# Lecture 15
# THREE PHASE TRANSFORMER ADVANCED TOPICS

**Agenda**

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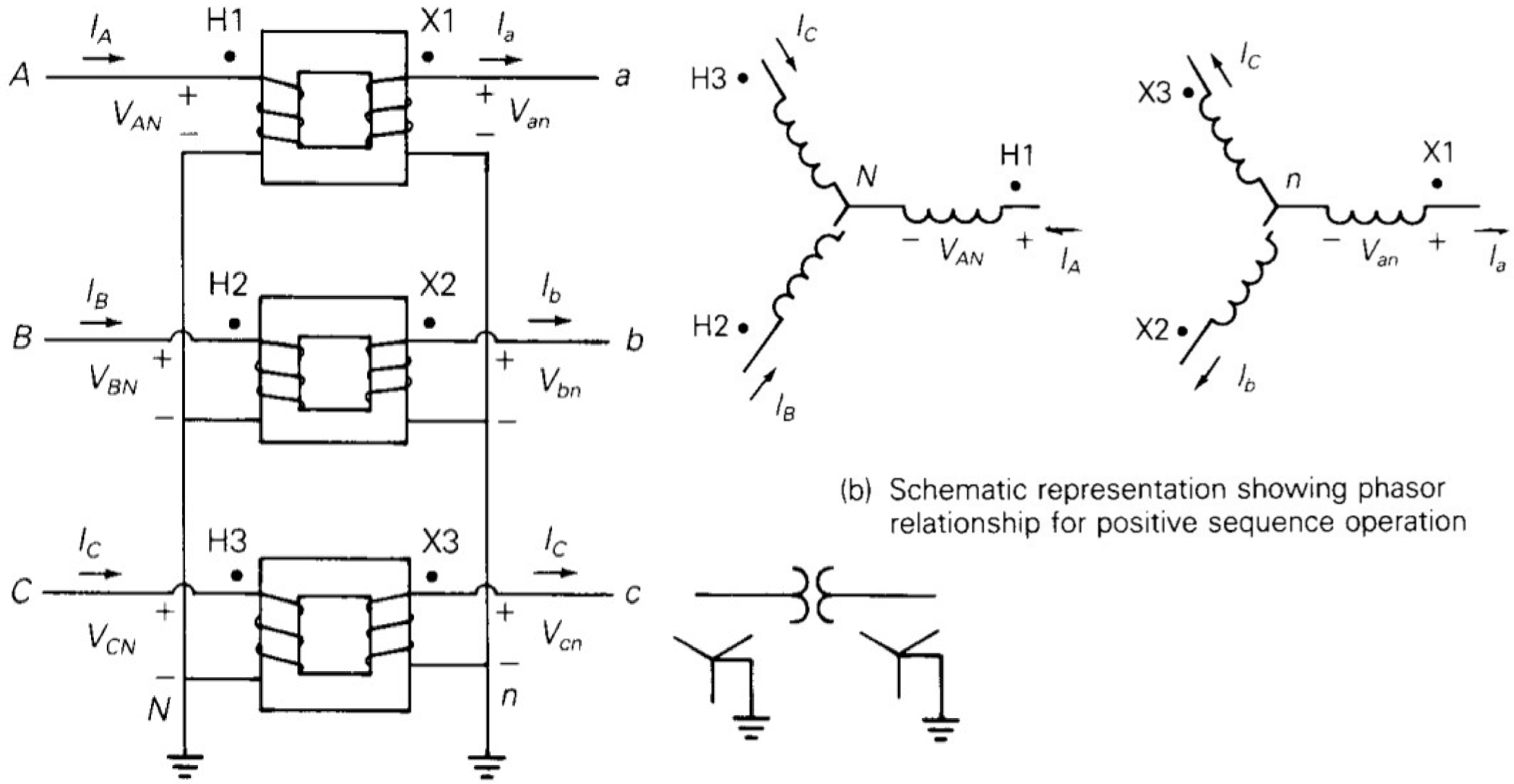
FROM SINGLE PHASE TO THREE PHASE


# Lecture Outcomes

at the end of the lecture, the student must be able to …

- Understand how phase shifts manifests in three-phase transformers
- Derive the models for different types of three-phase transformers

# Phase Shifts in Three-Phase Transformers

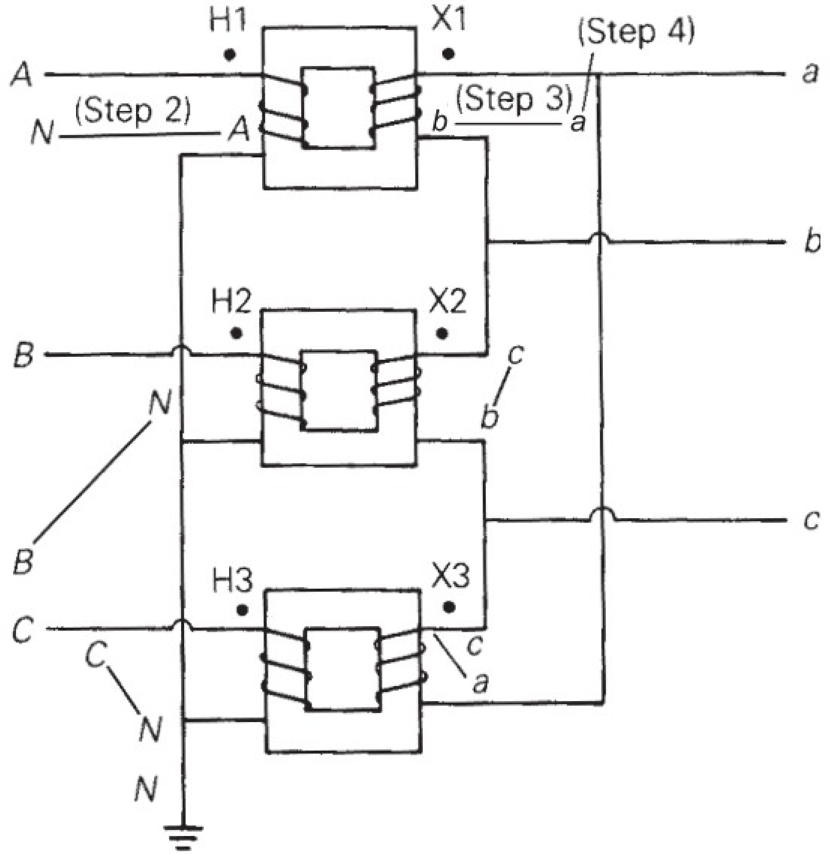



(a) Core and coil arrangements

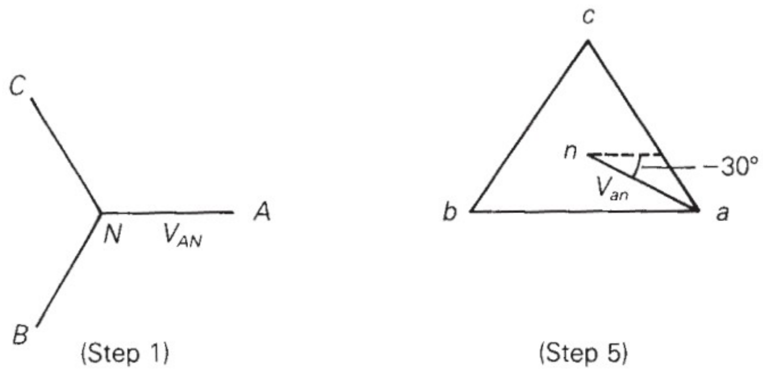
(b) Schematic representation showing phasor relationship for positive sequence operation

(c) Single-line diagram

# Phase Shifts in Three-Phase Transformers



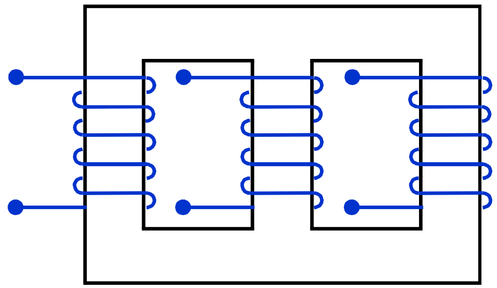

(a) Core and coil arrangement



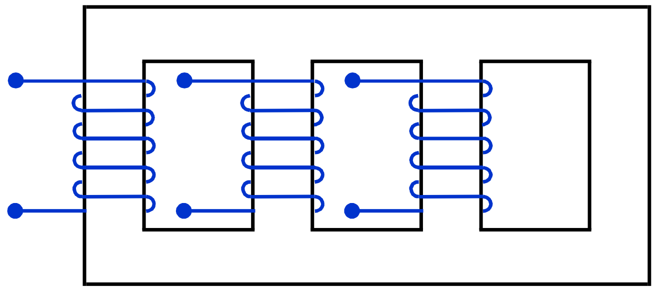

(b) Positive-sequence phasor diagram

# Three-Phase Transformer

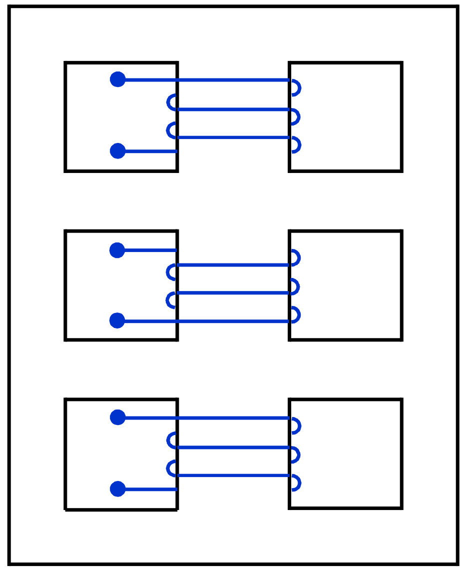
## Transformer Core



3-Legged Core Type



4-Legged Core Type



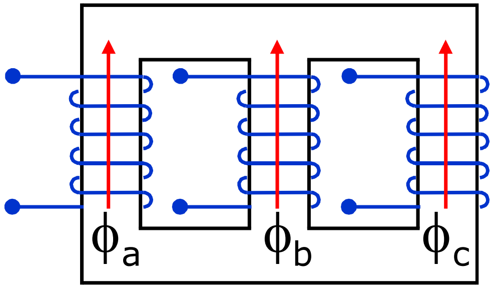
Shell Type

Note: Only the X windings are shown.

# Three-Phase Transformer

## Three-Legged Transformer Core

The 3-legged core type three-phase transformer uses the minimum amount of core material. For balanced three-phase condition, the sum of the fluxes is zero.




Note: For positive- or negative-sequence flux,

$$\phi_a + \phi_b + \phi_c = 0$$

The 3-legged core type three-phase transformer does not provide a path for zero-sequence flux. On the other hand, a bank of single-phase units, the 4-legged core type and the shell-type three-phase transformer provide a path for zero-sequence flux.

# Equivalent Circuit of Transformers

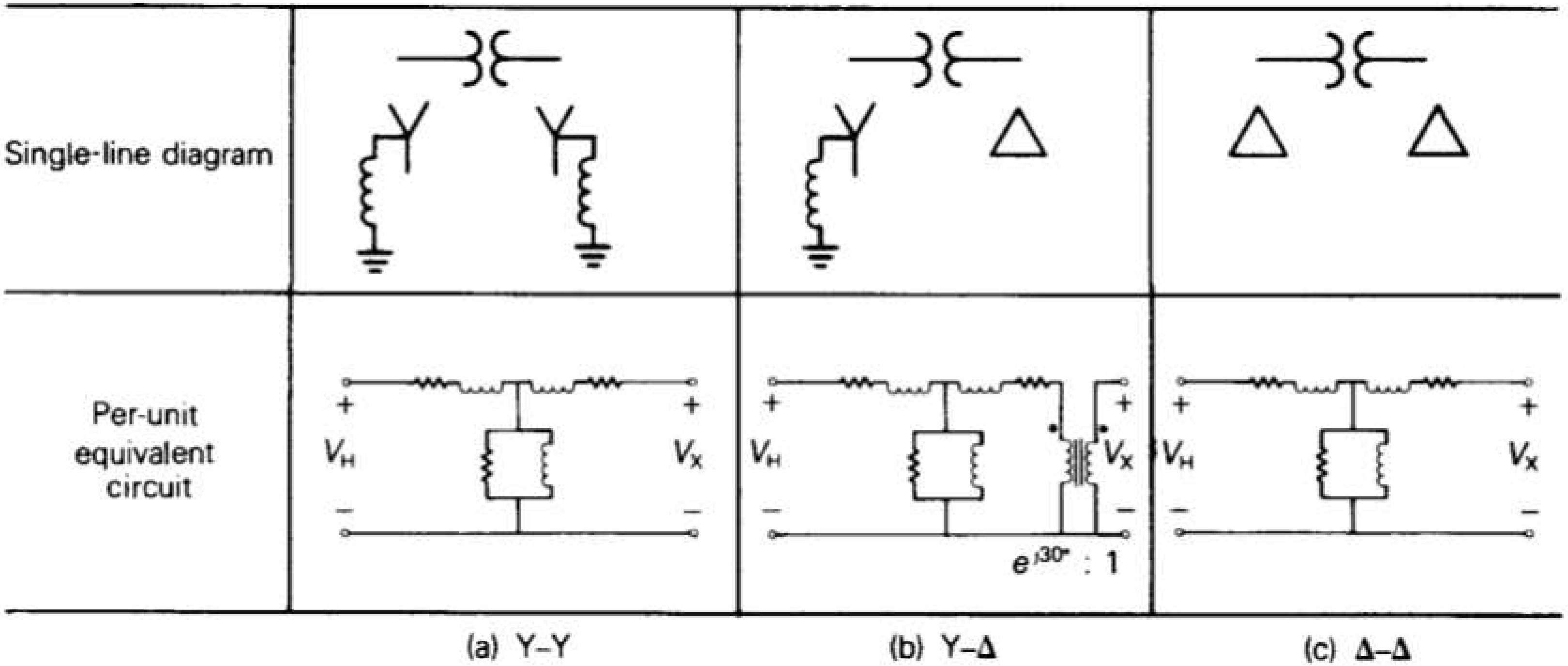


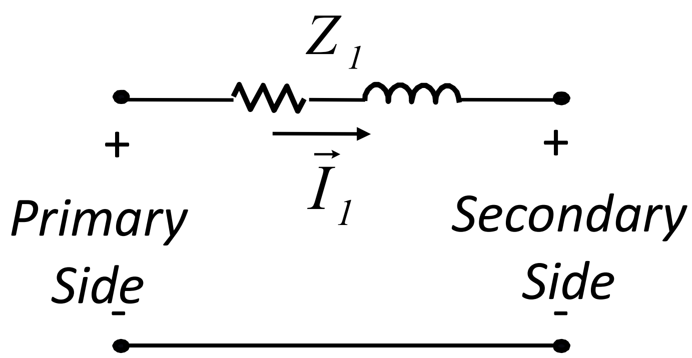

**FIGURE 3.17** Per-unit equivalent circuits of practical Y–Y, Y–Δ, and Δ–Δ transformers for balanced three-phase operation

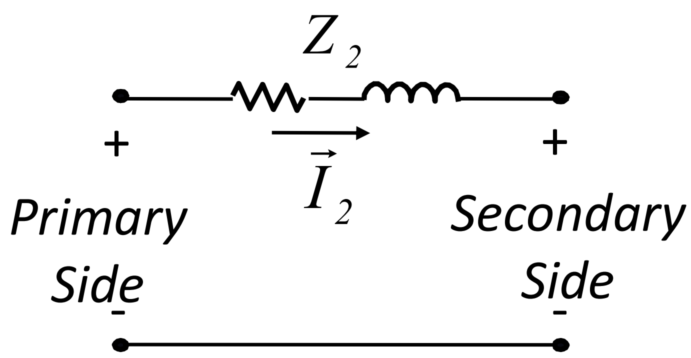
# Equivalent Circuit of Transformers

Positive & Negative Sequence Networks

Y-Y and Δ–Δ connected transformers (in per unit)

Assuming Large power transformer




*Positive Sequence Network*

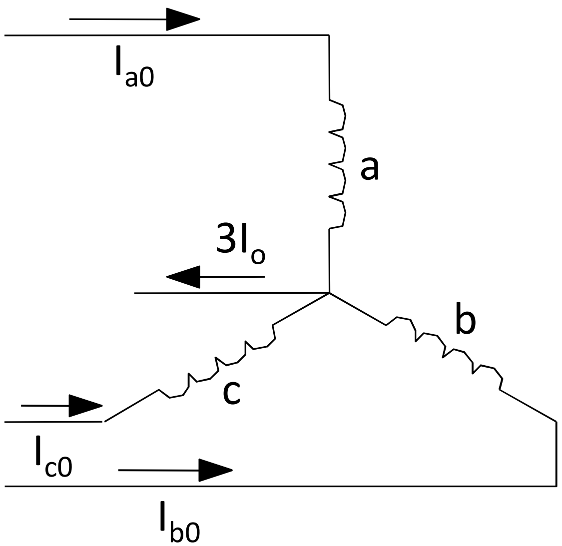
$$Z_1 = Z_2$$

*Negative Sequence Network*

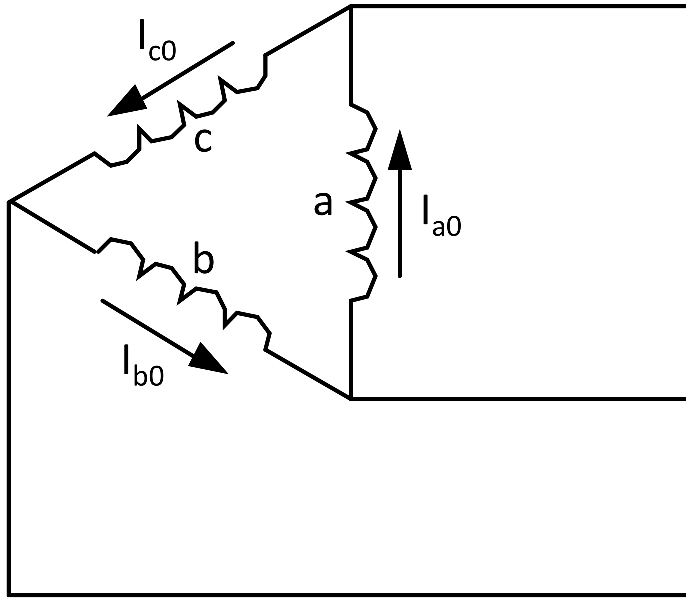
# Equivalent Circuit of Transformers

*Zero-Sequence Network*

<u>*ZERO-SEQUENCE CURRENTS:*</u>



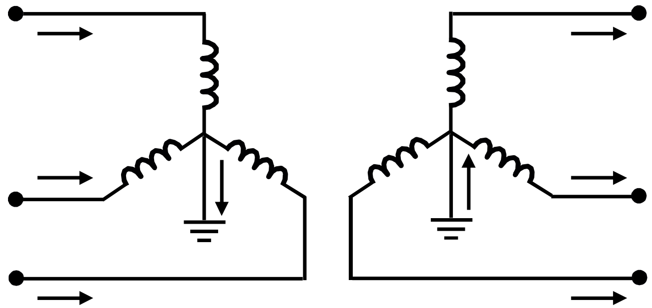
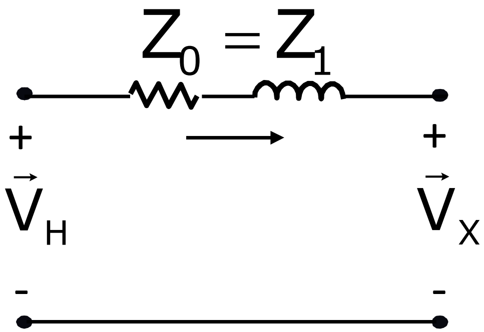
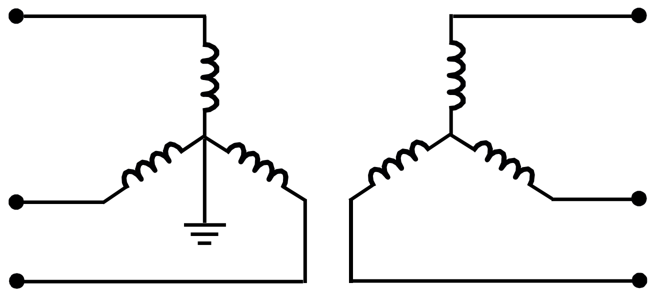
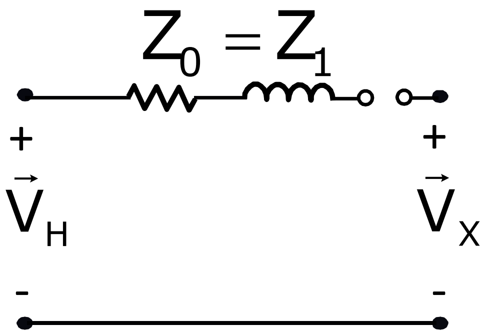

*The neutral return carries the in-phase zero-sequence currents.*




*Zero-sequence currents circulates in the delta-connected transformers. There is "balancing ampere turns" for the zero-sequence currents.*

# Equivalent Circuit of Transformers

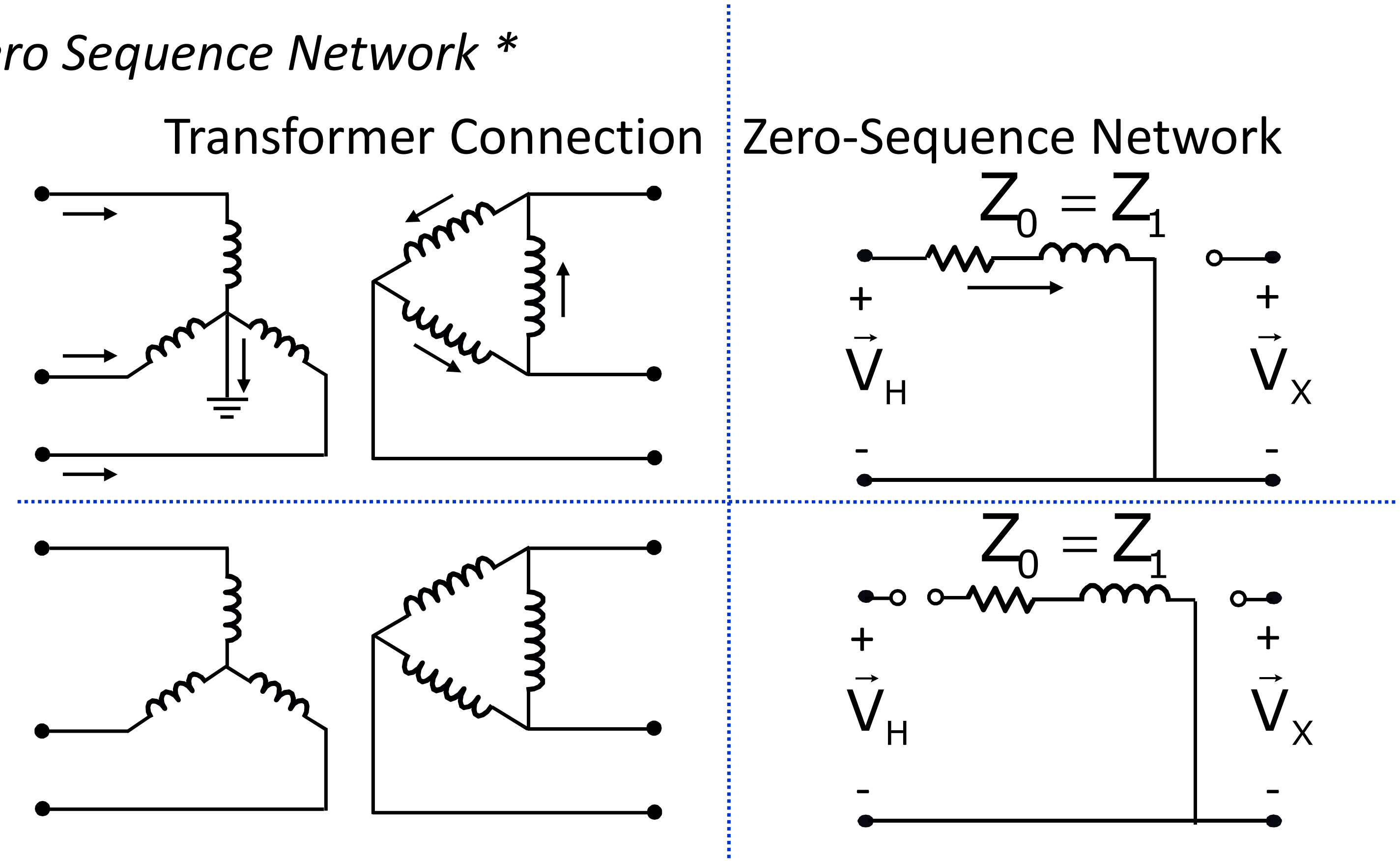
*Zero Sequence Network**

| Transformer Connection | Zero-Sequence Network |
| --- | --- |
|  |  |
|  |  |

*Excluding 3-phase unit with a 3-legged core.

# Equivalent Circuit of Transformers

*Zero Sequence Network **

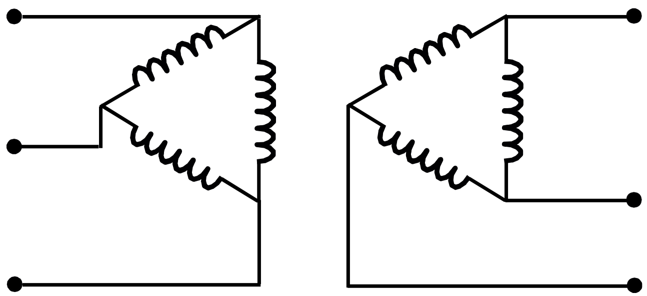


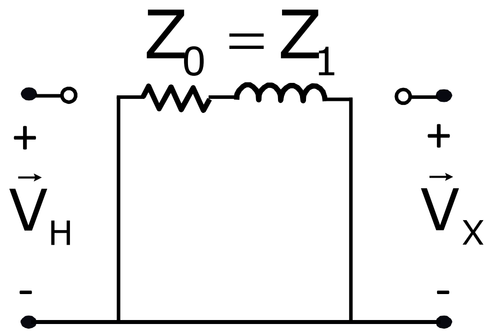

*Excluding 3-phase unit with a 3-legged core.

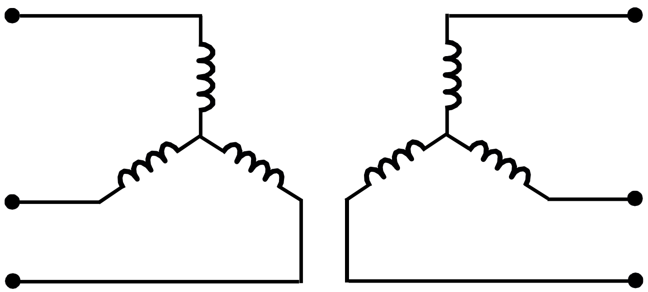
# Equivalent Circuit of Transformers

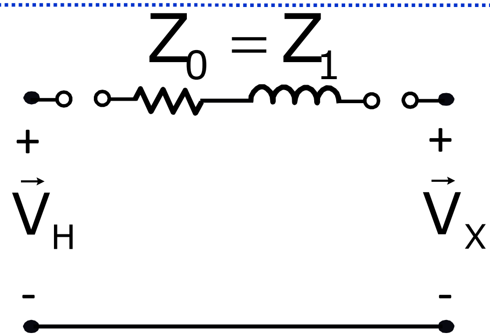
*Zero Sequence Network **

| Transformer Connection | Zero-Sequence Network |
|---|---|



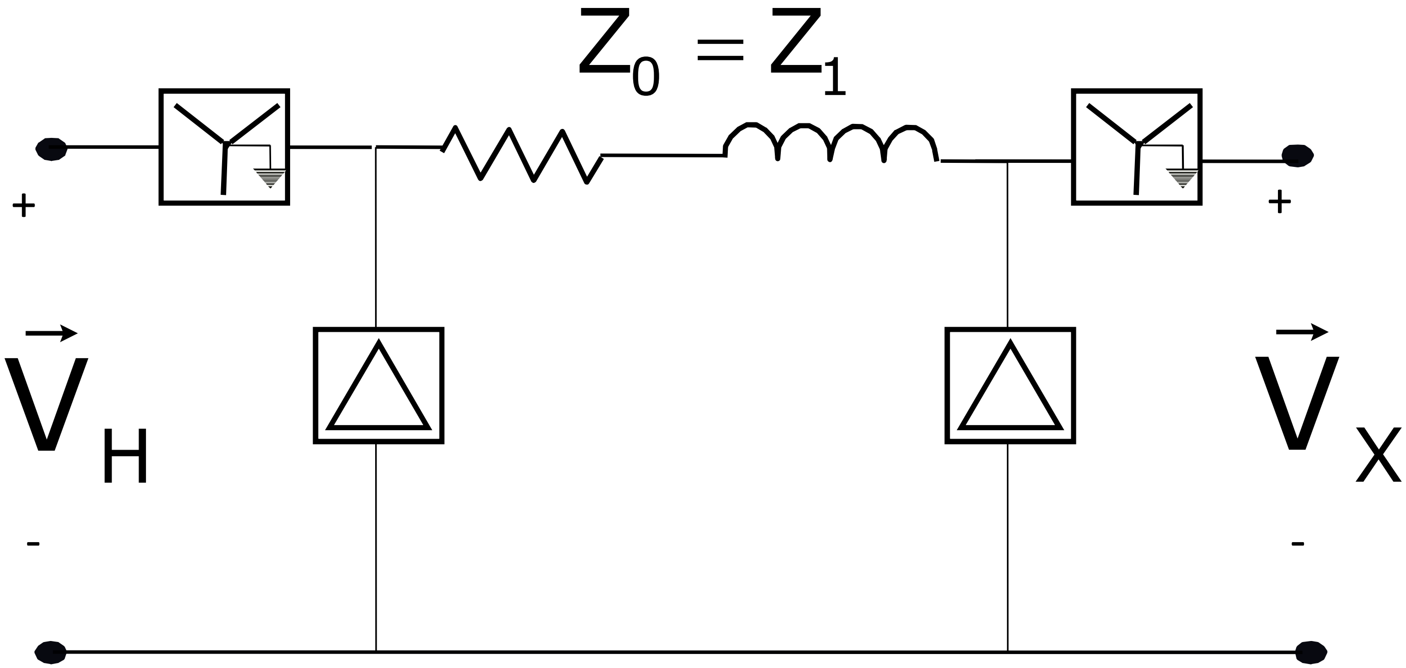





*Excluding 3-phase unit with a 3-legged core.

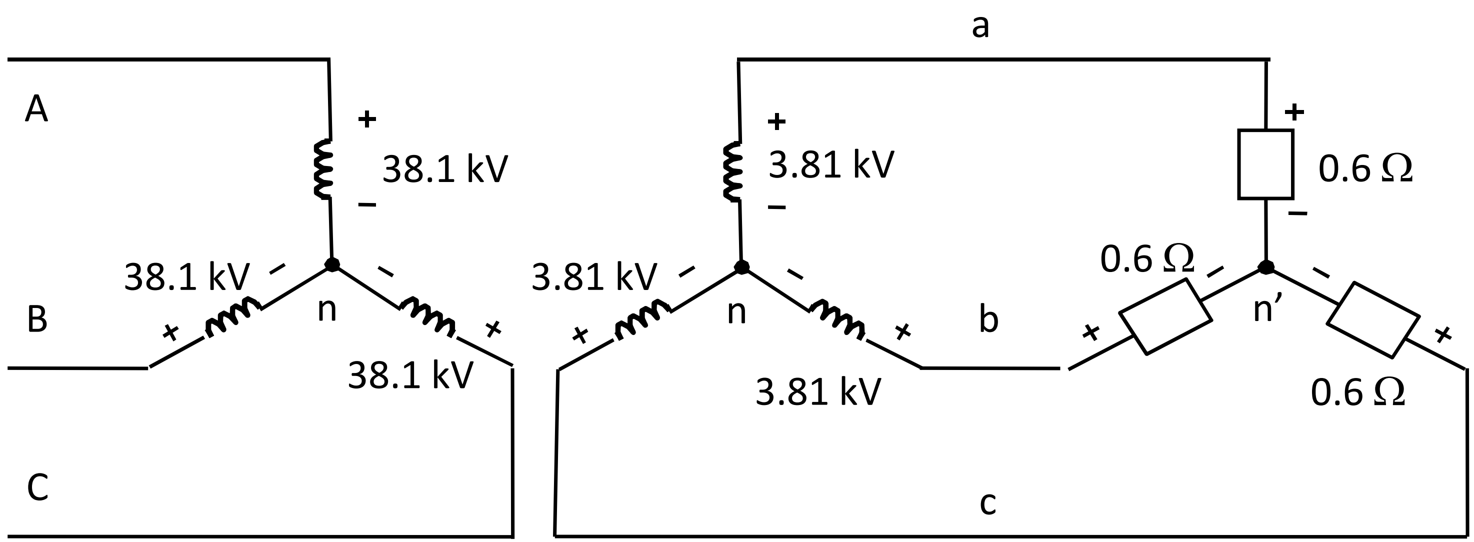
# A Mnemonic Zero-Sequence Equivalent Circuit of Three-Phase Transformers




- normally-open switch that closes when the transformer has the illustrated connection on the corresponding side (H or X)

# Referred Impedances (3-phase transformers)

Consider a 3-phase wye-connected load, 0.6-$\Omega$/phase. Three single-phase transformers are used, each rated 25 MVA, 38.1/3.81 kV, connected wye-wye, to serve the 3-phase load.



# Referred Impedances (3-phase transformers)

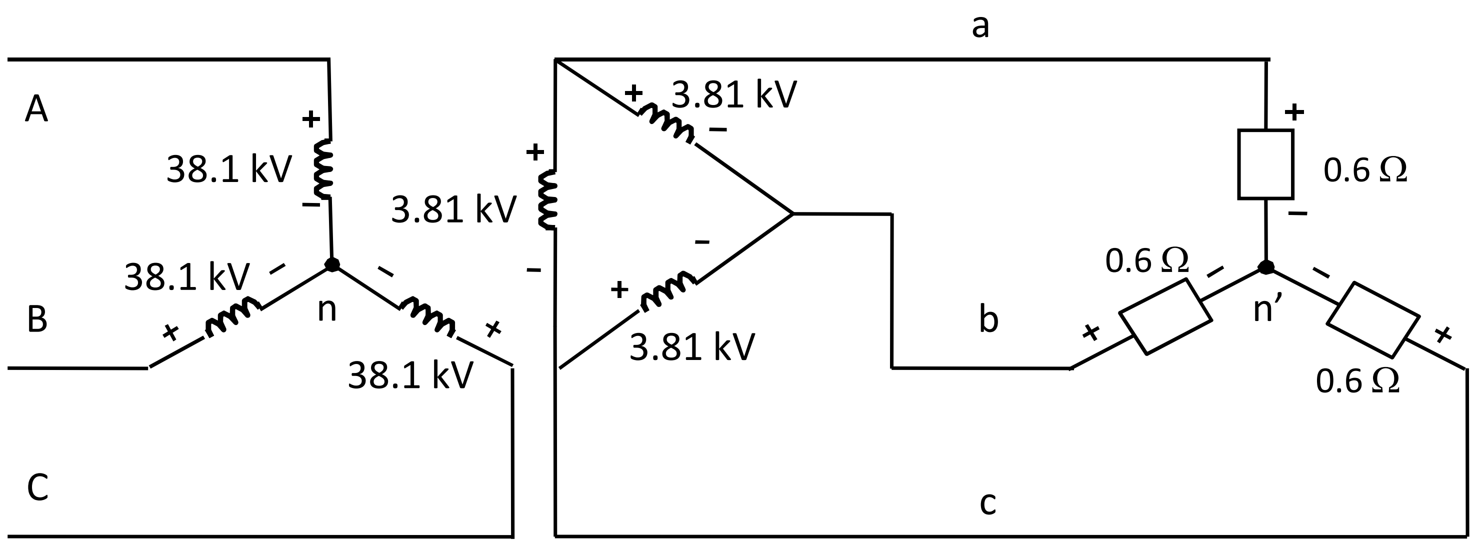
Assuming we have a balanced system, we can consider each 0.6-$\Omega$ resistor to be directly connected across 3.81-kV winding, with or without the neutral conductor. On the high-voltage side the impedance measured from line to neutral is:

$$0.6\Omega \cdot \left(\frac{38.1\,kV}{3.81\,kV}\right)^2 = 0.6\,\Omega \cdot \left(\frac{66\,kV}{6.6\,kV}\right)^2 = 60\Omega$$

Note: 66-kV line-to-line = 38.1-kV line-to-neutral,
and 6.6-kV line-to-line = 3.81-kV line-to-neutral.

# Referred Impedances (3-phase transformers)

Let us consider the same 3-phase wye-connected load, 0.6-$\Omega$/phase, and the same 3 single-phase transformer (25 MVA, 38.1/3.81 kV). If we connect the transformers wye-delta:



# Referred Impedances (3-phase transformers)

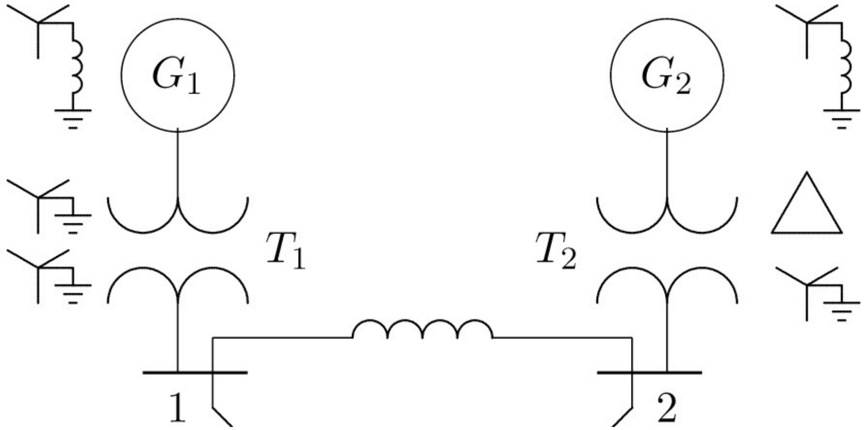
With the same assumptions as before, we can convert the low-voltage side of the transformer from delta- to wye-connected; the secondary voltage will change from 3.81 $kV_{LL}$ to 2.2 $kV_{LN}$ = (3.81 kV / √3).

$$0.6\Omega \cdot \left( \frac{38.1 kV}{2.2 kV} \right)^2 = 0.6\Omega \cdot \left( \frac{66 kV}{3.81 kV} \right)^2 = 180\Omega$$

Note: To transfer the ohmic value of impedances from one side of a three-phase transformer to the other side, the multiplying factor is the square of the ratios of the line-to-line voltage, regardless of transformer connection.

Concept Test:

1. Draw the positive-sequence impedance diagram for the system shown.
2. Draw the zero-sequence impedance diagram for the system shown




$X_{G1}^{(1)}$, $X_{G1}^{(0)}$, $X_{G1n}$

$X_{G2}^{(1)}$, $X_{G2}^{(0)}$, $X_{G2n}$

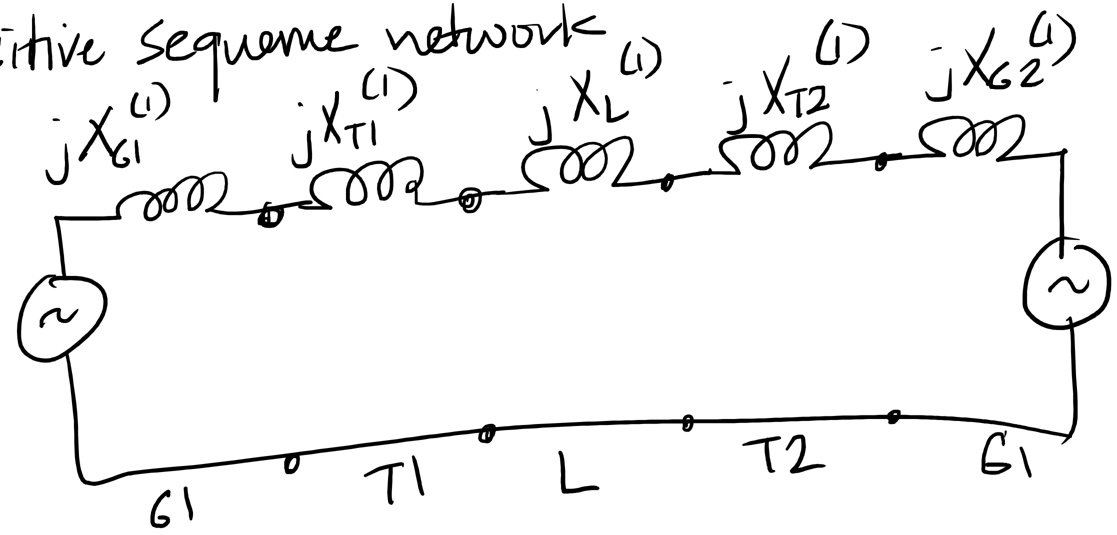
$X_{T1}^{(1)} = X_{T1}^{(0)}$

$X_{T2}^{(1)} = X_{T2}^{(0)}$

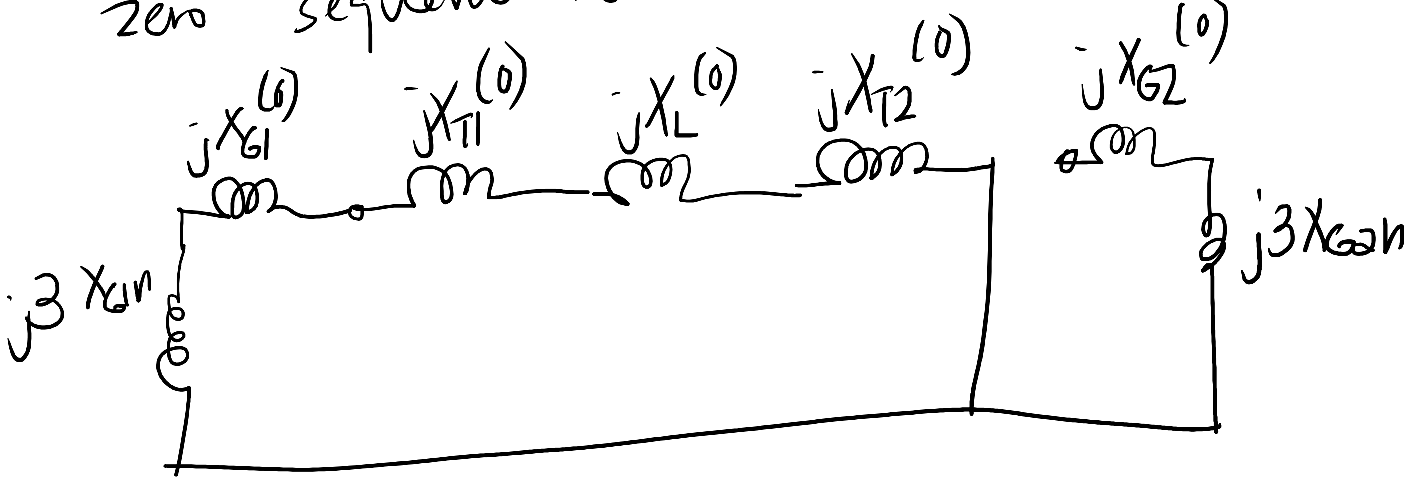
$X_L^{(1)}$, $X_L^{(0)}$

Note: we are particularly interested on the generator and transformer models.

positive sequence network




zero sequence network



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