Symmetrical Components and Sequence Networks

Symmetrical components

- The method of symmetrical components is a powerful technique for analyzing unbalanced three phase systems.
- It is a linear transformation that transforms from phase components to a new set of components called symmetrical components.
- The advantage of this transformation for balanced three phase networks the equivalent circuit obtained called the sequence network are separated into three uncoupled networks.
- For unbalanced three phase systems, the three sequence networks are connected only at point of unbalance.

Symmetrical components

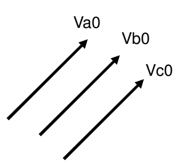
- Assume that a set of three phase voltages designated V_a, V_b and V_c is given.
- These phase voltages are resolved into the following three sets of sequence components:

a) *Zero sequence components:* consisting of three phasors with equal magnitudes and zero phase displacement.

b) *Positive sequence components:* consisting of three phasors with equal magnitudes and 120 phase displacement and positive sequence.

c) *Negative sequence components:* consisting of three phasors with equal magnitudes and 120 phase displacement and negative sequence.

Symmetrical components

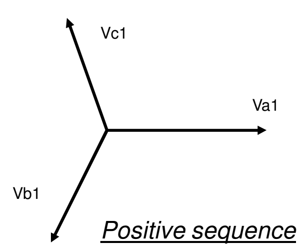


Zero sequence components

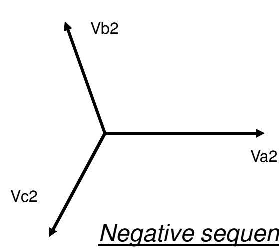
$$V_a = V_{a1} + V_{a2} + V_{a0}$$

$$V_b = V_{b1} + V_{b2} + V_{b0}$$

$$V_c = V_{c1} + V_{c2} + V_{c0}$$

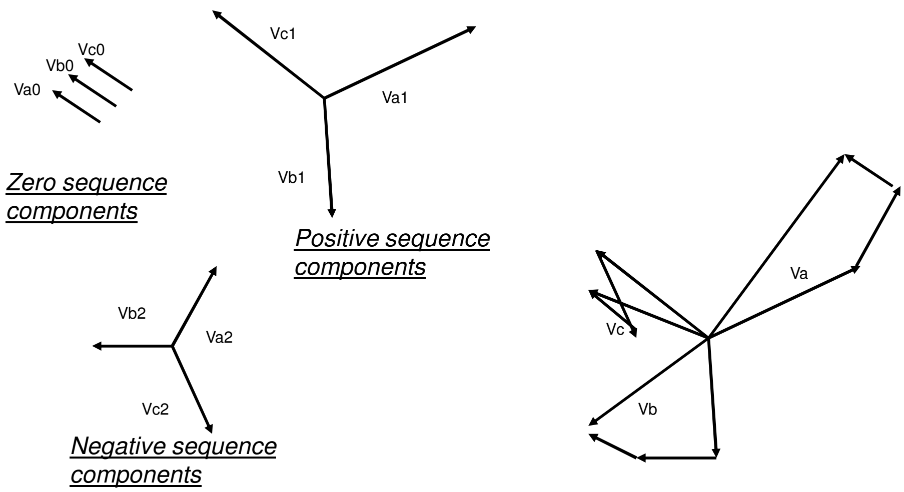


Positive sequence components



Negative sequence components

Symmetrical components



Symmetrical components

$V_a = V_{a1} + V_{a2} + V_{a0}$ $V_b = V_{b1} + V_{b2} + V_{b0}$ $V_c = V_{c1} + V_{c2} + V_{c0}$

Let us define the following operator a as follows:

$$a = 1\angle 120 \Longrightarrow a^2 = 1\angle 240$$

$$\left.\begin{aligned} V_{b1} &= a^2 V_{a1} & V_{c1} &= aV_{a1} \\ V_{b2} &= aV_{a2} & V_{c2} &= a^2 V_{a2} \\ V_{b0} &= V_{a0} & V_{c0} &= V_{a0} \end{aligned}\right\} \quad \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix}$$

Symmetrical components

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

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

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

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

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

Symmetrical components

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

• This equation shows that no zero sequence components exists if the sum of the unbalanced phasors is zero.

• Since the sum of the line-line voltage phasors in a three phase system is always zero (Why?), zero sequence components are never present in the line voltages regardless of the amount of unbalance.

• However, the sum of the three line-neutral voltage phasors is not necessary zero and hence line-neutral voltages may contain zero sequence components.

Symmetrical components

The previous set of equations can be written for currents as well as shown below:

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

$$I_b = I_{b1} + I_{b2} + I_{b0}$$

$$I_c = I_{c1} + I_{c2} + I_{c0}$$

$$\Rightarrow$$

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

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

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

In a three phase system, the sum of the line currents is equal to the current I_n in the return path

$$(I_a + I_b + I_c) = I_n \Rightarrow I_n = 3I_{a0}$$

- Symmetrical Components don't have a separate existence. They are only mathematical components of unbalanced currents which flow in the system.
- In a balanced 3 Phase system, zero and negative sequence currents are zero.
- The presence of zero or negative sequence currents introduces the unsymmetry

Example 1:

Calculate the sequence components of the following balanced line-neutral voltages with abc sequence:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} 277\angle 0 \\ 277\angle -120 \\ 277\angle +120 \end{bmatrix}$$

Solution:

$$V_0 = \frac{1}{3}(V_a + V_b + V_c) = 0$$

$$V_1 = \frac{1}{3}(V_a + aV_b + a^2 V_c) = 277\angle 0$$

$$V_2 = \frac{1}{3}(V_a + a^2 V_b + aV_c) = 0$$

Example 2:

A Y connected load has balanced currents with acb sequence as follows, find the sequence currents:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 10\angle 0 \\ 10\angle +120 \\ 10\angle -120 \end{bmatrix}$$

Solution:

$$I_0 = \frac{1}{3}(I_a + I_b + I_c) = 0$$

$$I_1 = \frac{1}{3}(I_a + aI_b + a^2 I_c) = 0$$

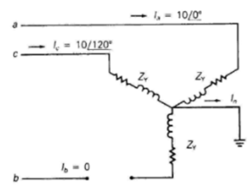
$$I_2 = \frac{1}{3}(I_a + a^2 I_b + aI_c) = 10\angle 0$$

Example 3:

A three phase line feeding a balanced Y load has on of its phases (phase b) open. The load neutral is grounded and the unbalanced currents are

Calculate the sequence and neutral currents:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 10\angle 0 \\ 0 \\ 10\angle 120 \end{bmatrix}$$



Solution:

$$I_0 = \frac{1}{3}(I_a + I_b + I_c) = 3.33\angle 60$$

$$I_1 = \frac{1}{3}(I_a + aI_b + a^2 I_c) = 6.67\angle 0$$

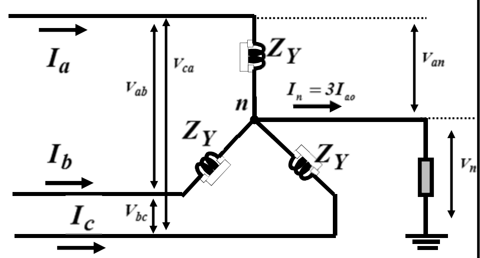
$$I_2 = \frac{1}{3}(I_a + a^2 I_b + aI_c) = 3.33\angle -60$$

$$I_n = (I_a + I_b + I_c) = 10\angle 60$$

OR

$$I_n = 3I_0 = 10\angle 60$$

<u>1. The Sequence circuits for Wye and Delta connected loads</u>



For the star connected load with grounded neutral point,

$$I_n = I_a + I_b + I_c$$

Representing the unbalance currents with their symmetrical components we get:

$$I_n = I_{ao} + I_{a1} + I_{a2} + I_{bo} + I_{b1} + I_{b2} + I_{co} + I_{c1} + I_{c2}$$

$$I_n = I_{ao} + I_{bo} + I_{co} + \underbrace{I_{a1} + I_{b1} + I_{c1}}_{zero} + \underbrace{I_{a2} + I_{b2} + I_{c2}}_{zero}$$

Since the positive and negative sequence components are add to zero at the neutral point, therefore there is ***no positive or negative sequence components flow from the neutral to the ground***.

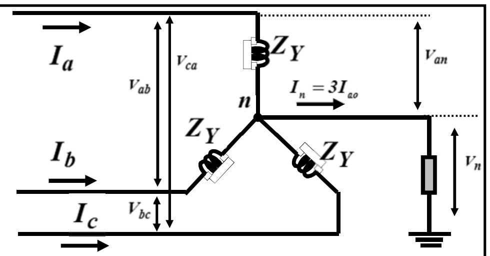
$$I_n = 3I_{ao}$$

Under unbalance condition:

$$I_n = 3I_{ao}$$

The voltage drop between neutral and ground is:

$$V_n = I_n Z_n = 3I_{ao}Z_n$$



It is very important to distinguish between voltages to neutral and voltages to ground.

$$V_a = V_{an} + V_n = V_{an} + 3I_{ao}Z_n$$

For *unbalance three phase system*, the phase voltages are:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} + \begin{bmatrix} V_n \\ V_n \\ V_n \end{bmatrix} = Z_Y \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + 3I_{ao}Z_n \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

Using the symmetrical components:

$$A\begin{bmatrix} V_{ao} \\ V_{a1} \\ V_{a2} \end{bmatrix} = Z_Y \; A\begin{bmatrix} I_{ao} \\ I_{a1} \\ I_{a2} \end{bmatrix} + 3I_{ao}Z_n \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

Multiplying by A^{-1}

$$\begin{bmatrix} V_{ao} \\ V_{a1} \\ V_{a2} \end{bmatrix} = Z_Y \begin{bmatrix} I_{ao} \\ I_{a1} \\ I_{a2} \end{bmatrix} + 3I_{ao}Z_n \; A^{-1}\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} V_{ao} \\ V_{a1} \\ V_{a2} \end{bmatrix} = Z_Y \begin{bmatrix} I_{ao} \\ I_{a1} \\ I_{a2} \end{bmatrix} + 3I_{ao}Z_n \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

OR

$$V_{ao} = (Z_Y + 3Z_n)I_{ao}$$

$$V_{ao} = Z_o \; I_{ao} \qquad \textit{Eq. 1}$$

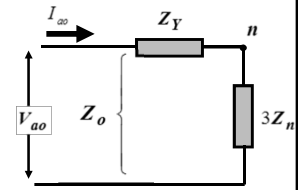
$$V_{a1} = Z_Y I_{a1} \qquad \textit{Eq. 2}$$

$$V_{a2} = Z_Y I_{a2} \qquad \textit{Eq. 3}$$

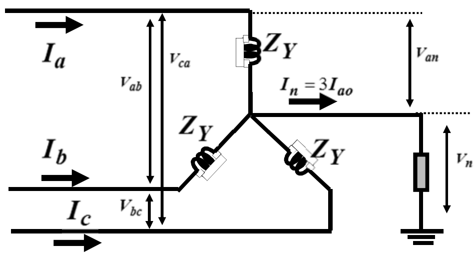
Using the three previous equations (*Eqs. 1, 2 and 3*) then the Symmetrical circuits for a Wye-connected load with neutral point connected to ground is:

$$V_{ao} = (Z_Y + 3Z_n)I_{ao}$$

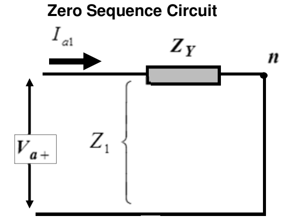
$$Z_o = Z_Y + 3Z_n$$



Zero Sequence Circuit

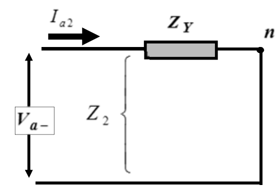


$$V_{a1} = Z_Y I_{a1}$$



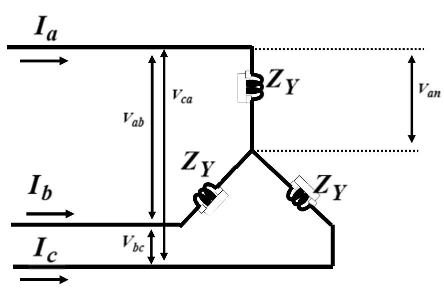
Positive Sequence Circuit

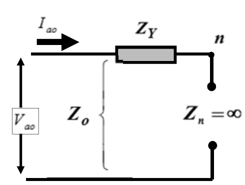
$$V_{a2} = Z_Y I_{a2}$$



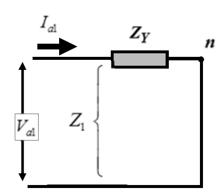
Negative Sequence Circuit

Y-connected load (Isolated Neutral):





Zero Sequence Circuit

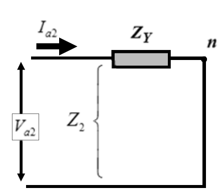


Positive Sequence Circuit

If the neutral point of a Y-connected load is not grounded, therefore, no zero sequence current can flow, and

$$Z_n = \infty$$

Symmetrical circuits for Y-connected load with neutral point is not connected to ground are presented as shown:



Negative Sequence Circuit

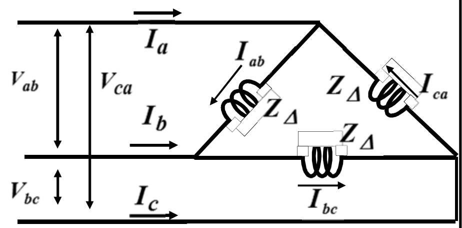
Delta connected load:

The Delta circuit can not provide a path through neutral. Therefore for a *Delta connected load* or its *equivalent Y-connected* can not contain any zero sequence components.

$$V_{ab} = Z_{\Delta} I_{ab}$$

$$V_{bc} = Z_{\Delta} I_{bc}$$

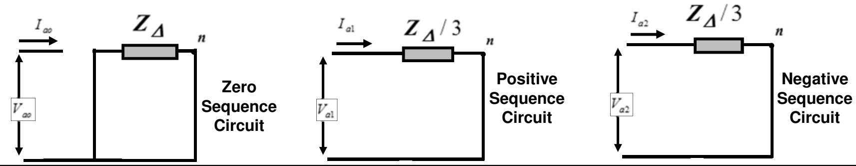
$$V_{ca} = Z_{\Delta} I_{ca}$$



The summation of the line-to-line voltages or phase currents are always zero

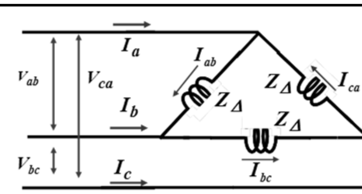
$$\frac{1}{3}(V_{ab} + V_{bc} + V_{ca}) = V_{ab0} = 0 \quad \textbf{and} \quad \frac{1}{3}(I_{ab} + I_{bc} + I_{ca}) = I_{ab0} = 0$$

Therefore, for a ***Delta-connected loads*** without sources or mutual coupling there will be no zero sequence currents at the lines (There are *some cases where a circulating currents may circulate inside a delta load and not seen at the terminals of the zero sequence circuit*).



Example:

The Delta circuit have balanced impedances of 21 ohms. Determine the sequence impedances.



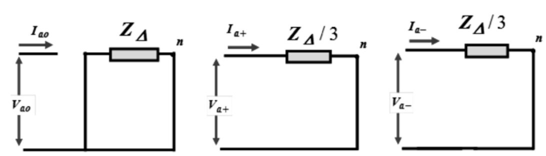
Solution:

The positive- and negative-sequence circuits have *per-phase* impedance

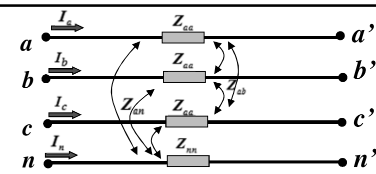
$$Z_1 = Z_{\Delta} / 3 = 7\Omega$$

$$Z_2 = Z_{\Delta} / 3 = 7\Omega$$

The zero-sequence circuit have *per-phase* impedance of 21 ohms. The zero sequence current is circulating in Delta circuit.



2. Sequence Circuits of Transmission Lines

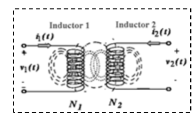


Consider a symmetrical transmission line where,

Z_{aa}: is the self-impedance and is the same for each phase $Z_{aa} = Z_{bb} = Z_{cc}$
Z_{ab}: is the mutual-impedance between each two phases $Z_{ab} = Z_{ac} = Z_{bc}$
Z_{nn}: is the self-impedance of the neutral conductor
Z_{an}: is the mutual-impedance between the neutral and each phase $Z_{an} = Z_{bn} = Z_{cn}$

Using KVL

$$V_{an} = Z_{aa}I_a + Z_{ab}I_b + Z_{ab}I_c + Z_{an}I_n + V_{a'n'} - Z_{an}I_a - Z_{an}I_b - Z_{an}I_c - Z_{nn}I_n$$



$V_1 = j\omega L_1 I_1 + j\omega M_{12} I_2$

The voltage drop across the line section is:

$$V_{an} - V_{a'n'} = (Z_{aa} - Z_{an})I_a + (Z_{ab} - Z_{an})I_b + (Z_{ab} - Z_{an})I_c + (Z_{an} - Z_{nn})I_n$$

$$V_{an} - V_{a'n'} = (Z_{aa} - Z_{an})I_a + (Z_{ab} - Z_{an})(I_b + I_c) + (Z_{an} - Z_{nn})I_n \qquad \text{Eq. 1}$$

Similarly, for phases b and c:

$$V_{bn} - V_{b'n'} = (Z_{aa} - Z_{an})I_b + (Z_{ab} - Z_{an})(I_a + I_c) + (Z_{an} - Z_{nn})I_n \qquad \text{Eq. 2}$$

$$V_{cn} - V_{c'n'} = (Z_{aa} - Z_{an})I_c + (Z_{ab} - Z_{an})(I_a + I_b) + (Z_{an} - Z_{nn})I_n \qquad \text{Eq. 3}$$

The neutral current is:

$$I_n = -(I_a + I_b + I_c) \qquad \text{Eq. 4}$$

Substituting Eq. 4 into Eqs. 1,2 and 3

$$V_{an} - V_{a'n'} = (Z_{aa} - Z_{an})I_a + (Z_{ab} - Z_{an})(I_b + I_c) + (Z_{an} - Z_{nn})(-I_a - I_b - I_c)$$

$$V_{an} - V_{a'n'} = (\underline{Z_{aa} + Z_{nn} - 2Z_{an}})I_a + (\underline{Z_{ab} + Z_{nn} - 2Z_{an}})I_b + (\underline{Z_{ab} + Z_{nn} - 2Z_{an}})I_c$$

$$V_{bn} - V_{b'n'} = (\underline{Z_{ab} + Z_{nn} - 2Z_{an}})I_a + (\underline{Z_{aa} + Z_{nn} - 2Z_{an}})I_b + (\underline{Z_{ab} + Z_{nn} - 2Z_{an}})I_c$$

$$V_{cn} - V_{c'n'} = (\underline{Z_{ab} + Z_{nn} - 2Z_{an}})I_a + (\underline{Z_{ab} + Z_{nn} - 2Z_{an}})I_b + (\underline{Z_{aa} + Z_{nn} - 2Z_{an}})I_c$$

Let:

$$Z_s = \underline{Z_{aa} + Z_{nn} - 2Z_{an}}$$

$$Z_m = \underline{Z_{ab} + Z_{nn} - 2Z_{an}}$$

Then, the voltage drops across the lines are

$$\begin{bmatrix} V_{aa'} \\ V_{bb'} \\ V_{cc'} \end{bmatrix} = \begin{bmatrix} V_{an} - V_{a'n'} \\ V_{bn} - V_{b'n'} \\ V_{cn} - V_{c'n'} \end{bmatrix} = \begin{bmatrix} Z_s & Z_m & Z_m \\ Z_m & Z_s & Z_m \\ Z_m & Z_m & Z_s \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

Using symmetrical components and rearranging the impedance matrix, we get:

$$A \begin{bmatrix} V_{aa'0} \\ V_{aa'1} \\ V_{aa'2} \end{bmatrix} = \left\{ \begin{bmatrix} (Z_s - Z_m) & 0 & 0 \\ 0 & (Z_s - Z_m) & 0 \\ 0 & 0 & (Z_s - Z_m) \end{bmatrix} + \begin{bmatrix} Z_m & Z_m & Z_m \\ Z_m & Z_m & Z_m \\ Z_m & Z_m & Z_m \end{bmatrix} \right\} A \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

Multiplying by A^{-1}

$$\begin{bmatrix} V_{aa'0} \\ V_{aa'1} \\ V_{aa'2} \end{bmatrix} = A^{-1} \left\{ (Z_s - Z_m) \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} + Z_m \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \right\} A \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

Or,

$$\begin{bmatrix} V_{aa'0} \\ V_{aa'1} \\ V_{aa'2} \end{bmatrix} = \begin{bmatrix} (Z_s + 2Z_m) & 0 & 0 \\ 0 & (Z_s - Z_m) & 0 \\ 0 & 0 & (Z_s - Z_m) \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{b1} \\ I_{c2} \end{bmatrix}$$

Therefore,

$$Z_o = Z_s + 2Z_m$$

$$Z_1 = Z_s - Z_m$$

$$Z_2 = Z_s - Z_m$$

Where,

$$Z_s = Z_{aa} + Z_{nn} - 2Z_{an}$$

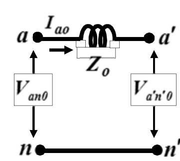
$$Z_m = Z_{ab} + Z_{nn} - 2Z_{an}$$

Substituting for Z_s and Z_m

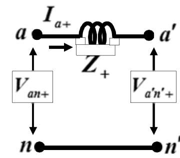
$$Z_o = Z_s + 2Z_m$$

$$Z_o = (Z_{aa} + Z_{nn} - 2Z_{an}) + 2(Z_{ab} + Z_{nn} - 2Z_{an})$$

$$Z_o = Z_{aa} + 2Z_{ab} + 3Z_{nn} - 6Z_{an}$$



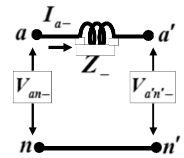
And



$$Z_1 = Z_s - Z_m$$

$$Z_1 = (Z_{aa} + Z_{nn} - 2Z_{an}) - (Z_{ab} + Z_{nn} - 2Z_{an})$$

$$Z_1 = Z_{aa} - Z_{ab}$$



$$Z_2 = Z_1 = Z_s - Z_m$$

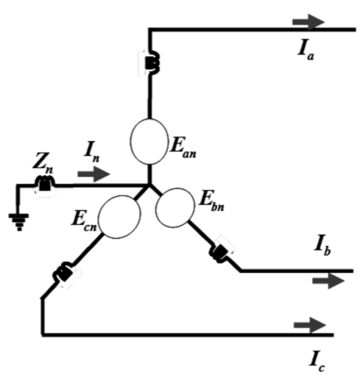
$$Z_2 = Z_{aa} - Z_{ab}$$

Notes:

The positive and negative sequence impedances are equal and don't include the neutral conductor impedances ***(Z_{nn} or Z_{an})*** . The return path conductors enter into the zero sequence impedances only.

The ground wires (***above overhead TL***) combined with the earth works as a neutral conductor with impedance parameters ***(Z_{nn} and Z_{an})*** that effects the zero sequence components. Having a good grounding (depends on the soil resistively), then the voltages to the neutral can be considered as the voltages to ground.

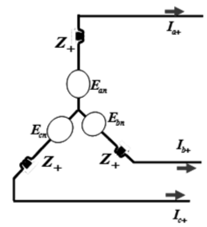
3. Sequence Circuits of Synchronous Machines

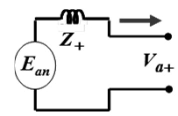


3. Sequence Circuits of Synchronous Machines

Positive Sequence Circuit:

• The windings of a synchronous machine are symmetrical.
• ***Thus the generator voltages are of positive sequence only***.
• The positive sequence network consists of an ***EMF*** (equal to no-load terminal voltage) in series with the ***positive sequence impedance of the machine***.



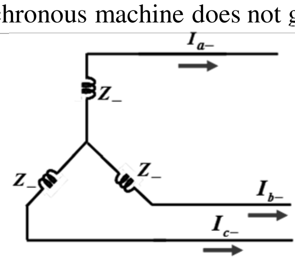


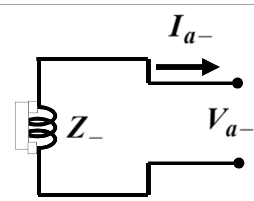
The neutral impedance (Z_n) does not appear in this circuit because no positive sequence current will flow through it.

$$I_{a1} + I_{b1} + I_{c1} = 0$$

Negative Sequence Circuit:

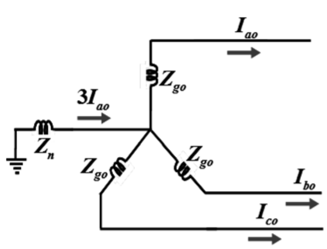
The synchronous machine does not generate any negative sequence voltages.

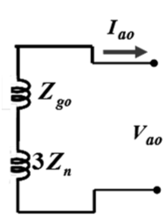




Zero Sequence Circuit:

No zero sequence voltage is included in a synchronous machine.



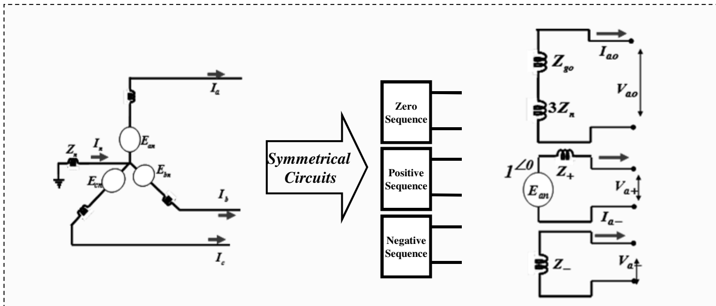


Z_{go} :Zero sequence impedance per phase.

$$I_{ao} + I_{bo} + I_{co} = 3I_{ao}$$

$$Z_o = 3Z_n + Z_{go}$$

Summary of the three sequence circuits

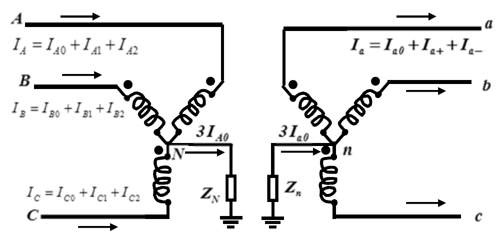


4. Sequence Circuits of Delta and Wye Transformers

The flow of the sequence currents depend on the winding connections. The different installations of ***Delta-Wye*** windings determine the configuration of the *zero sequence circuit* and the *phase shift in the positive and negative sequence circuits*.

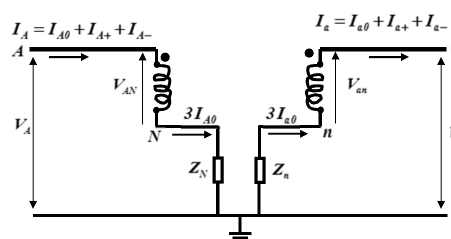
A. Wye-Wye Bank, Both Neutrals Grounded

With both wyes grounded, zero sequence current can flow. The presence of the current in one winding means that secondary current exists in the other.



$$V_A = V_{AN} + V_N \qquad \text{.... Eq. 1}$$

$$V_{A0} + V_{A+} + V_{A-} = (V_{AN0} + V_{AN+} + V_{AN-}) + 3I_{A0}Z_N \qquad \text{.... Eq. 2}$$



Two linked windings

The negative- and positive-sequence voltages to ground are equal to negative- and positive-sequence voltages to neutral.

Similarly, on the low voltage side

The negative sign comes from the direction of the zero sequence current

$$V_a = V_{an} - V_n \quad \text{.... Eq. 3}$$

$$V_{a0} + V_{a+} + V_{a-} = (V_{an0} + V_{an+} + V_{an-}) - 3I_{a0}Z_n \quad \text{.... Eq. 4}$$

The voltages and currents on both sides of the transformer are related by the turns ration ***(N_1 / N_2).*** Therefore, ***Eq. 4*** can be written as

$$V_{a0} + V_{a+} + V_{a-} = (\frac{N_2}{N_1}V_{AN0} + \frac{N_2}{N_1}V_{AN+} + \frac{N_2}{N_1}V_{AN-}) - 3Z_n(\frac{N_1}{N_2})I_{A0} \quad \text{.... Eq. 5}$$

Multiplying ***Eq. 5*** by (N_1 / N_2).

$$\frac{N_1}{N_2}(V_{a0} + V_{a+} + V_{a-}) = V_{AN0} + V_{AN+} + V_{AN-} - 3Z_n(\frac{N_1}{N_2})^2 I_{A0} \quad \text{.... Eq. 6}$$

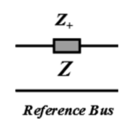
Substituting from ***Eq. 2*** for $(V_{AN0} + V_{AN+} + V_{AN-}) = V_{A0} + V_{A+} + V_{A-} - 3I_{A0}Z_N$

Then,

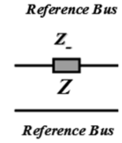
$$\frac{N_1}{N_2}(V_{a0} + V_{a+} + V_{a-}) = V_{A0} + V_{A+} + V_{A-} - 3Z_N I_{A0} - 3Z_n(\frac{N_1}{N_2})^2 I_{A0} \quad \text{.... Eq. 7}$$

By equating voltages of the same sequence, we can write

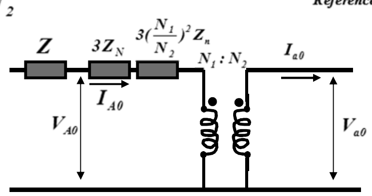
$$\frac{N_1}{N_2}V_{a+} = V_{A+} \quad \text{and} \quad \frac{N_1}{N_2}V_{a-} = V_{A-} \quad \text{.... Eq. 8}$$



This is similar to a regular transformer, and therefore, the positive and negative sequence circuits for a transformer are applicable.



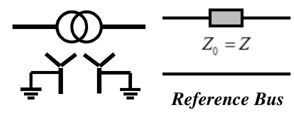
$$\frac{N_1}{N_2}V_{a0} = V_{A0} - [3Z_N + 3Z_n(\frac{N_1}{N_2})^2]I_{A0} \quad \text{.... Eq. 9}$$



Eq. 9 represents the relation for the zero sequence. This relation can be represented as shown in the Fig. ***When the voltages on both sides of the transformer are expressed in per unit, the turns ratio becomes unity***. The **zero sequence impedance** of the circuit, **(*adding the leakage impedance Z),*** is:

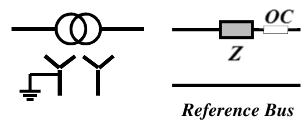
$$Z_0 = Z + 3Z_N + 3Z_n \ \ per\ unit \quad \text{.... Eq. 10}$$

A. Wye-Wye bank with both neutrals grounded, zero sequence current can flow. The presence of the current in one winding means that secondary current exists in the other. The equivalent circuit is as shown in the Figure.



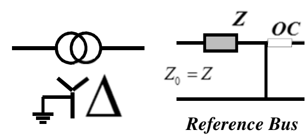
B. Wye-wye Bank, One Neutral Grounded

With ungrounded wye, no zero sequence current can flow. No current in one winding means that no current exists in the other.



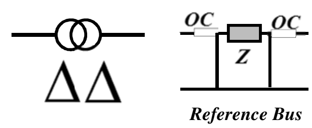
C. Wye-delta Bank, Grounded Wye

Zero sequence currents will pass through the wye winding to ground. As a result, secondary zero sequence currents will circulate through the delta winding. *No zero sequence current will exist on the lines of the secondary*.



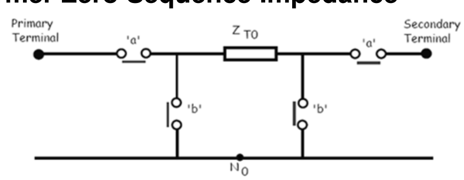
E. Delta-delta Bank

Since for a delta circuit no return path for zero sequence current exists, *no zero sequence current can flow into a delta-delta bank*, although it can circulate within the delta windings.



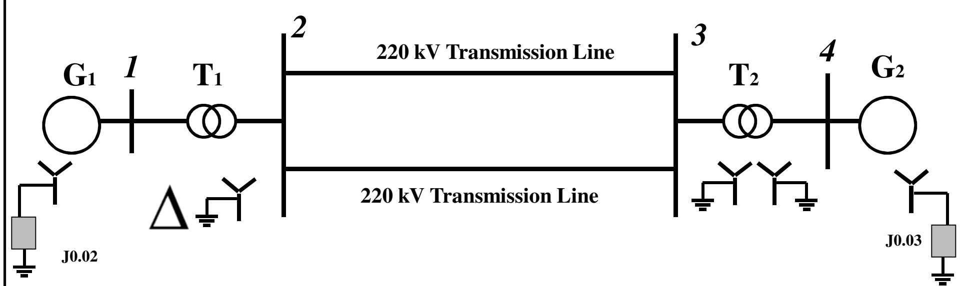
Summary of Transformer Sequence Networks

Transformer Zero Sequence Impedance



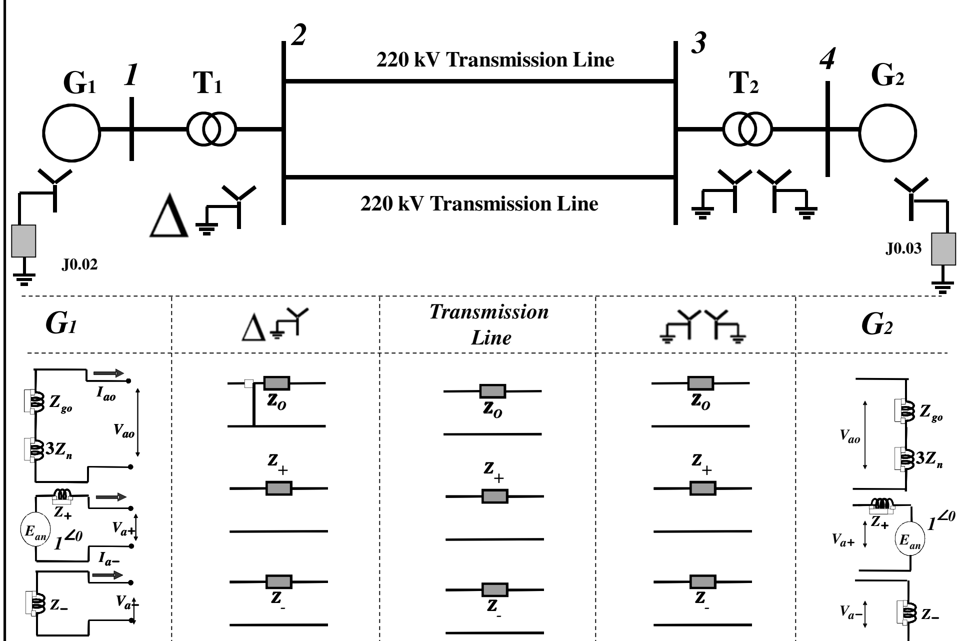
Earthed Star Winding	-	Close link 'a' Open link 'b'
Delta Winding	-	Open link 'a' Close link 'b'
Unearthed Star Winding	-	Both links open

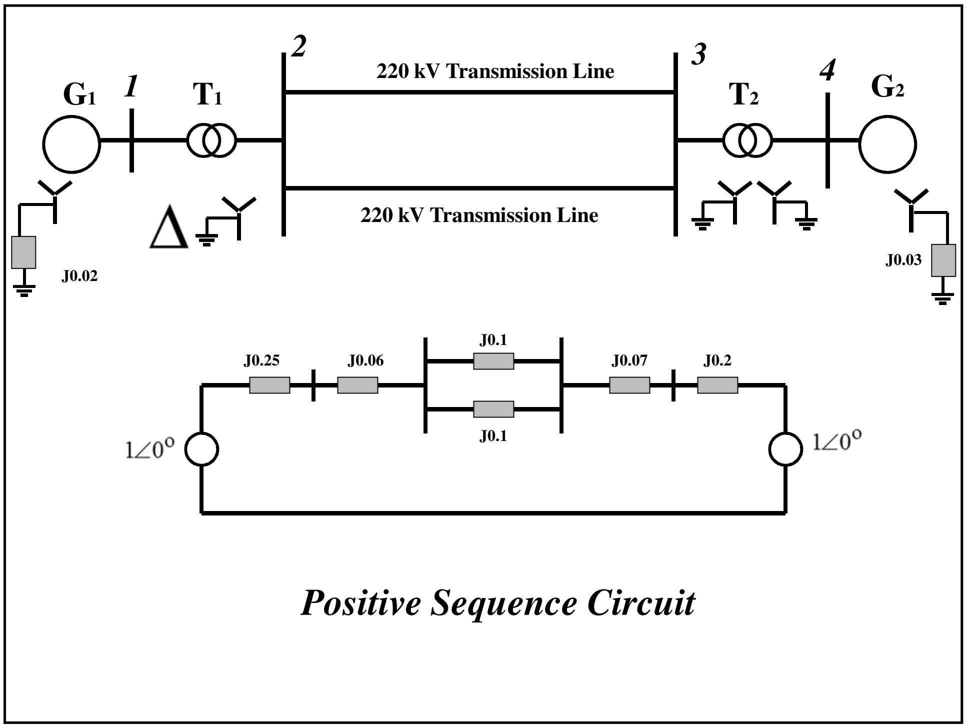
Example 4: Draw the sequence circuits for the network.

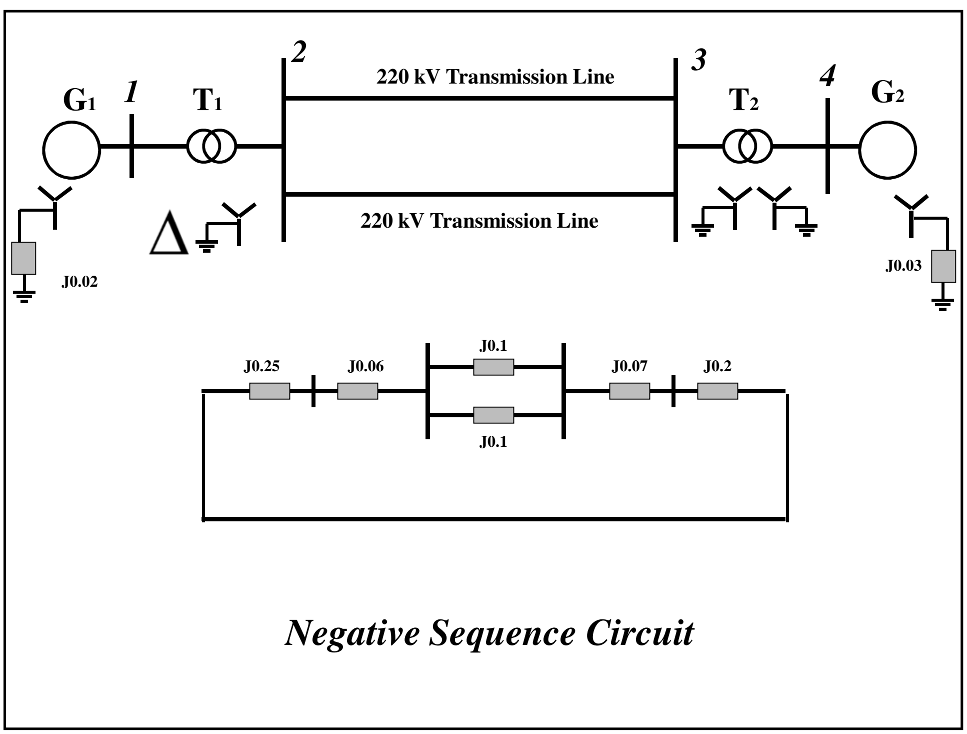


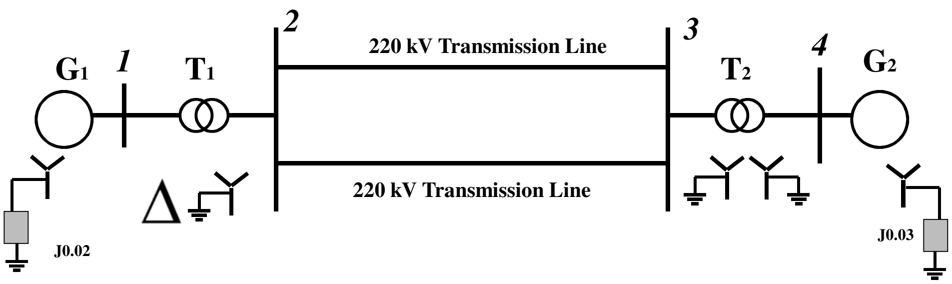
	MVA	Voltage	X_+	X_-	X_o
G1	100	11 kV	0.25	0.25	0.05
G2	100	11 kV	0.20	0.20	0.05
T1	100	11/220	0.06	0.06	0.06
T2	100	11/220	0.07	0.07	0.07
Line	100	220kV	0.10	0.10	0.30

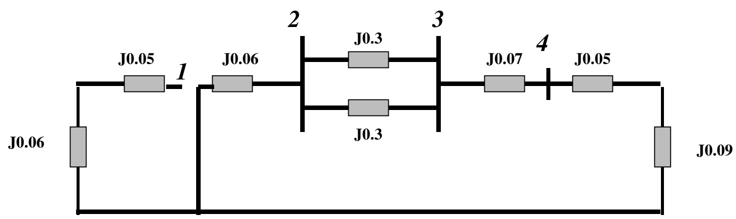
Solution: *The System Sequence Circuits*




2
3
220 kV Transmission Line
G1
1
T1
T2
4
G2
220 kV Transmission Line
J0.02
J0.03
J0.1
J0.25
J0.06
J0.07
J0.2
J0.1
1∠0°
1∠0°
Positive Sequence Circuit


2
3
220 kV Transmission Line
G1
1
T1
T2
4
G2
220 kV Transmission Line
J0.02
J0.03
J0.1
J0.25
J0.06
J0.07
J0.2
J0.1
Negative Sequence Circuit

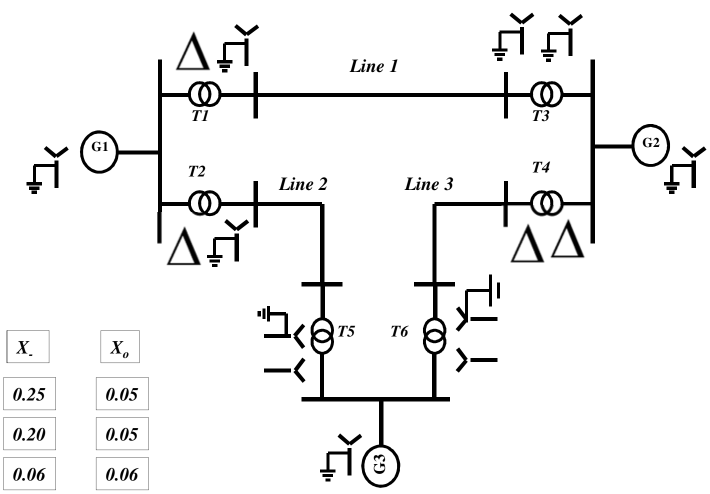




Zero Sequence Circuit

Example 5:

Draw the zero sequence circuit for the network.



	X_+	X_-	X_o
G1	*0.25*	*0.25*	*0.05*
G2 , G3	*0.20*	*0.20*	*0.05*
T1-T6	*0.06*	*0.06*	*0.06*
Line 1-3	*0.10*	*0.10*	*0.30*

Solution

The zero sequence circuit for the network

	X_+	X_-	X_o
G1	***0.25***	***0.25***	***0.05***
G2 , G3	***0.20***	***0.20***	***0.05***
T1-T6	***0.06***	***0.06***	***0.06***
Line 1-3	***0.10***	***0.10***	***0.30***