16-Three Phase Transformers

ECEGR 450
Electromechanical Energy Conversion

Overview

- Y-Y Transformer Connection
- Y-Y Transformer Analysis
- Delta-Delta Transformer Connection
- Delta-Delta Transformer Analysis

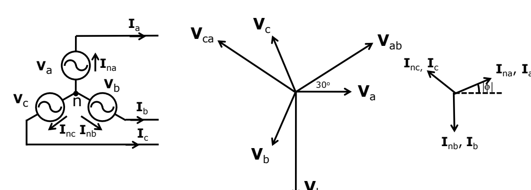
Three-Phase Transformer Connections

- We are generally more concerned with three phase transformers
- Three-phase transformers can be composed of three single-phase transformers or be wound on the same core
- Many combinations are possible:
  - Y-Y
  - Delta-Delta
  - Y-Delta } next lecture
  - Delta-Y

Y-Connected Circuits

- Recall from previous lectures:
  - Line current = Phase current
  - Line voltage = Phase voltage x $\sqrt{3}\angle 30^\circ$

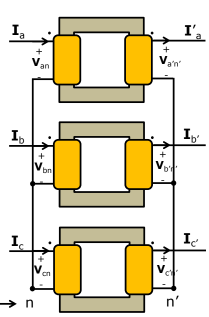
Vector Diagrams



Y-Y Transformer

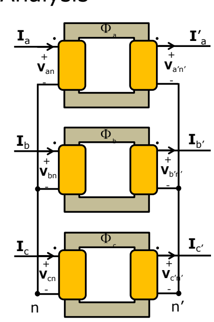
- Each side has a common point, n or n′
- Neutral points usually grounded
- Tertiary winding (Delta) sometimes connected to avoid distortion if harmonics are present
- <u>Phase voltages appear across the coils on each side</u>
- Insulation is stressed to only 58% of line voltage

Do not confuse this n with 1/a



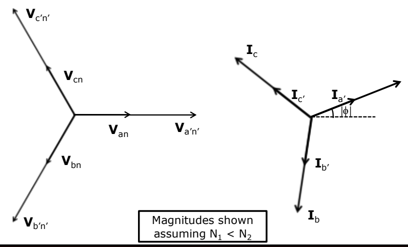
Y-Y Transformer Analysis

- Mutual flux in each core are out of phase by 120º
- Φ_a links primary and secondary
- Faraday's law: $\mathbf{V}_{an}$ and $\mathbf{V}_{a'n'}$ must be in phase and lead Φ_a by 90º
  - similar result for b, c phases
- Ampere's Law: $\mathbf{I}_a$ and $\mathbf{I}_{a'}$ are also in phase
  - similar result for b, c phases



Y-Y Transformer Analysis

Phasor Diagram for Ideal Y-Y Connected Transformer



Three-Phase Transformer Analysis: Y-Y

- Let k be the transformer voltage gain
- For Y-Y transformers:

$$\mathbf{V}_{a'n'} = k\mathbf{V}_{an} = \frac{N_2}{N_1}\mathbf{V}_{an}$$

therefore $k = n$ ← Do not confuse this n with the neutral point

$$\mathbf{I}_{a'} = \frac{\mathbf{I}_a}{k} = \frac{\mathbf{I}_a}{n}$$

$$\mathbf{V}_{a'b'} = \mathbf{V}_{a'n'}\sqrt{3}e^{\frac{j\pi}{6}} = n\mathbf{V}_{an}\sqrt{3}e^{\frac{j\pi}{6}} \quad \text{(secondary line voltage)}$$

$$= \sqrt{3}\left(n\frac{\mathbf{V}_{ab}}{\sqrt{3}}e^{\frac{-j\pi}{6}}\right)e^{\frac{j\pi}{6}} = n\mathbf{V}_{ab}$$

Recall: $e^{\frac{j\pi}{6}} = 1\angle 30^\circ$

Three-Phase Transformer Analysis: Y-Y

- Phase voltages

$\mathbf{V}_{a'n'} = n\mathbf{V}_{an}$, $\mathbf{V}_{a'b'} = n\mathbf{V}_{ab}$

$\mathbf{V}_{b'n'} = n\mathbf{V}_{bn}$, $\mathbf{V}_{b'c'} = n\mathbf{V}_{bc}$

$\mathbf{V}_{c'n'} = n\mathbf{V}_{cn}$, $\mathbf{V}_{c'a'} = n\mathbf{V}_{ca}$

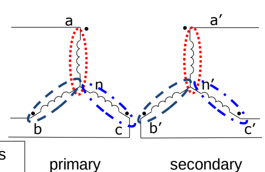
- Line currents

$\mathbf{I}_{a'} = \frac{\mathbf{I}_a}{n}$

$\mathbf{I}_{b'} = \frac{\mathbf{I}_b}{n}$

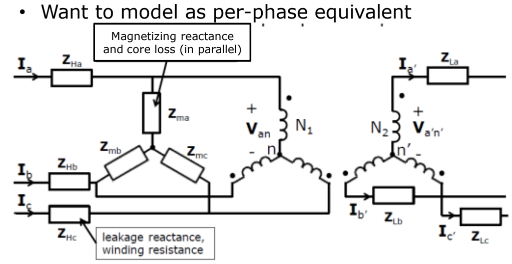
$\mathbf{I}_{c'} = \frac{\mathbf{I}_c}{n}$

Recall: phase currents = line current for Y connections



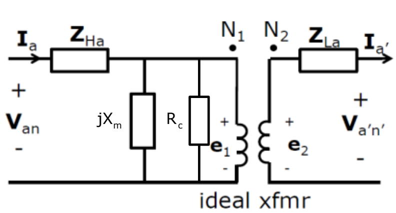
Per-Phase Y-Y Analysis

- Three phase non-ideal Y-Y transformer model
- Want to model as per-phase equivalent



Per Phase Y-Y Analysis

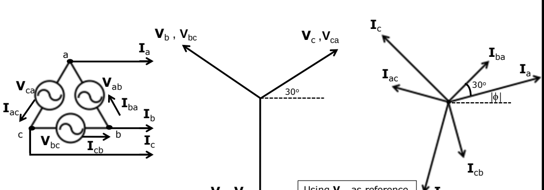
- Per-phase equivalent of non-ideal Y-Y transformer
- Analyze like a single-phase transformer



Delta-Connected Circuits

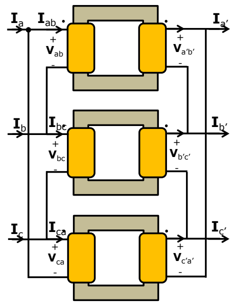
- Recall from previous lectures:
  - Line current = Phase current x $\sqrt{3}\angle -30^\circ$
  - Line voltage = Phase voltage (but per-phase voltage is line voltage x $\frac{1}{\sqrt{3}}\angle -30^\circ$)

Vector Diagrams



Δ-Δ Transformer

- No neutral point
- $\mathbf{V}_{ab}$, $\mathbf{V}_{a'b'}$ in phase
- $\mathbf{I}_{ab}$, $\mathbf{I}_{a'b'}$ in phase
  - Similar results for b, c phase
- Line-line voltages appear across the coils on primary and secondary
- Best suited for lower voltage applications



Three-Phase Transformer Analysis: Δ-Δ

- Let k be the transformer voltage gain
- For Δ-Δ transformers:

$$\mathbf{V}_{a'b'} = k\mathbf{V}_{ab} = \frac{N_2}{N_1}\mathbf{V}_{ab}$$

therefore k = n

$$\mathbf{I}_{a'b'} = \frac{\mathbf{I}_{ab}}{k} = \frac{\mathbf{I}_{ab}}{n}$$

$$\mathbf{V}_{a'n'} = \frac{\mathbf{V}_{a'b'}e^{\frac{-j\pi}{6}}}{\sqrt{3}} = \frac{n\mathbf{V}_{ab}e^{\frac{-j\pi}{6}}}{\sqrt{3}}$$

$$= \frac{n(\sqrt{3}\mathbf{V}_{an}e^{\frac{j\pi}{6}})e^{\frac{-j\pi}{6}}}{\sqrt{3}} = n\mathbf{V}_{an} \quad \text{(per phase voltage)}$$

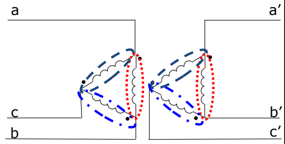
Three-Phase Transformer Analysis: Δ–Δ

- Voltage Relationships

$$\mathbf{V}_{a'b'} = n\mathbf{V}_{ab}$$
$$\mathbf{V}_{b'c'} = n\mathbf{V}_{bc}$$
$$\mathbf{V}_{c'a'} = n\mathbf{V}_{ca}$$

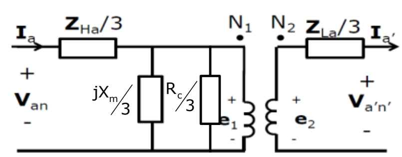
- Current Relationships

$$\mathbf{I}_{a'} = \frac{\mathbf{I}_a}{n}, \quad \mathbf{I}_{b'a'} = \frac{\mathbf{I}_{ab}}{n}$$
$$\mathbf{I}_{b'} = \frac{\mathbf{I}_b}{n}, \quad \mathbf{I}_{c'b'} = \frac{\mathbf{I}_{bc}}{n}$$
$$\mathbf{I}_{c'} = \frac{\mathbf{I}_c}{n}, \quad \mathbf{I}_{a'c'} = \frac{\mathbf{I}_{ca}}{n}$$



Per-Phase Δ-Δ Transformer

- Need to convert each side of the transformer to Y
- Recall that: $\mathbf{Z}_Y = \frac{\mathbf{Z}_\Delta}{3}$
- Per-phase equivalent circuit of non-ideal Δ-Δ transformer

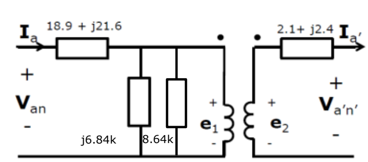


Example

- Consider three, single-phase transformers. The transformers have the following specifications:
  - 720VA, 360/120V, R_H = 18.9Ω, X_H = 21.6Ω, R_L = 2.1Ω, X_L = 2.4Ω, R_{cH} = 8.64kΩ, X_{mH} = 6.84kΩ
- Draw the per-phase equivalent circuit if the transformers are connected as Y-Y
- What are the nominal line voltages on each side of the transformer?

Example

- Nominal per-phase voltage on primary is 360V and 120V on secondary
  - Nominal primary line voltage: 623.5V
  - Nominal secondary line voltage: 207.8V

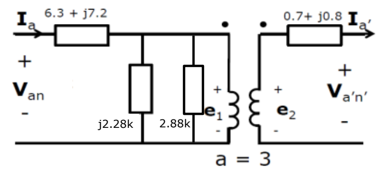


Example

- Consider three, single-phase transformers. The transformers have the following specifications:
  - 720VA, 360/120V, R_H = 18.9Ω, X_H = 21.6Ω, R_L = 2.1Ω, X_L = 2.4Ω, R_{cH} = 8.64kΩ, X_{mH} = 6.84kΩ
- Draw the per-phase equivalent circuit if the transformers are connected as Δ–Δ
- What are the nominal line voltages on each side of the transformer?

Example

- Nominal primary line voltage: 360V
- Nominal secondary line voltage: 120V
- Nominal primary per-phase voltage: 208V
- Nominal secondary per-phase voltage: 69V



Summary

- Y-Y, Delta-Delta transformers result in magnitude changes of k = n from primary to secondary
  - No phase shifting occurs
- Y-Y transformers grant access to neutral point, which is usually grounded to prevent distortion
- Delta-Delta transformers have no neutral point, but are less prone to distortion
- Per phase analysis can be used on Y-Y, Delta-Delta transformers
  - Ensure impedances and voltages are properly converted