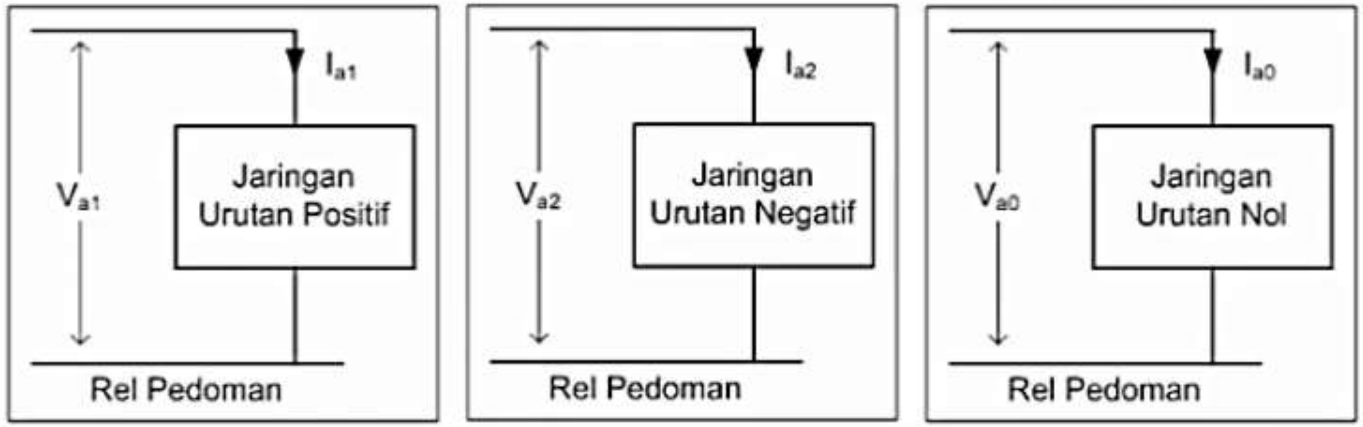


$$V_{nG} = V_{nN} + V_{NG}$$

$$V_{nG} = V_a - Z_a I_a = V_b - Z_b I_b = V_c - Z_c I_c$$



ANALISIS

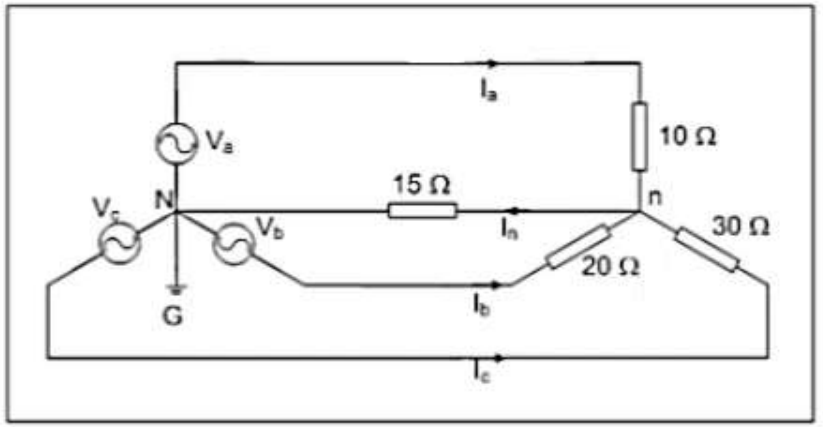


$$I_{a1} + I_{b1} + I_{c1} = 0 \qquad I_{a2} + I_{b2} + I_{c2} = 0$$

- Komponen simetris yang digunakan hanya pada salah satu fasa (misalnya fasa a).
- Pada proses akhir analisis, besaran fasa a, b dan c diperoleh berdasarkan komponen simetris fasa a.

Contoh 2

Tegangan sumber $380/\sqrt{3}$ V fasa ke netral (seimbang). Hitung arus beban, tegangan beban, arus netral dan tegangan netral beban ke ground !



$$[V_{abc}] = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 219.3931\angle 0 \\ 219.3931\angle -120 \\ 219.3931\angle 120 \end{bmatrix} \quad [V_{120}] = [A^{-1}][V_{abc}]$$

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

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

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

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

$$[V_{120}] = \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \begin{bmatrix} 219.3931\angle 0 \\ 0 \\ 0 \end{bmatrix}$$

$$Z_{abc} = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 20 & 0 \\ 0 & 0 & 30 \end{bmatrix}$$

impedansi urutan beban : $Z_{120} = A^{-1}Z_{abc}A$

$$Z_{120\,(beban)} = \begin{bmatrix} 20 & -5+j2{,}8868 & -5-j2{,}8868 \\ -5-j2{,}8868 & 20 & -5+j2{,}8868 \\ -5+j2{,}8868 & -5-j2{,}8868 & 20 \end{bmatrix}$$

Resistansi penghantar netral 15 Ω ,

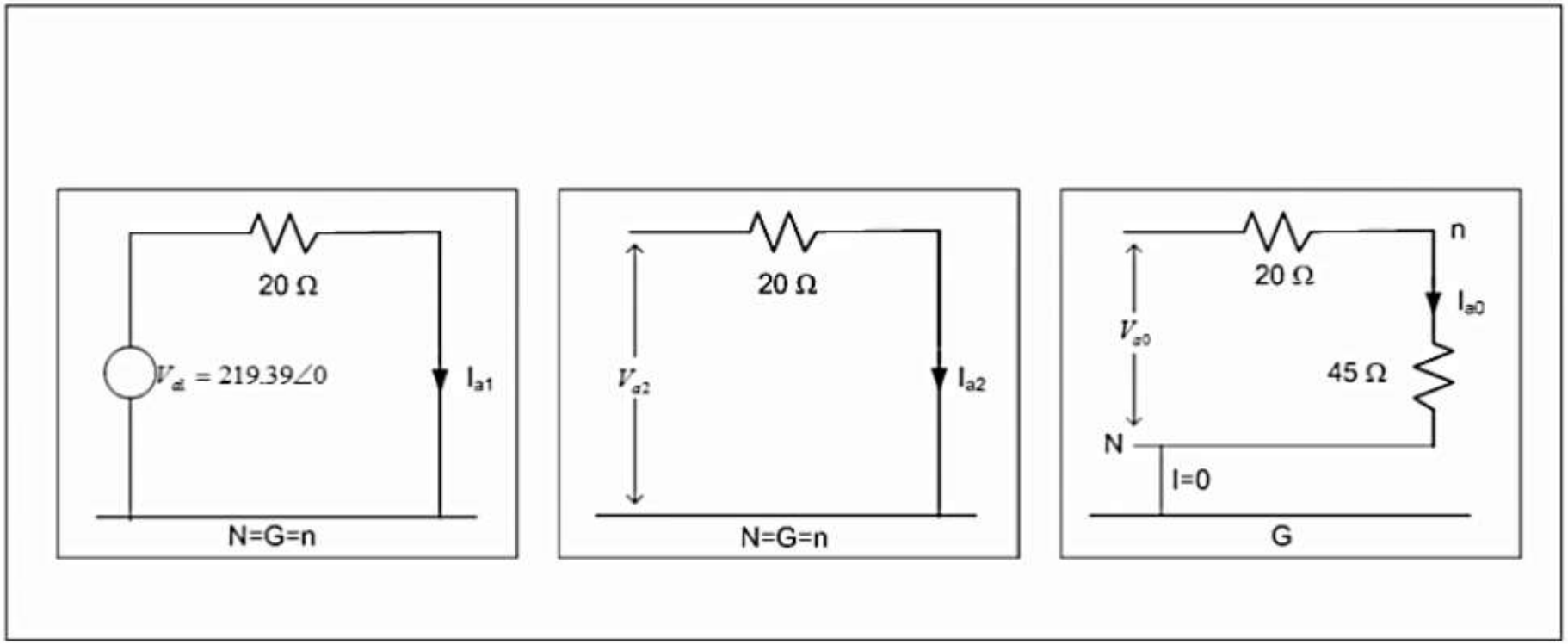
$$Z_0 = 3Z_n = 45$$

Impedansi total untuk urutan nol = 65 Ω

$$Z_{120\,(total)} = \begin{bmatrix} 20 & -5+j2{,}8868 & -5-j2{,}8868 \\ -5-j2{,}8868 & 20 & -5+j2{,}8868 \\ -5+j2{,}8868 & -5-j2{,}8868 & 65 \end{bmatrix}$$

$$[V_{120}] = \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \begin{bmatrix} 219.3931\angle 0 \\ 0 \\ 0 \end{bmatrix}$$

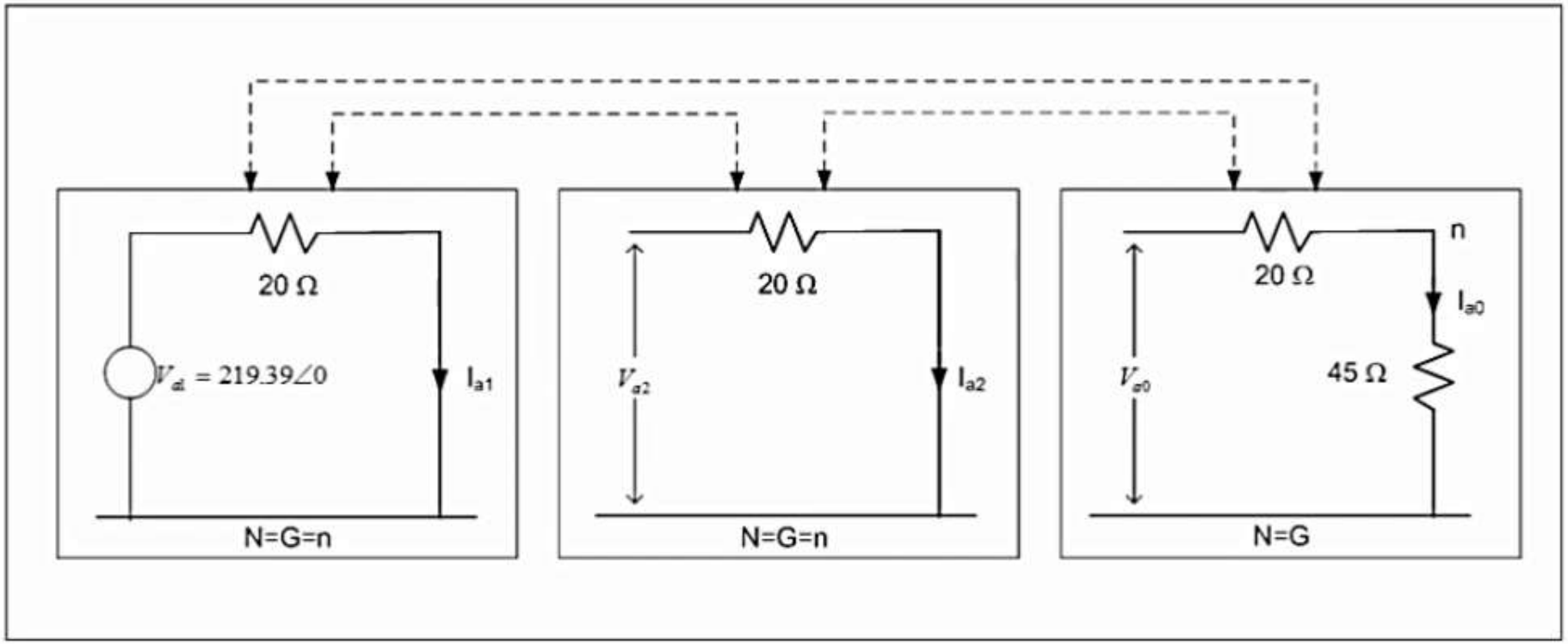
$$Z_{120\,(total)} = \begin{bmatrix} 20 & -5 + j2{,}8868 & -5 - j2{,}8868 \\ -5 - j2{,}8868 & 20 & -5 + j2{,}8868 \\ -5 + j2{,}8868 & -5 - j2{,}8868 & 65 \end{bmatrix}$$



$$[V_{120}] = \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \begin{bmatrix} 219.3931\angle 0 \\ 0 \\ 0 \end{bmatrix}$$

$$Z_{120\,(total)} = \begin{bmatrix} 20 & -5 + j2{,}8868 & -5 - j2{,}8868 \\ -5 - j2{,}8868 & 20 & -5 + j2{,}8868 \\ -5 + j2{,}8868 & -5 - j2{,}8868 & 65 \end{bmatrix}$$

Komponen nondiagonal matriks impedansi urutan ≠ 0. Terdapat gandengan antara jaringan urutan positif, negatif dan nol



$$\begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \begin{bmatrix} 219{,}3931\angle 0 \\ 0 \\ 0 \end{bmatrix}$$

$$Z_{120\,(total)} = \begin{bmatrix} 20 & -5 + j2{,}8868 & -5 - j2{,}8868 \\ -5 - j2{,}8868 & 20 & -5 + j2{,}8868 \\ -5 + j2{,}8868 & -5 - j2{,}8868 & 65 \end{bmatrix}$$

$$[V_{120}] = [Z_{120}][I_{120}]$$

Arus urutan positif, negatif dan nol :

$$[I_{120}] = [Z_{120}]^{-1}[V_{120}]$$

$$\begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \begin{bmatrix} 12.3510\angle 0 \\ 3.6737\angle 24.9 \\ 1.1719\angle -13.9 \end{bmatrix}$$

arus fasa a, b dan c :

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

$$[I_{abc}] = [A][I_{120}]$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ a^2 & a & 1 \\ a & a^2 & 1 \end{bmatrix} \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} \qquad \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 16.8678\angle 4.3 \\ 11.9721\angle -132.2 \\ 8.6255\angle 128.4 \end{bmatrix}$$

Komponen simetris tegangan beban : $[V_{120}] = [Z_{120}][I_{120}]$

$$Z_{120} = \begin{bmatrix} 20 & -5 + j2.8868 & -5 - j2.8868 \\ -5 - j2.8868 & 20 & -5 + j2.8868 \\ -5 + j2.8868 & -5 - j2.8868 & 20 \end{bmatrix} \qquad \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \begin{bmatrix} 12.3510\angle 0 \\ 3.6737\angle 24.9 \\ 1.1719\angle -13.9 \end{bmatrix} \qquad \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \begin{bmatrix} 219.3931\angle 0 \\ 0 \\ 52.7355\angle 166.1 \end{bmatrix}$$

Tegangan beban : $[V_{abc}] = [A][V_{120}]$

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

$$V_a = V_{a1} + V_{a2} + V_{a0} \qquad V_a = 168.6776\angle 4.3$$

$$V_b = a^2 V_{a1} + a V_{a2} + V_{a0} \qquad V_b = 239.4413\angle \text{-}132.2$$

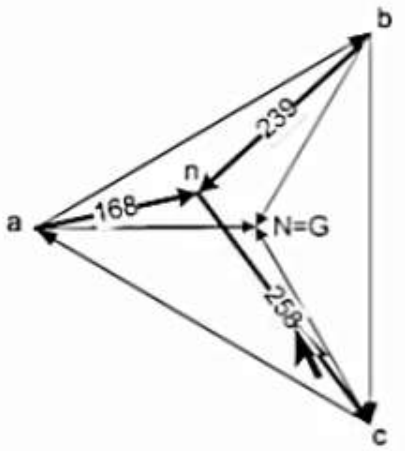
$$V_c = a V_{a1} + a^2 V_{a2} + V_{a0} \qquad V_c = 258.7640\angle 128.4$$

atau :

$$V_a = Z_a I_a$$
$$V_b = Z_b I_b$$
$$V_c = Z_c I_c$$

Arus netral :

$$I_n = 3I_{a0} = 3(1.1719\angle -13.9) = 3.5157\angle -13.9$$

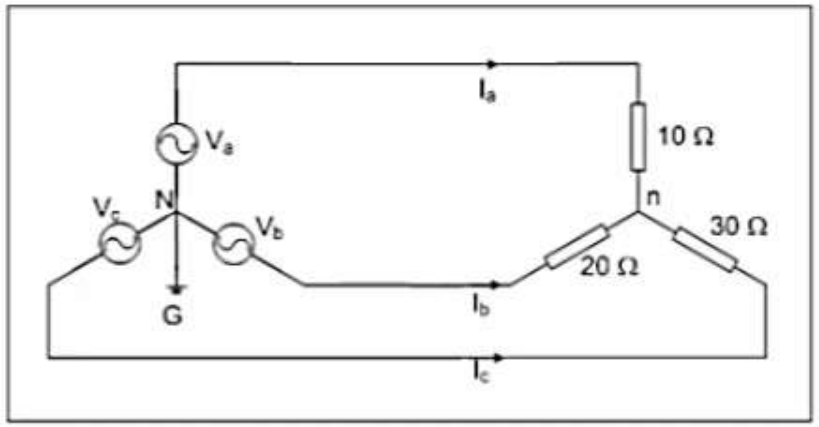


Tegangan netral beban ke ground

$$V_{nG} = I_n \times Z_n = 3.5157\angle -13.9 \times 15 = 52.7355\angle -13.9 \text{ V}$$

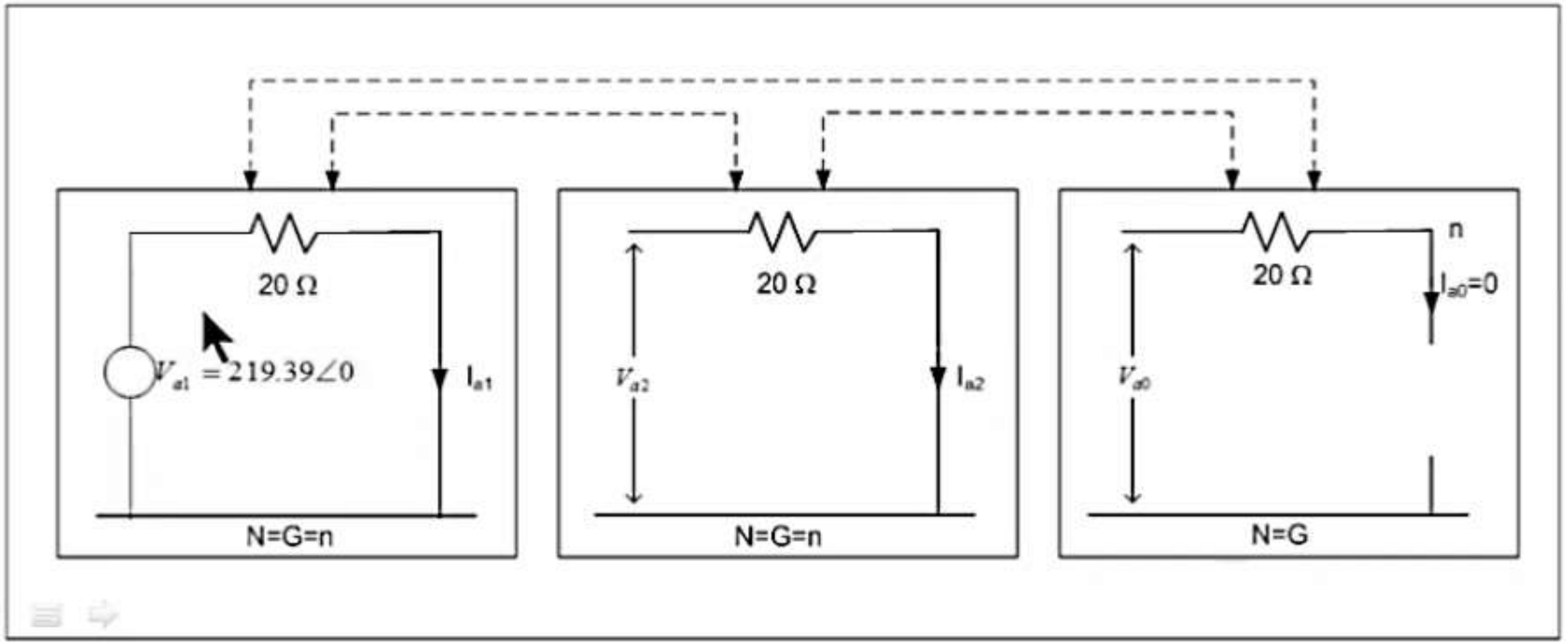
Contoh 3

Jika penghantar netral pada contoh 2 terputus, hitung arus beban, tegangan beban dan tegangan netral beban ke tanah



$$[V_{120}] = \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \begin{bmatrix} 219.3931\angle 0 \\ 0 \\ 0 \end{bmatrix}$$

$$Z_{120(total)} = \begin{bmatrix} 20 & -5+j2{,}8868 & -5-j2{,}8868 \\ -5-j2{,}8868 & 20 & -5+j2{,}8868 \\ -5+j2{,}8868 & -5-j2{,}8868 & \infty \end{bmatrix}$$



$$[I_{120}] = [Z_{120}]^{-1}[V_{120}]$$

Impedansi urutan nol nilainya tak berhingga, arus urutan nol = 0. Matriks yang digunakan hanya baris/kolom 1 dan 2.

$$\begin{bmatrix} V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 219{,}3931\angle 0 \\ 0 \end{bmatrix} \qquad Z_{12} = \begin{bmatrix} 20 & -5 + j2{,}8868 \\ -5 - j2{,}8868 & 20 \end{bmatrix}$$

Arus urutan positif, dan negatif : $[V_{12}] = [Z_{12}][I_{12}]$

$[I_{12}] = [Z_{12}]^{-1}[V_{12}]$ $\quad \begin{bmatrix} I_{a1} \\ I_{a2} \end{bmatrix} = \begin{bmatrix} 11{,}9669\angle 0 \\ 3.4545\angle 30 \end{bmatrix}$

Arus fasa a, b dan c : $\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ a^2 & a & 1 \\ a & a^2 & 1 \end{bmatrix} \begin{bmatrix} I_{a1} \\ I_{a2} \\ 0 \end{bmatrix} \quad \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 15.0580\angle 6.6 \\ 12.4555\angle \text{-}136.1 \\ 9.1399\angle 130.9 \end{bmatrix}$

Komp. simetris tegangan beban : $[V_{120}] = [Z_{120}][I_{120}]$

$$Z_{120} = \begin{bmatrix} 20 & -5 + j2{,}8868 & -5 - j2{,}8868 \\ -5 - j2{,}8868 & 20 & -5 + j2{,}8868 \\ -5 + j2{,}8868 & -5 - j2{,}8868 & 20 \end{bmatrix} \quad \begin{bmatrix} I_{a1} \\ I_{a2} \\ I_{a0} \end{bmatrix} = \begin{bmatrix} 11.9669\angle 0 \\ 3.4545\angle 30 \\ 0 \end{bmatrix} \quad \begin{bmatrix} V_{a1} \\ V_{a2} \\ V_{a0} \end{bmatrix} = \begin{bmatrix} 219.39\angle 0 \\ 0 \\ 71.9\angle 166.1 \end{bmatrix}$$

Tegangan beban : $[V_{abc}] = [A][V_{120}]$ atau :

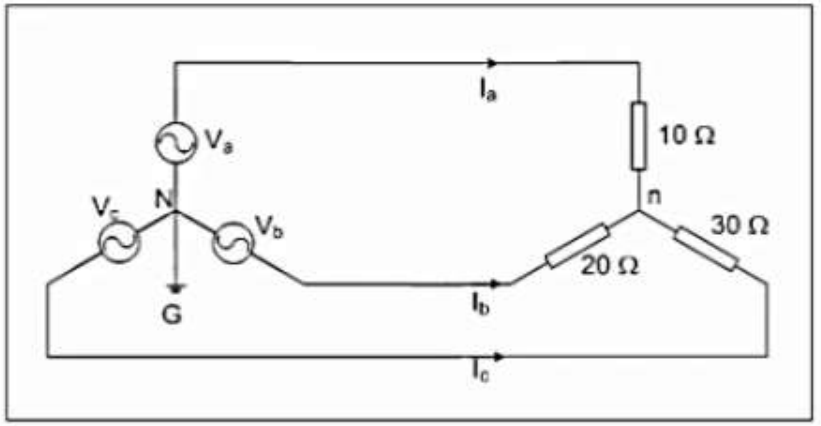
$V_a = Z_a I_a$ $\quad V_a = 150.5801\angle 6.6$

$V_b = Z_b I_b$ $\quad V_b = 249.1108\angle \text{-}136.1$

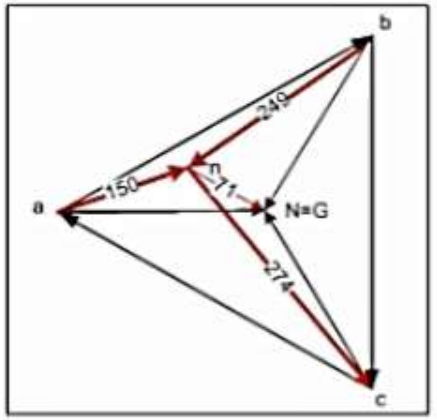
$V_c = Z_c I_c$ $\quad V_c = 274.1960\angle 130.9$

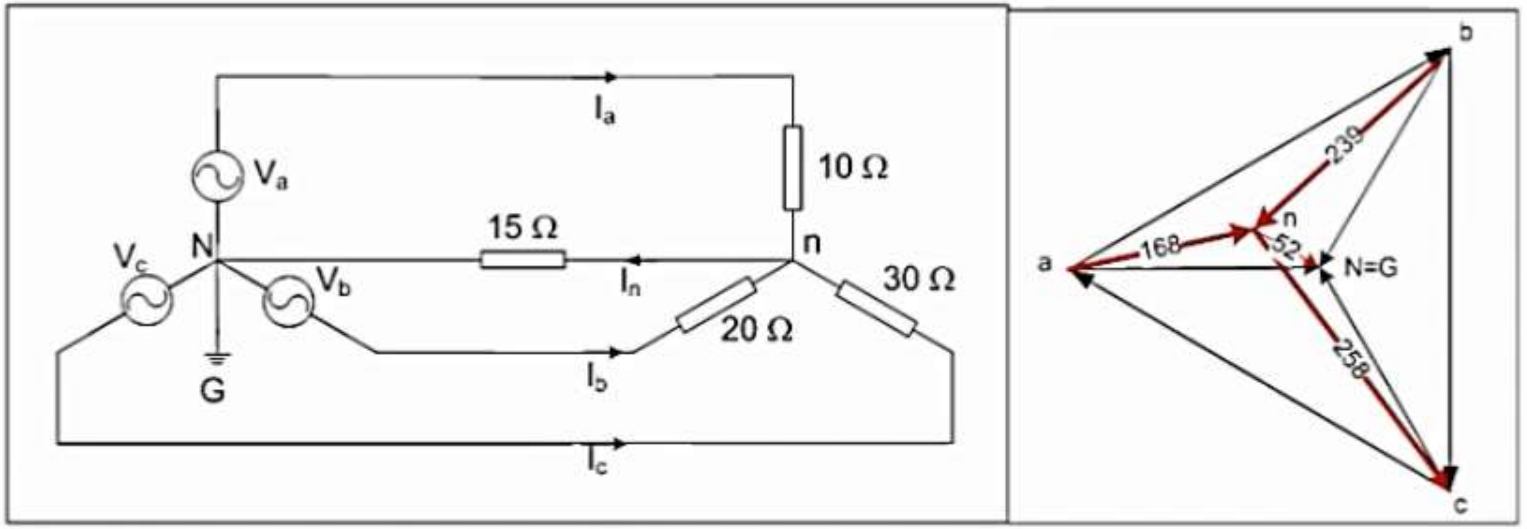
Tegangan netral beban ke ground : $V_{nG} = 219{,}3931\angle 0 - 150.5801\angle 6.6$

$$V_{nG} = 71{,}9\angle -13.9$$

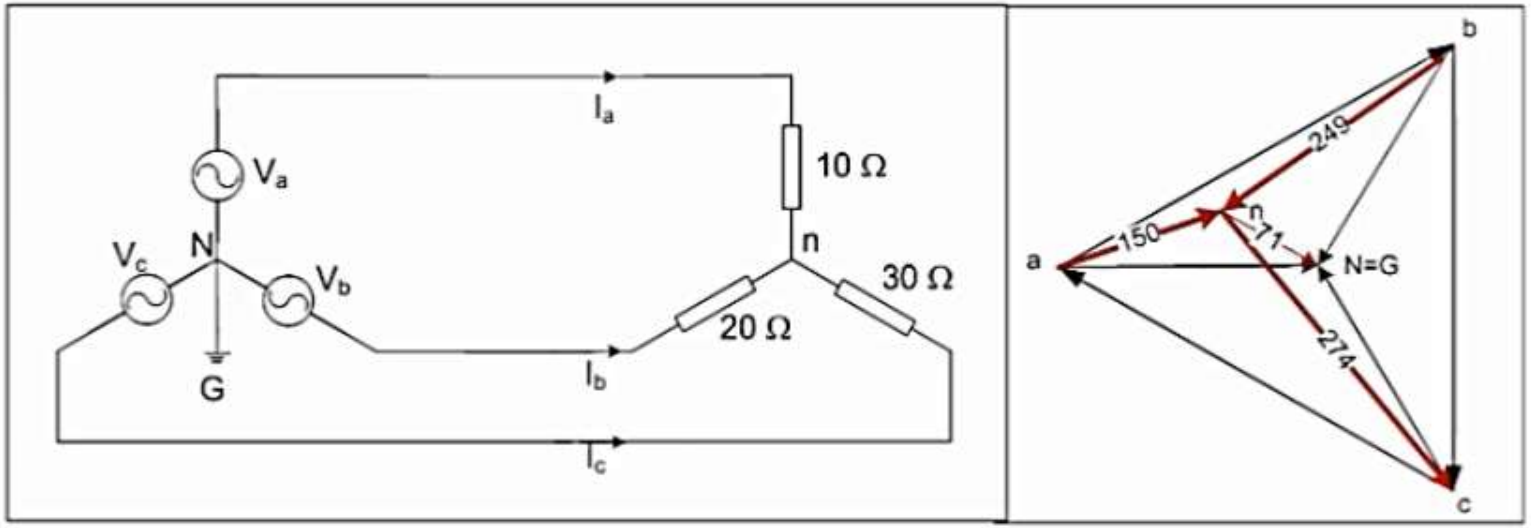


$$V_a = 150.5801\angle 6.6$$
$$V_b = 249.1108\angle -136.1$$
$$V_c = 274.1960\angle 130.9$$




I_a
V_a
10 Ω
15 Ω
N
n
V_c
V_b
I_n
30 Ω
20 Ω
G
I_b
I_c

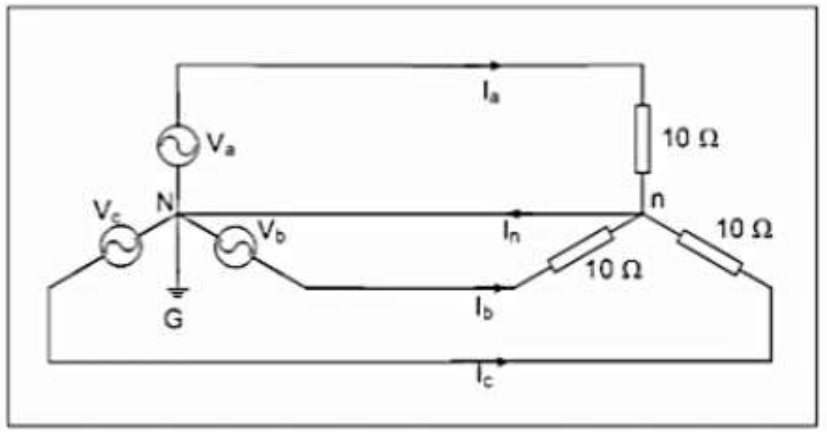
b
239
n
a
168
52
N=G
258
c


I_a
V_a
10 Ω
N
n
V_c
V_b
30 Ω
20 Ω
G
I_b
I_c

b
249
a
150
71
N=G
274
c

```
%Contoh 2, 3
clear all; clc
%============================================================
teg_sumber_fasa_a = 380/sqrt(3); sdt_sumber_fasa_a = 0;
teg_sumber_fasa_b = 380/sqrt(3); sdt_sumber_fasa_b = -120;
teg_sumber_fasa_c = 380/sqrt(3); sdt_sumber_fasa_c = 120;
Za = 10 ; Zb = 20 ; Zc = 30;
Zn = 15 ;
%============================================================
a = cosd(120)+1i*sind(120);A = [1 1 1;a^2 a 1;a a^2 1];
Va = teg_sumber_fasa_a * (cosd(sdt_sumber_fasa_a) + i*sind(sdt_sumber_fasa_a));
Vb = teg_sumber_fasa_b * (cosd(sdt_sumber_fasa_b) + i*sind(sdt_sumber_fasa_b));
Vc = teg_sumber_fasa_c* (cosd(sdt_sumber_fasa_c) + i*sind(sdt_sumber_fasa_c)); V_fasa = [Va ; Vb ; Vc]
Va_sumber_120 = inv(A) * V_fasa ;Z0 = 3*Zn;Zabc_beban = [Za 0 0;0 Zb 0;0 0 Zc];
Z120beban = inv(A)*Zabc_beban*A ;Z120 =  Z120beban
Z120(3,3) = Z120beban(3,3) + Z0 %impedansi urutan total
I_120 = inv(Z120)*Va_sumber_120;I_abc = A*I_120; V_120_beban = Z120beban *I_120;
V_abc_beban = A*V_120_beban;
magnitude_I_120 = abs(I_120);sudut_I_120 = angle(I_120)*180/pi;
magnitude_I_abc =abs(I_abc)
sudut_I_abc =angle(I_abc)*180/pi
magnitude_V_abc_beban = abs(V_abc_beban)
sudut_V_abc_beban = angle(V_abc_beban)*180/pi
arus_netral = abs(I_120(3))*3
mag_V_nG = abs(I_120(3)*3*Zn) % V_NG = 0
sudut_V_nG = angle(I_120(3)*3*Zn)*180/pi
```

Contoh 4



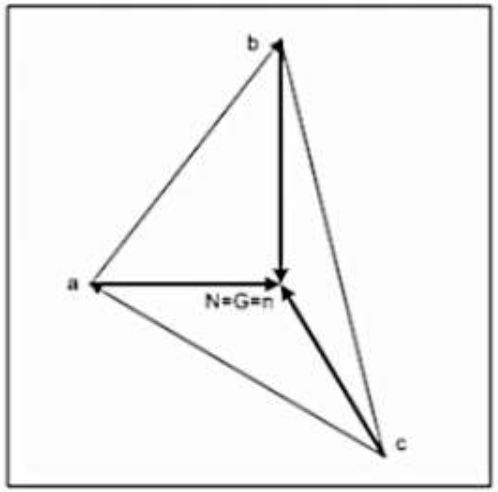
Tegangan fasa ke netral :

$$V_a = 180\angle 0$$
$$V_b = 250\angle -90$$
$$V_c = 220\angle 100$$

Hitung magnitude arus & magnitude tegangan beban, tegangan netral ke ground. Abaikan impedansi penghantar.

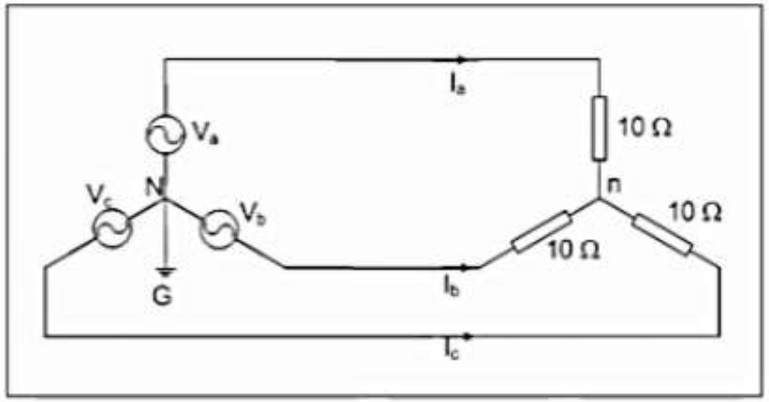
$$V_a = 180\angle 0 \qquad I_a = 18\angle 0 \ \text{A}$$
$$V_b = 250\angle -90 \qquad I_b = 25\angle -90 \ \text{A}$$
$$V_c = 220\angle 100 \qquad I_c = 22\angle 100 \ \text{A}$$

$$V_{nG} = V_{nN} = 0$$



Contoh 5

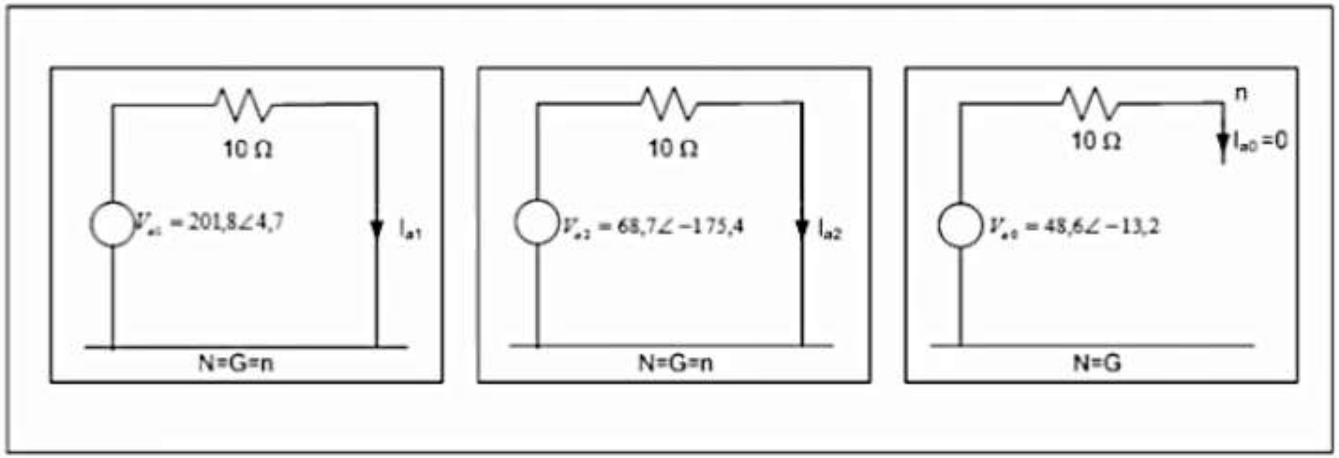
Jika penghantar netral pada contoh 4 terputus, hitung arus beban, tegangan beban dan tegangan netral beban ke tanah



$$V_a = 180\angle 0$$
$$V_b = 250\angle -90$$
$$V_c = 220\angle 100$$

$$[V_{120}] = [A^{-1}][V_{abc}]$$
$$V_{a1} = 201{,}8\angle 4{,}7$$
$$V_{a2} = 68{,}6\angle -175{,}4$$
$$V_{a0} = 48{,}6\angle -13{,}2$$

$$Z_{abc} = \begin{bmatrix} Z_a & 0 & 0 \\ 0 & Z_b & 0 \\ 0 & 0 & Z_c \end{bmatrix} = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & 10 \end{bmatrix} \qquad Z_{120} = A^{-1} Z_{abc} A = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & 10 \end{bmatrix}$$



$$Z_{120(total)} = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & \infty \end{bmatrix}$$

$$V_{a1} = 201{,}8\angle 4{,}7$$
$$V_{a2} = 68{,}6\angle -175{,}4$$
$$V_{a0} = 48{,}6\angle -13{,}2$$

$$Z_{120\,(total)} = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & \infty \end{bmatrix}$$

$$[I_{120}] = [Z_{120}]^{-1}[V_{120}]$$
$$I_{a1} = 20{,}18\angle 4{,}7$$
$$I_{a2} = 6{,}86\angle -175{,}4$$
$$I_{a0} = 0$$

$$[I_{abc}] = [A][I_{120}]$$
$$I_a = 13{,}3\angle 4.78 \text{ A}$$
$$I_b = 24{,}4\angle -101.19 \text{ A}$$
$$I_c = 24{,}3\angle 110.56 \text{ A}$$

Komponen simetris tegangan beban : $[V_{120}] = [Z_{120}][I_{120}]$

$$Z_{120(beban)} = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & 10 \end{bmatrix}$$

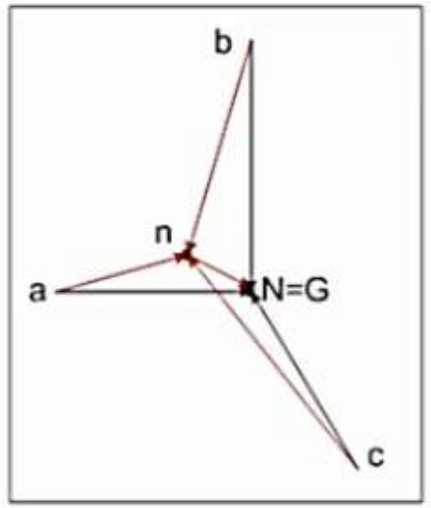
$$I_{a1} = 20{,}18\angle 4{,}7$$
$$I_{a2} = 6{,}86\angle -175{,}4$$
$$I_{a0} = 0$$

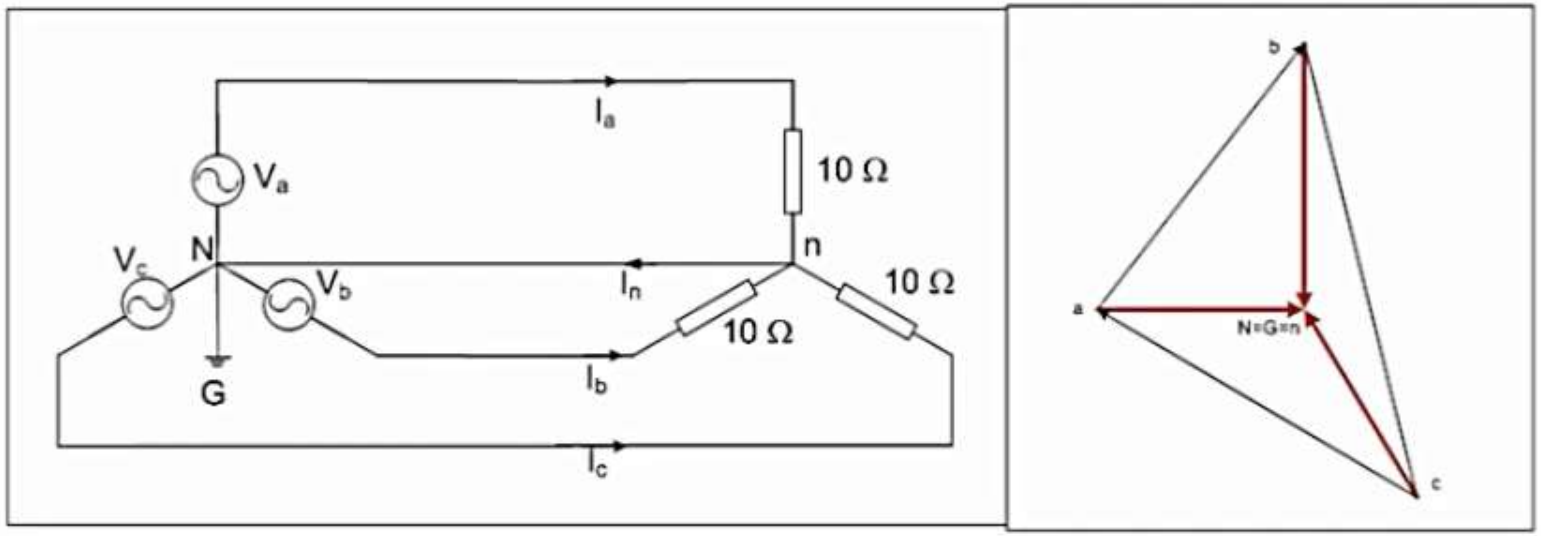
$$V_{a1} = 201{,}8\angle 4{,}7$$
$$V_{a2} = 68{,}6\angle -175{,}4$$
$$V_{a0} = 0$$

Tegangan beban : $[V_{abc}] = [A][V_{120}]$

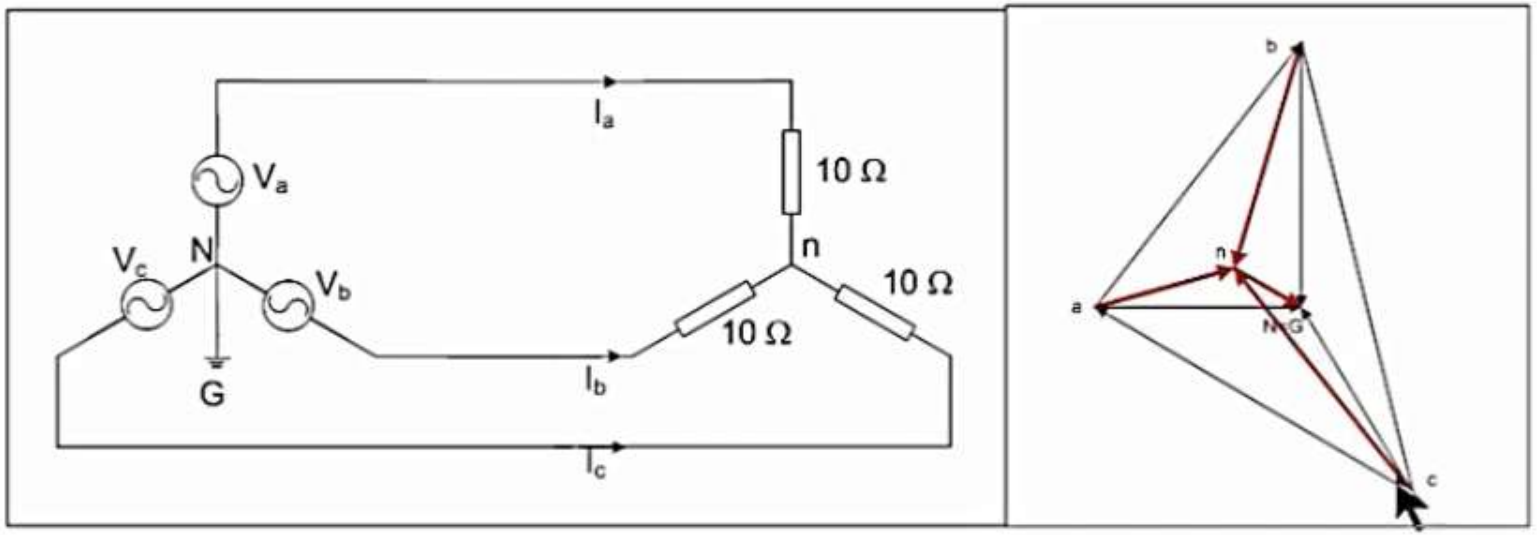
$$V_a = 133\angle 4.78 \text{ V}$$
$$V_b = 244\angle -101.19 \text{ V}$$
$$V_c = 243\angle 110.56 \text{ V}$$

$$V_{NG} = 0$$
$$V_{nN} = V_{nG} = 48{,}6\angle -13{,}2$$




I_a
V_a
10 Ω
V_c
N
n
V_b
I_n
10 Ω
10 Ω
G
I_b
I_c

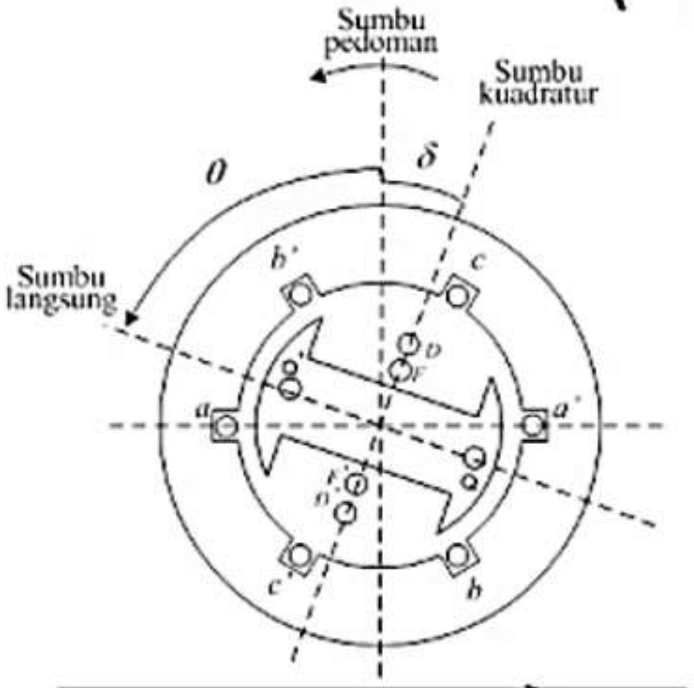
b
a
N=G=n
c

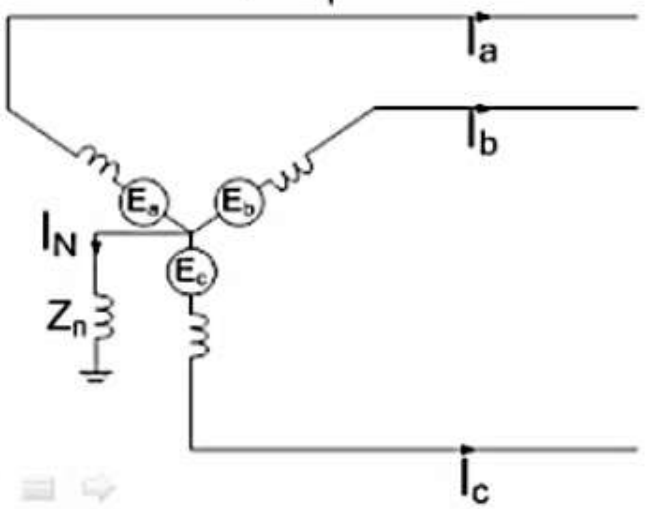

I_a
V_a
10 Ω
V_c
N
n
V_b
10 Ω
10 Ω
G
I_b
I_c

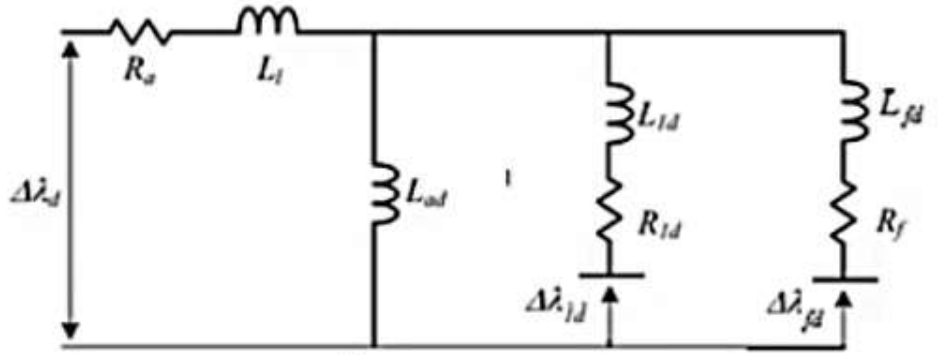
b
n
a
N G
c

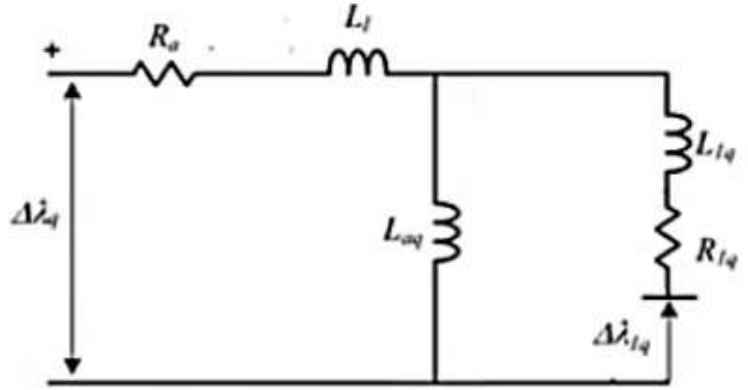
```
%Contoh 5
clear all; clc
%============================================================
teg_sumber_fasa_a = 180;  sdt_sumber_fasa_a = 0;
teg_sumber_fasa_b = 250;  sdt_sumber_fasa_b = -90;
teg_sumber_fasa_c = 220;  sdt_sumber_fasa_c = 100;
Za = 10 ; Zb = 10 ; Zc = 10;
Zn = 999999999 ;
%============================================================
a = cosd(120)+1i*sind(120);A = [1 1 1;a^2 a 1;a a^2 1];
Va = teg_sumber_fasa_a * (cosd(sdt_sumber_fasa_a) + i*sind(sdt_sumber_fasa_a));
Vb = teg_sumber_fasa_b  * (cosd(sdt_sumber_fasa_b) + i*sind(sdt_sumber_fasa_b));
Vc = teg_sumber_fasa_c* (cosd(sdt_sumber_fasa_c) + i*sind(sdt_sumber_fasa_c)); V_fasa = [Va ; Vb ; Vc]
Va_sumber_120 = inv(A) * V_fasa ;Z0 = 3*Zn;Zabc_beban = [Za 0 0;0 Zb 0;0 0 Zc];
Z120beban = inv(A)*Zabc_beban*A ;Z120 =  Z120beban
Z120(3,3) = Z120beban(3,3) + Z0 %impedansi urutan total
I_120 = inv(Z120)*Va_sumber_120;I_abc = A*I_120; V_120_beban = Z120beban *I_120;
V_abc_beban = A*V_120_beban;
magnitude_I_120 = abs(I_120);sudut_I_120 = angle(I_120)*180/pi;
magnitude_I_abc =abs(I_abc)
sudut_I_abc =angle(I_abc)*180/pi
magnitude_V_abc_beban = abs(V_abc_beban)
sudut_V_abc_beban = angle(V_abc_beban)*180/pi
arus_netral = abs(I_120(3))*3
mag_V_nG = abs(I_120(3)*3*Zn) % V_NG = 0
sudut_V_nG = angle(I_120(3)*3*Zn)*180/pi
```

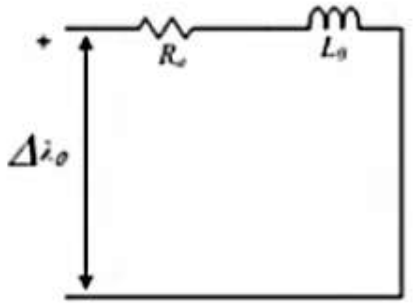
Impedansi Urutan Generator
(Lihat lampiran)

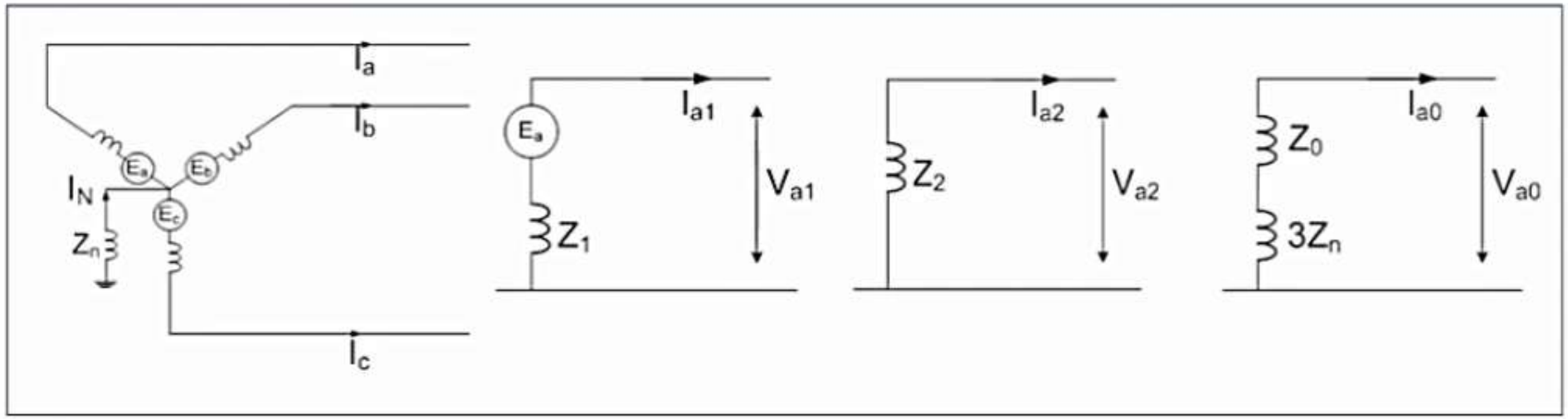


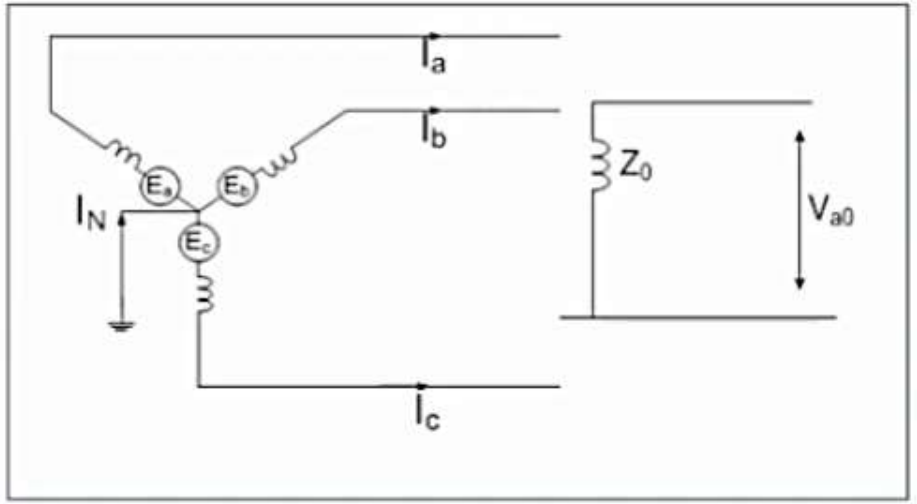


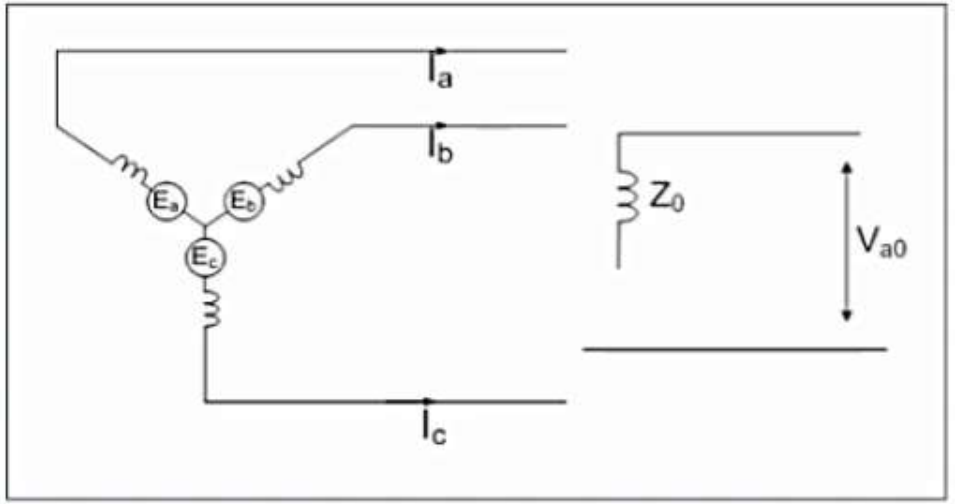










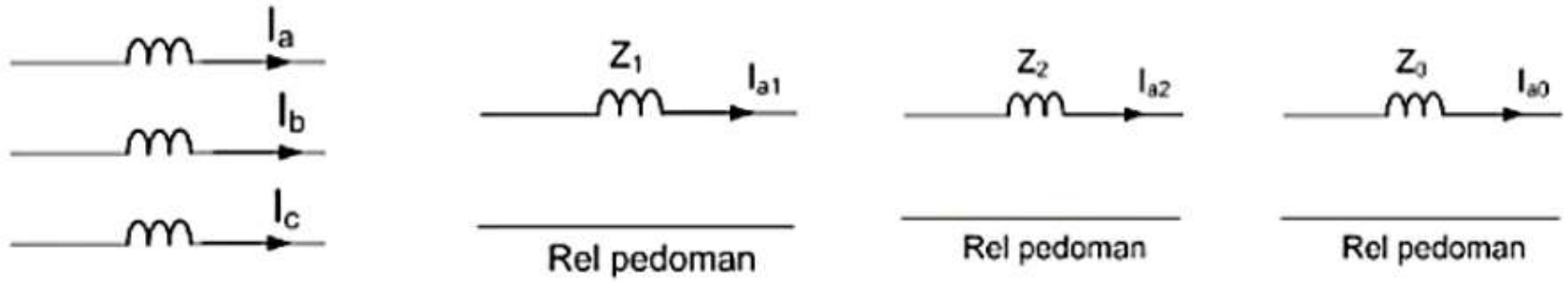


$Z_1 \neq Z_2 \neq Z_0$

Tegangan internal generator adalah tegangan seimbang sehingga tidak terdapat komponen sumber tegangan urutan negatif dan nol

Impedansi Urutan Saluran

- Gandengan fluks magnet yang ditimbulkan oleh arus urutan negatif pada saluran sama seperti gandengan fluks yang ditimbulkan oleh arus urutan positif. Reaktansi urutan negatif sama dengan urutan positif.
- Arus urutan nol memiliki sudut fasa yang sama sehingga medan magnet yang ditimbulkan oleh arus urutan nol sangat berbeda dengan medan magnet yang ditimbulkan oleh arus urutan positif. Nilai reaktans urutan nol saluran adalah dua sampai tiga kali lebih besar dari reaktans urutan positifnya

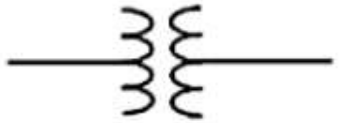


$$Z_1 = Z_2 \neq Z_0$$

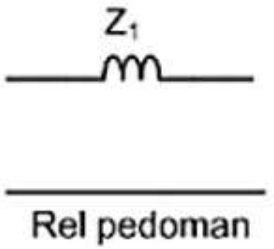
Impedansi Urutan Transformator

- Reaktansi urutan trafo 3 fasa yang terdiri dari 3 buah trafo satu fasa memiliki nilai yang sama.
- Pada satu unit trafo 3 fasa, reaktansi urutan nolnya sedikit berbeda dengan reaktansi urutan positif dan negatif akibat konstruksi trafo yang menggunakan satu inti.
- Umumnya reaktansi urutan trafo 3 fasa dianggap sama.

$$Z_1 = Z_2 = Z_0$$



Urutan positif/negatif :



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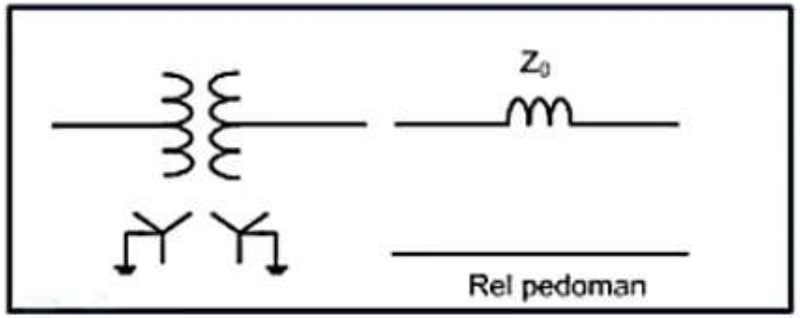
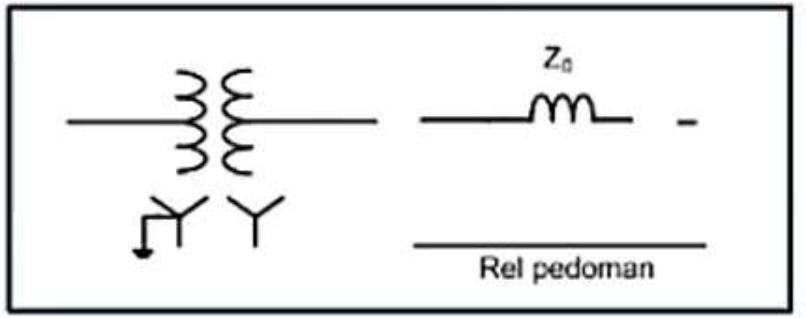
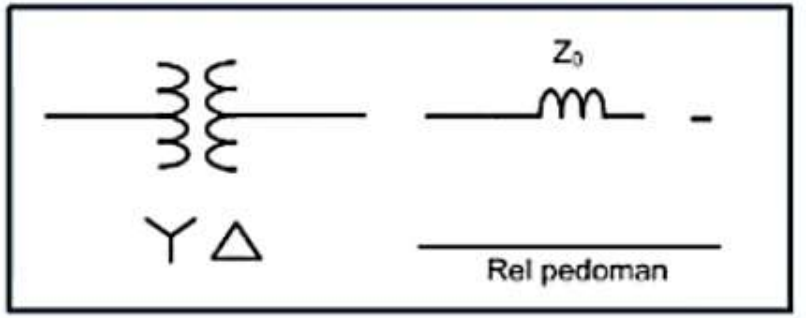
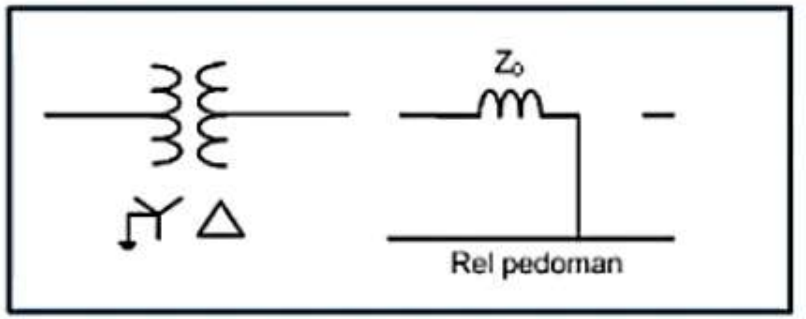
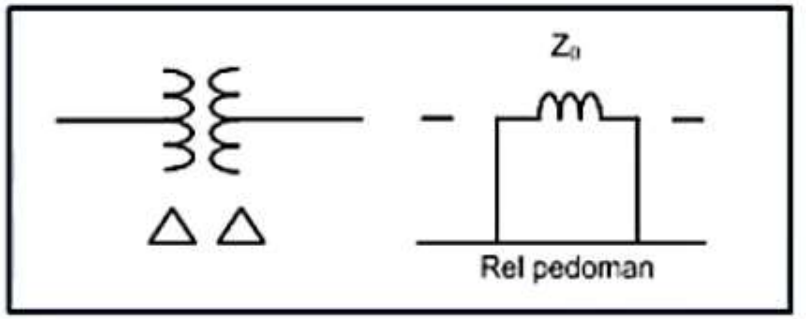




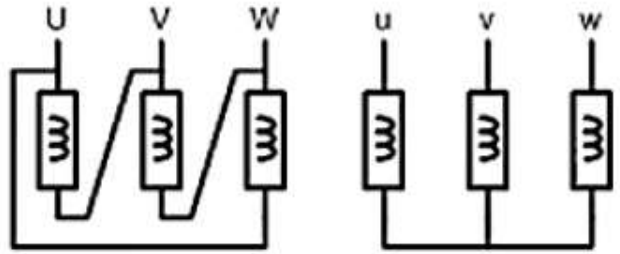


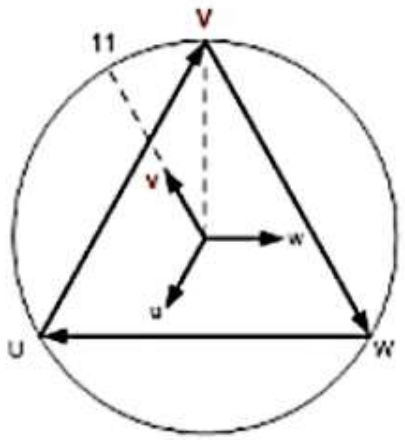


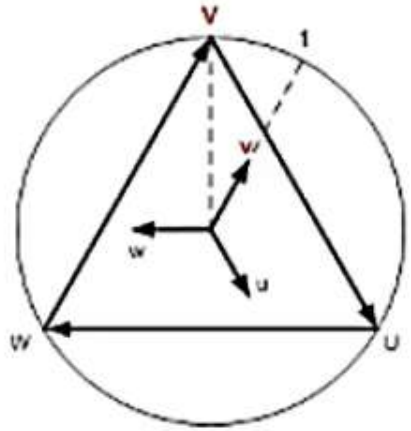


Pergeseran Fasa Komponen Urutan Positif & Negatif (VDE0532, Jerman)

Contoh Δy11 :



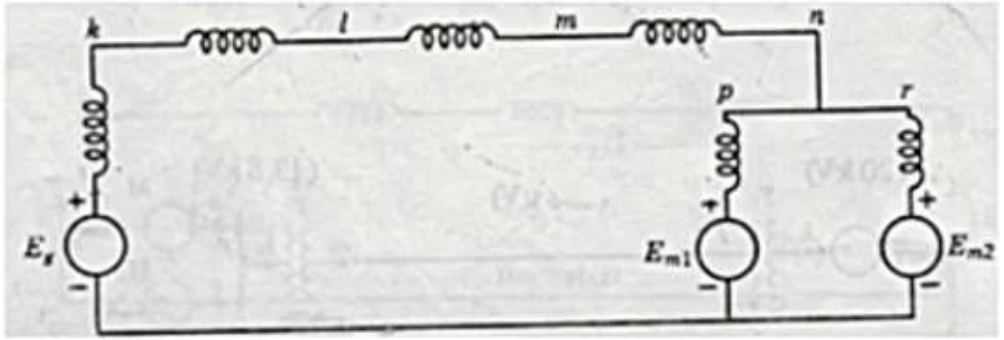


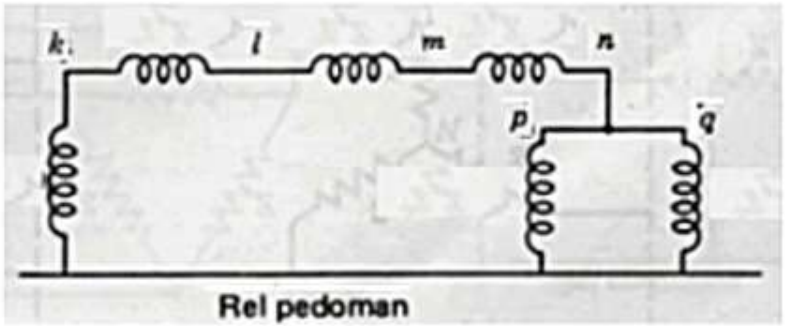


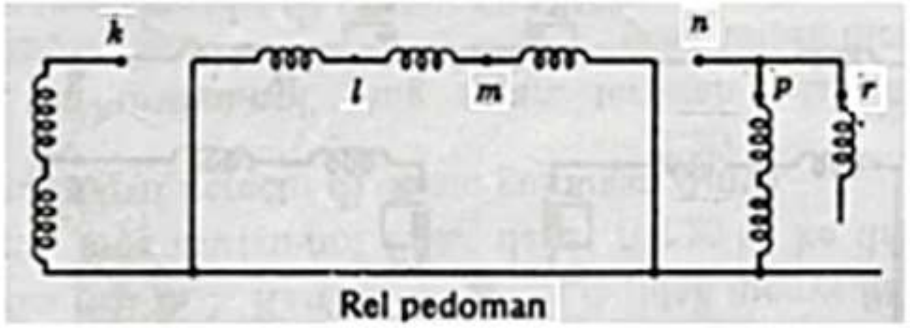
- Tegangan & arus urutan positif : sisi y mendahului 30°
- Tegangan & arus urutan negatif : sisi y tertinggal 30°

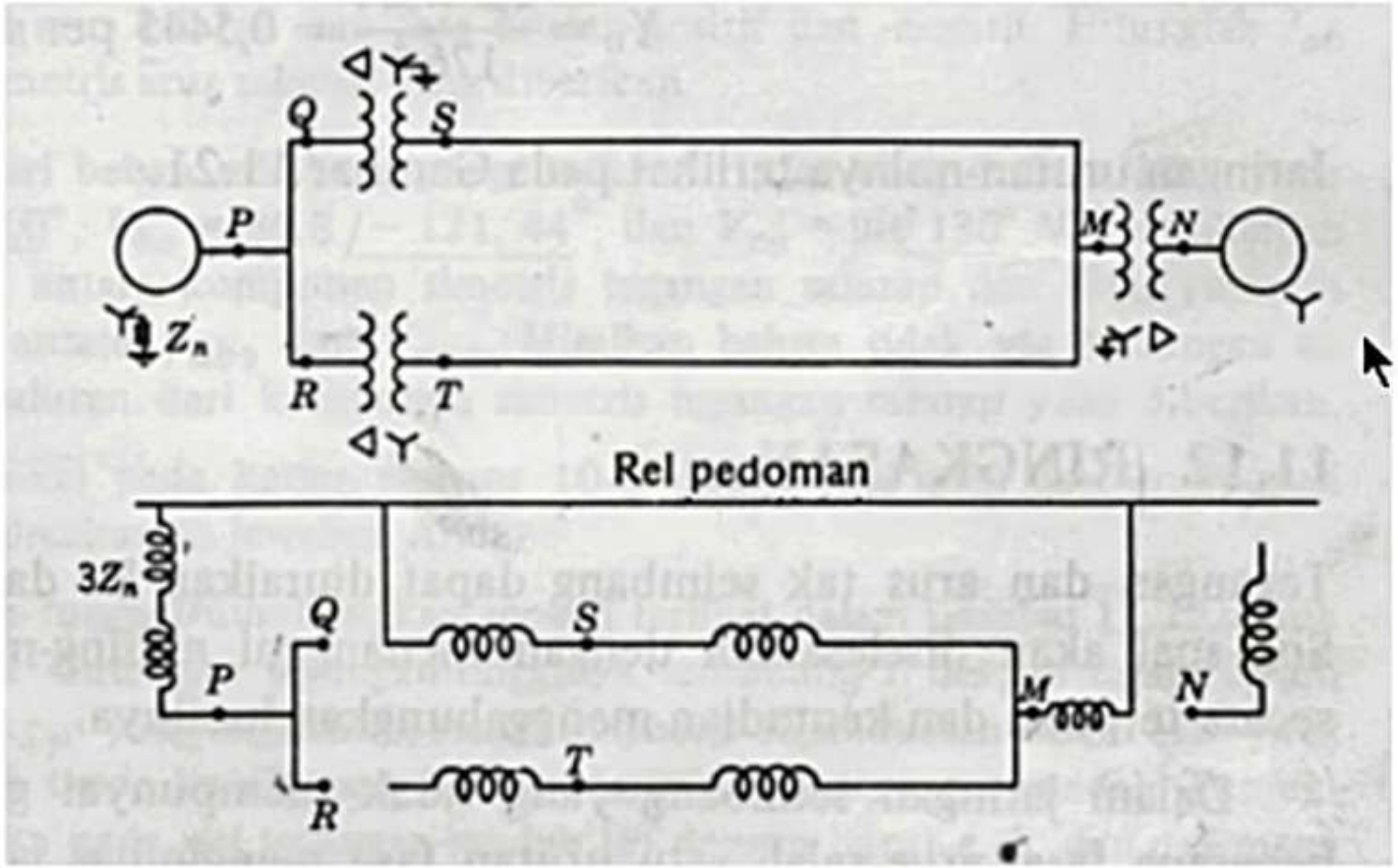
YΔ5?

Jaringan Urutan





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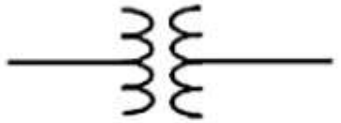
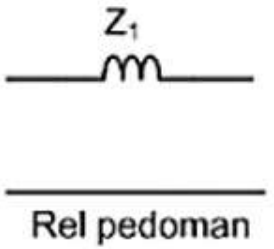
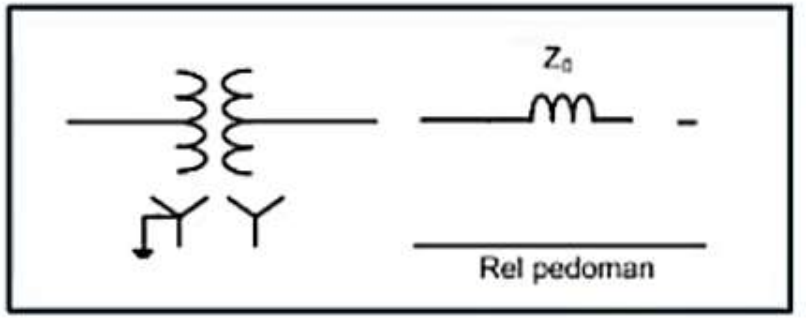
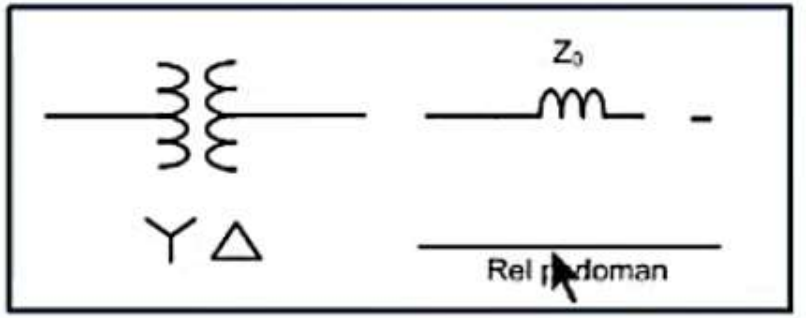
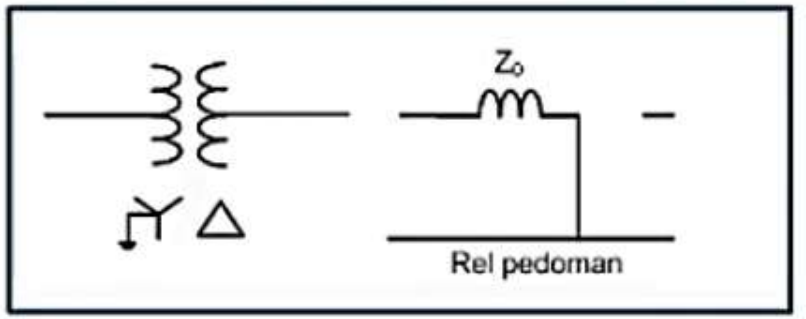


Urutan positif/negatif :

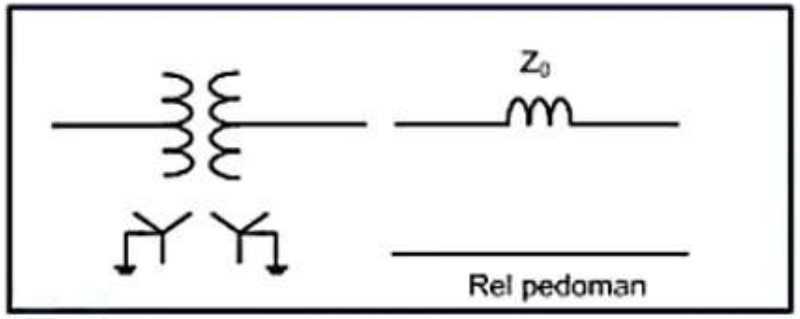


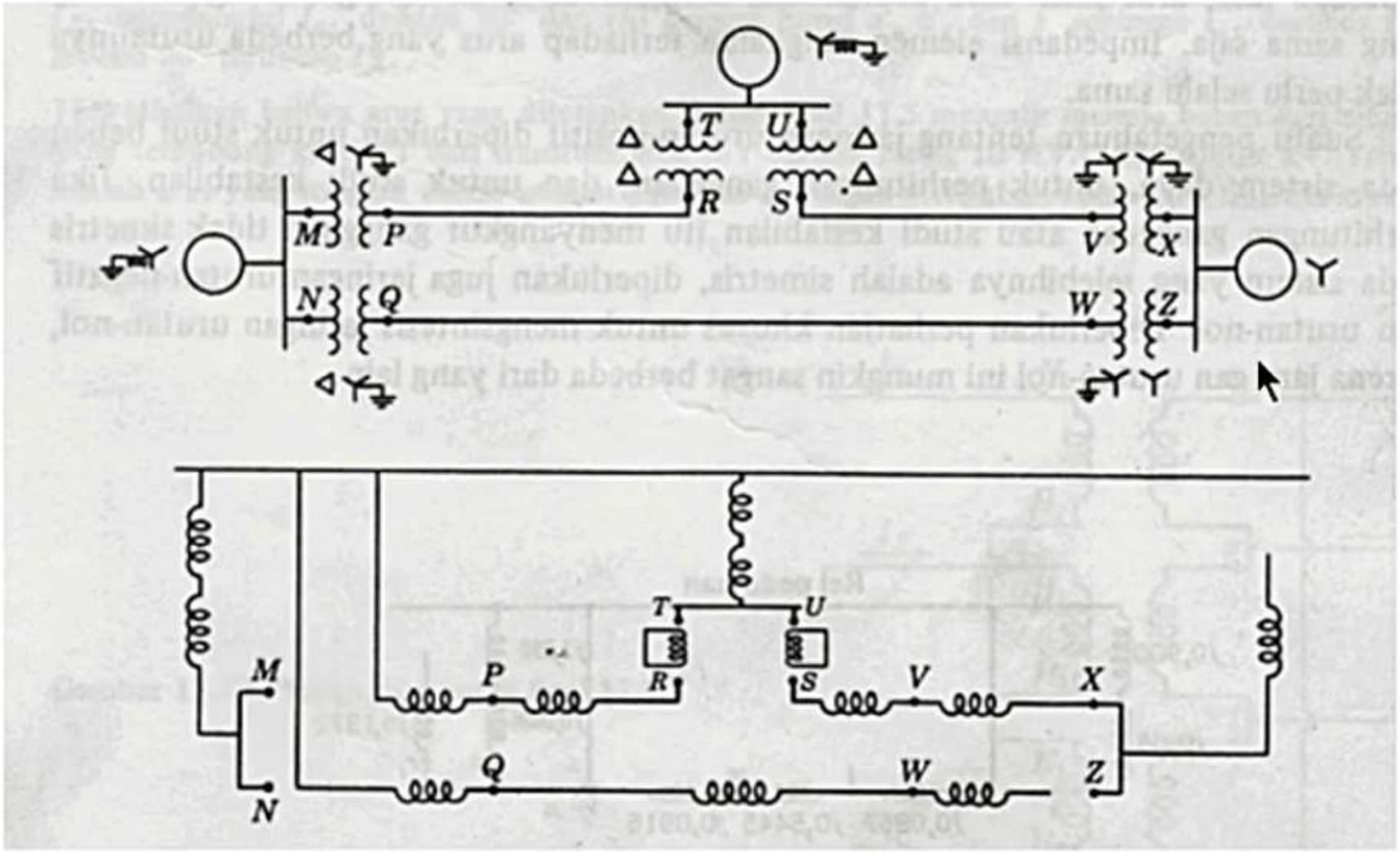






Urutan nol :

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ANALISIS SISTEM TIDAK SEIMBANG

- Bentuk jaringan urutan berdasarkan peralatan yang menyusun jaringan.
- Bentuk matriks admitansi dari setiap jaringan
- Hitung matriks admitansi beban pada setiap bus
- Gabungkan matriks admitansi jaringan dan beban
- Selesaikan dengan konsep komponen simetris dan teori rangkaian (persamaan simpul, thevenin, dll)

Tugas : Dihitunng manual

Contoh 6

Generator (10 MVA, 380 V)

- Impedans urutan positif = j0,8 pu
- Impedans urutan negatif =j0,3 pu
- Impedans urutan nol = j0,1 pu
- Pentanahan Zn = j0,1

Transformator (10 MVA, 20 kV/ 380 V) :

- Impedans urutan positif = j0,1 pu
- Impedans urutan negatif = j0,1 pu
- Impedans urutan nol = j0,1 pu
- Pentanahan sisi Y, Zn = 0

Saluran (nilai pu atas dasar 20 kV, 10 MVA)

- Impedans urutan positif = j0,2 pu
- Impedans urutan negatif = j0,2 pu
- Impedans urutan nol = j0,6 pu

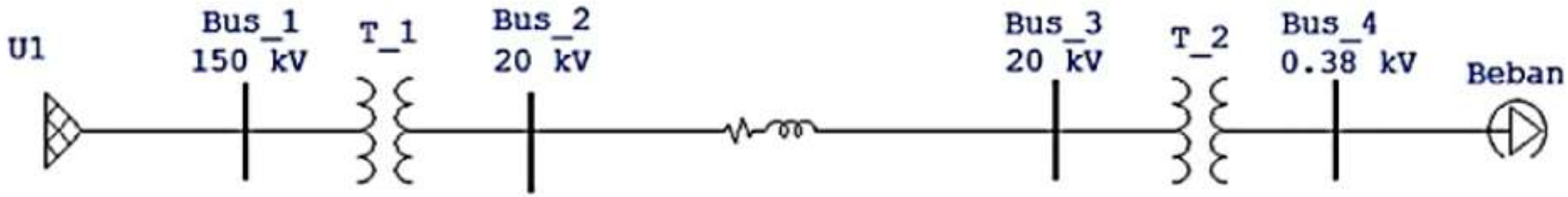
Beban resistif hubung Y (impedansi pu beban atas dasar 20 kV, 10 MVA)

- Fasa a : 2 pu
- Fasa b : 3 pu
- Fasa c : 5 pu
- Pentanahan beban : pentanahan langsung Zn =0

Jika tegangan internal generator 450 V, hitung tegangan beban !

ETAP, Dipandu Azzam .

SIMULASI



- Sumber : Power Grid : Z1=Z2= j0,1 pu, Z0 = j0,3 pu
- T1 : 30 MVA, 150/ 20 kV X = 10%.
- T2 : 3 MVA, 20/0,38 kV X = 10%.
- Saluran : menggunakan kabel alumunium, resistansi 0.2162 ohm/km, diameter 1,4 cm, GMR 0.00524 m, tinggi 15 m, jarak antar penghantar : 1 meter, dengan konfigurasi horizontal
- Beban nominal fasa a, b dan c : 1 MVA, 220 V, PF = 0,85
- Beban fasa a : 30 %, fasa b : 60 % fasa c : 100%

Contoh 6

Generator (10 MVA, 380 V)

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- Impedans urutan nol = j0,1 pu
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Jika tegangan internal generator 450 V, hitung tegangan beban !