Universiti Malaysia PAHANG
Engineering • Technology • Creativity

DEE 3143 BASIC ELECTRICAL MACHINE & POWER SYSTEMS

CHAPTER 1
TRANSFORMER

by
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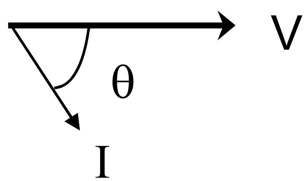
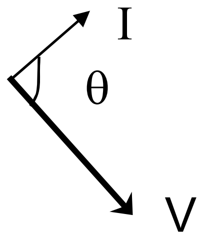
Power factor

Power factor = angle between voltage and current, *cos θ*.



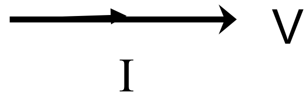
θ = -ve

Lagging



θ = +ve

Leading



θ = 0, Pf=1

unity

For real power transformer, the power factor is always lagging

Transformer Efficiency

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

$$= \frac{P_{out}}{P_{out} + P_{losses}} \times 100\%$$

$$= \frac{V_2 I_2 \cos\theta}{V_2 I_2 \cos\theta + P_c + P_{cu}} \times 100\%$$

$$* P_C = V_1^2 / R_C$$

$$* P_{Cu} = I_1^2 R_1 + I_2^2 R_2 = I_1^2 R_{eq,1} = I_2^2 R_{eq,2}$$

$$\eta_{(full\,load)} = \frac{VA\cos\theta}{VA\cos\theta + P_c + P_{cu}} \times 100\%$$

$$\eta_{(load\ n)} = \frac{nVA\cos\theta}{nVA\cos\theta + P_c + n^2 P_{cu}} \times 100\%$$

Where, if 1/2 loaded, hence n = 1/2 ,
1/3 loaded, n= 1/3 ,
90% of full load, n =0.9

Voltage Regulation

- To measure voltage drop between no load and full load

$$V.R = \frac{V_{S,NL} - V_{S,FL}}{V_{S.NL}} \times 100\%$$

$$V.R = \frac{V_P - aV_S}{aV_S} \times 100\%$$

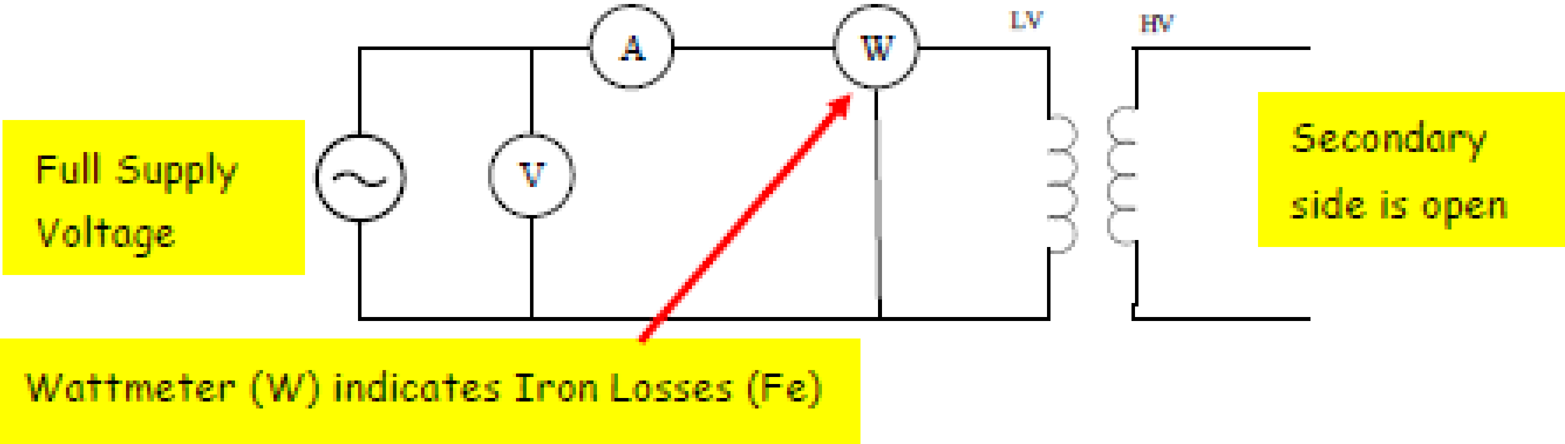
$$V.R = \frac{V_P / a - V_{S,FL}}{V_{S.FL}} \times 100\%$$

Measurement for Transformer

- Two type of tests
- The tests are conducted to determine the parameters of the transformer.
  - Open circuit test
  - Short circuit test

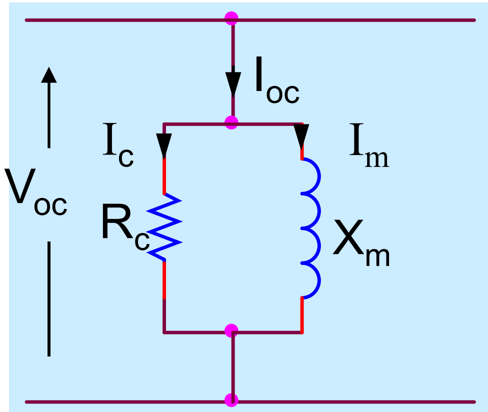
Open Circuit Test For Transformer

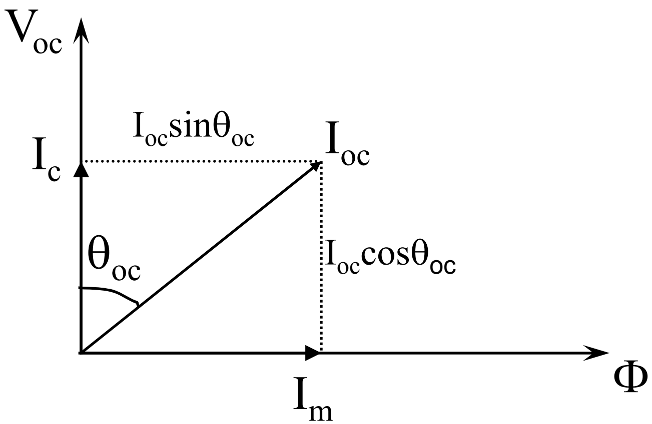
- Open circuit test is conducted to determine magnetism parameters, R_c and X_m
- Measurements are at high voltage side – transformer's secondary winding is open-circuited.



Open Circuit Test

From a given test parameters





Magnitude of the excitation admitance branch:

$$|Y_{OC}| = \frac{I_{OC}}{V_{OC}}$$

The angle of admitance:

$$PF = \cos\theta_{OC} = \frac{P_{OC}}{V_{OC} I_{OC}}$$

PF angle:

$$\theta_{OC} = \cos^{-1}\left(\frac{P_{OC}}{V_{OC} I_{OC}}\right)$$

PF always lagging for the real transformer:

$$|Y_{OC}| = \frac{I_{OC}}{V_{OC}} \angle -\theta$$

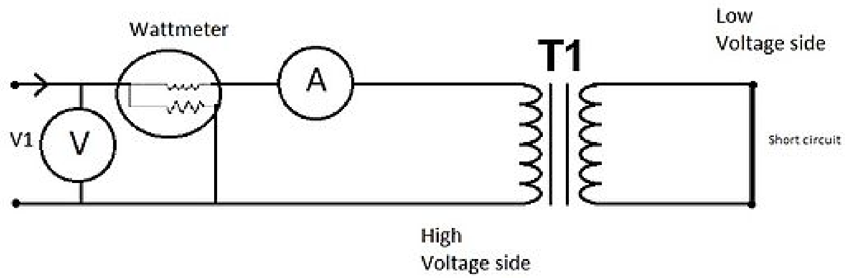
$$= \frac{I_{OC}}{V_{OC}} \angle -\cos^{-1} PF$$

Thus the complex admitance can be expressed as,

$$|Y_{OC}| = |Y_{OC}| \angle -\theta = G_C - jB_M = \frac{1}{R_C} - j\frac{1}{X_M}$$

Short Circuit Test For Transformer

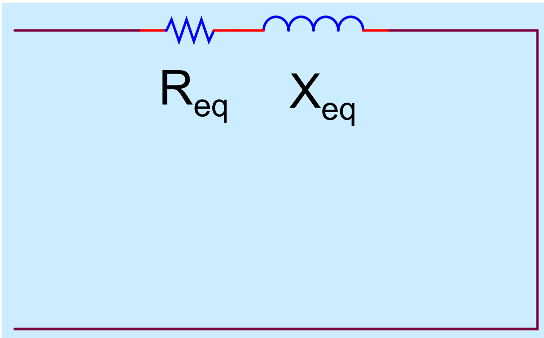
- The short circuit test is for determine the copper parameters based on which side it test. If the test is at primary, hence the parameters are R_{01} and X_{01} and vice-versa.
- If the given test parameters are taken on primary side, R_{01} and X_{01} will be obtained. Or else, vice-versa.



Source: https://commons.wikimedia.org/wiki/File:Short_Circuit_test.jpg

Short Circuit Test

From a given test parameters



For a case referred to Primary side

The magnitude of the series impedance :

$$|Z_{SE}| = \frac{V_{SC}}{I_{SC}}$$

The power factor of the current :

$$PF = \cos\theta = \left(\frac{P_{SC}}{V_{SC} I_{SC}}\right)$$

The current angle :

$$\theta = \cos^{-1}\left(\frac{P_{SC}}{V_{SC} I_{SC}}\right)$$

Therefore ,

$$|Z_{SE}| = \frac{V_{SC}\angle 0°}{I_{SC}\angle -\theta°} = \frac{V_{SC}}{I_{SC}}\angle 0°$$

The series impedance :

$$Z_{SE} = R_{eq} + jX_{eq}$$
$$= \left(R_P + a^2 R_S\right) + j\left(X_P + a^2 X_S\right)$$

1.3 THREE-PHASE TRANSFORMER

Introduction

- Most of utility company use 3-phase systems for generation, transmission and distribution

- The main advantages:
  - It occupies less floor space for equal rating.
  - Weighs less.
  - Costs about 15% less, and further.

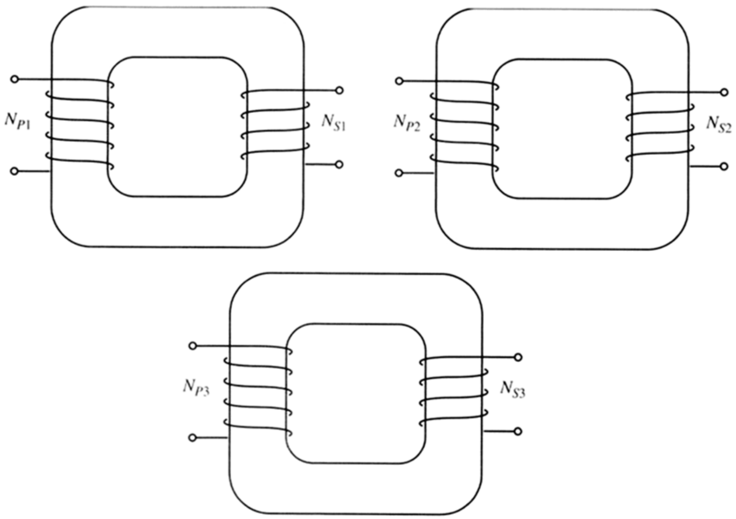
Three-phase transformer bank

Source: https://commons.wikimedia.org/wiki/File:37.5kVA_three_phase_utility_stepdown.jpg

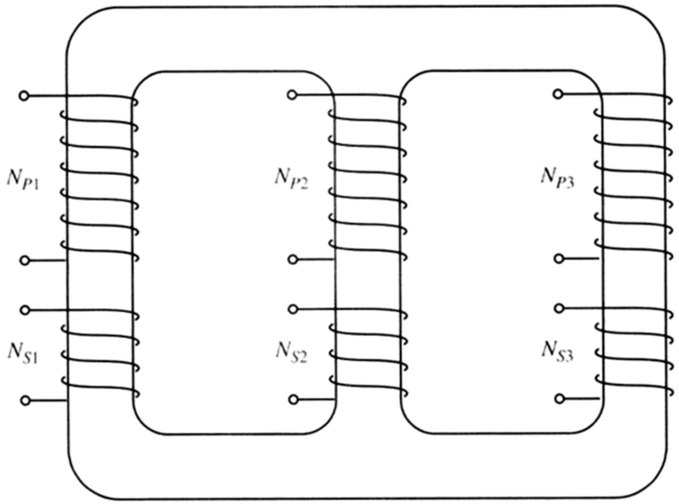
Construction

- The transformer can be constructed in two form:

3-phase of independent identical transformers



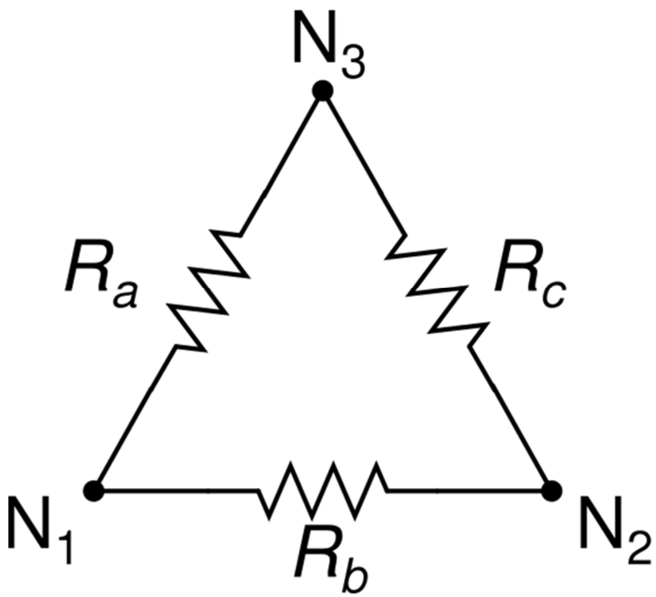
Single transformer wound with single 3-legged core

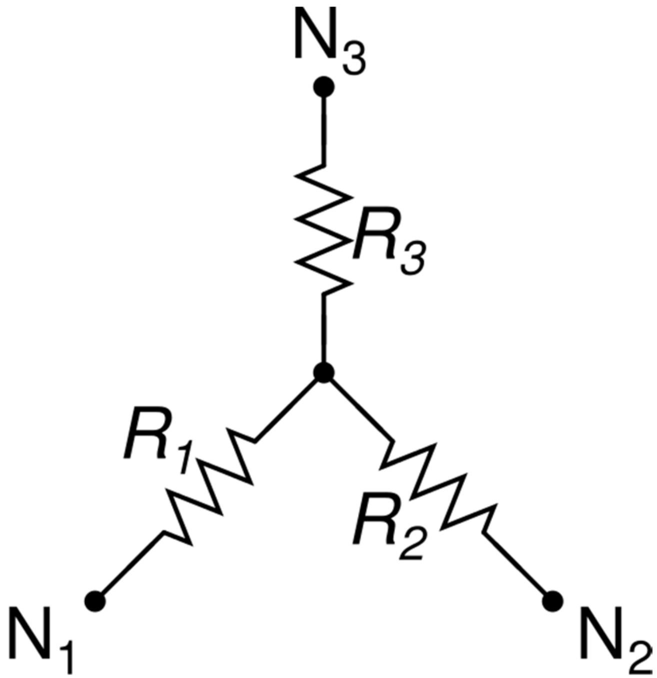


Source: http://machineryequipmentonline.com/electric-equipment/ transformersthree-phase-transformers/

Connection Technique

- Two possible connection technique are:

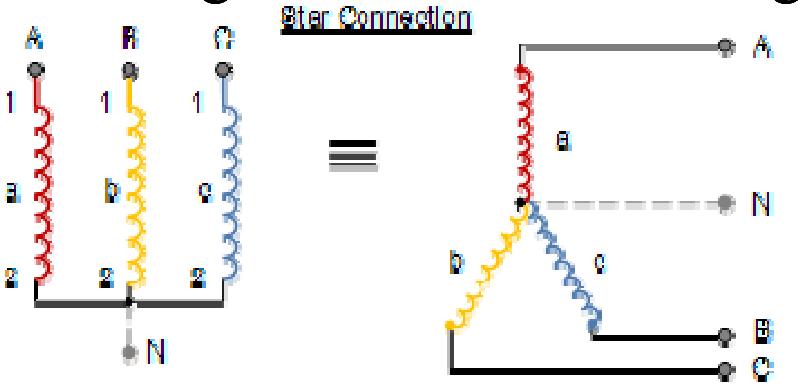




Source: wikipedia

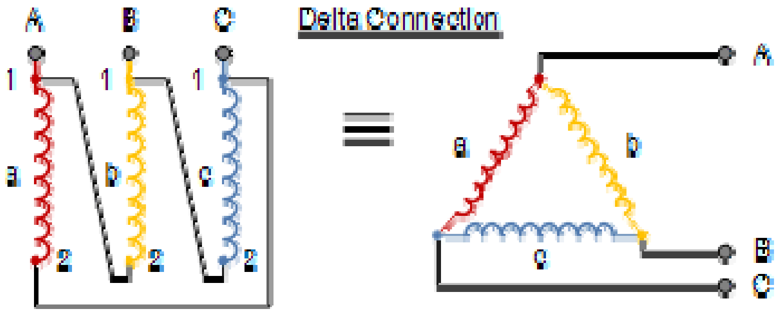
Delta Winding Connection

- Each windings are constructed by connecting each end of a winding to a different winding.



Voltage across a delta winding = line voltage

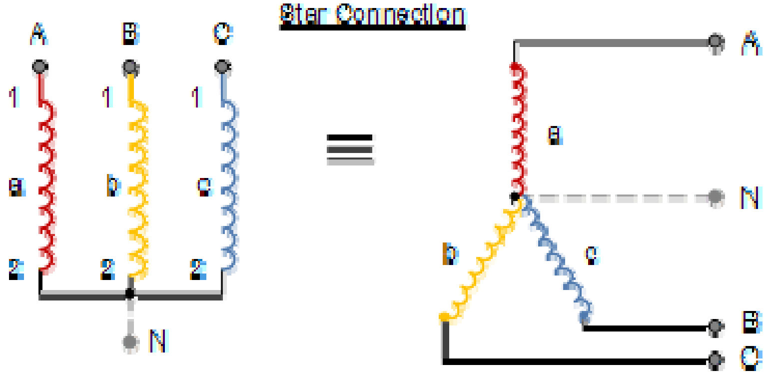
Current in a delta winding = $\dfrac{\textit{Line current}}{\sqrt{3}}$

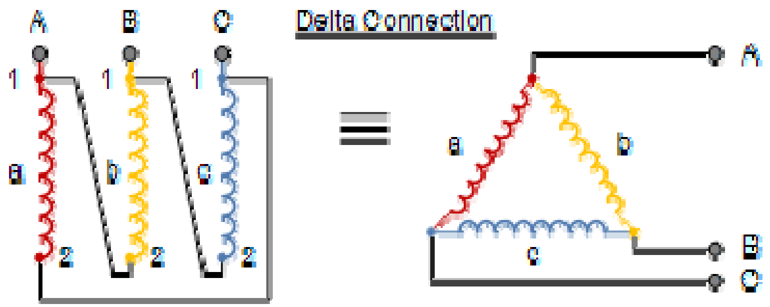


Source: http://www.electronics-tutorials.ws/transformer/three-phase-transformer.html

Star Winding Connection

- Star connected windings are constructed by connecting one end of each winding together.





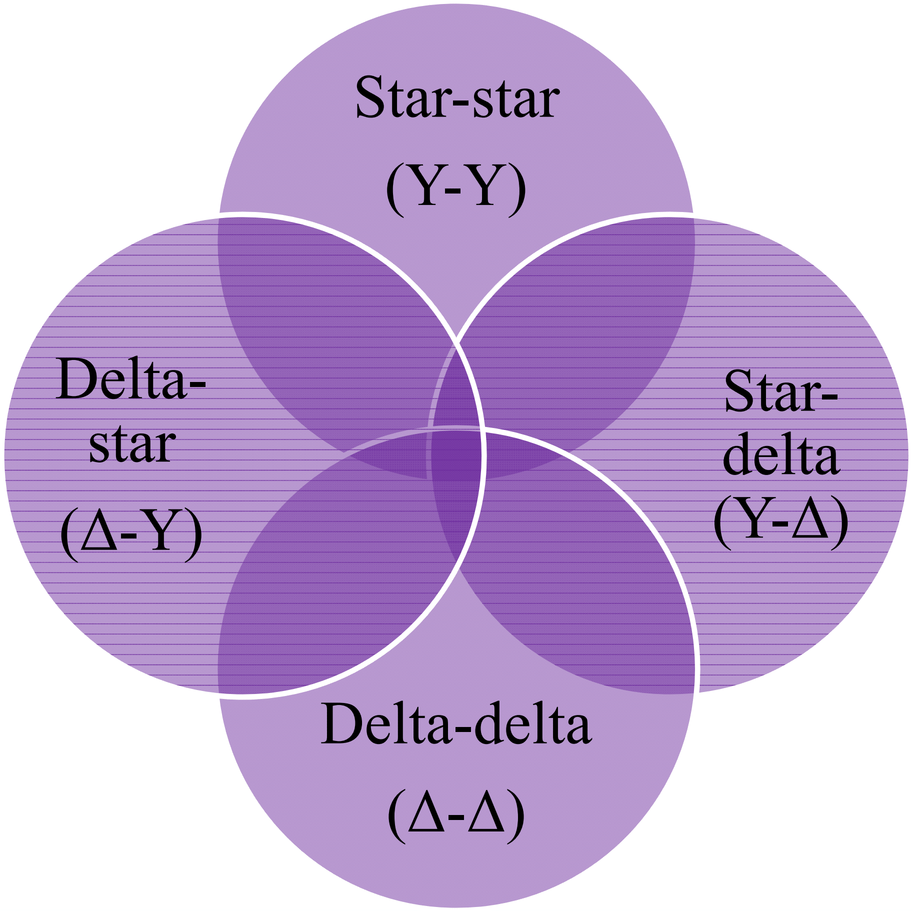
Voltage across a delta winding = $\dfrac{\textit{Line voltage}}{\sqrt{3}}$

Current in a delta winding = line current

Source: http://www.electronics-tutorials.ws/transformer/three-phase-transformer.html

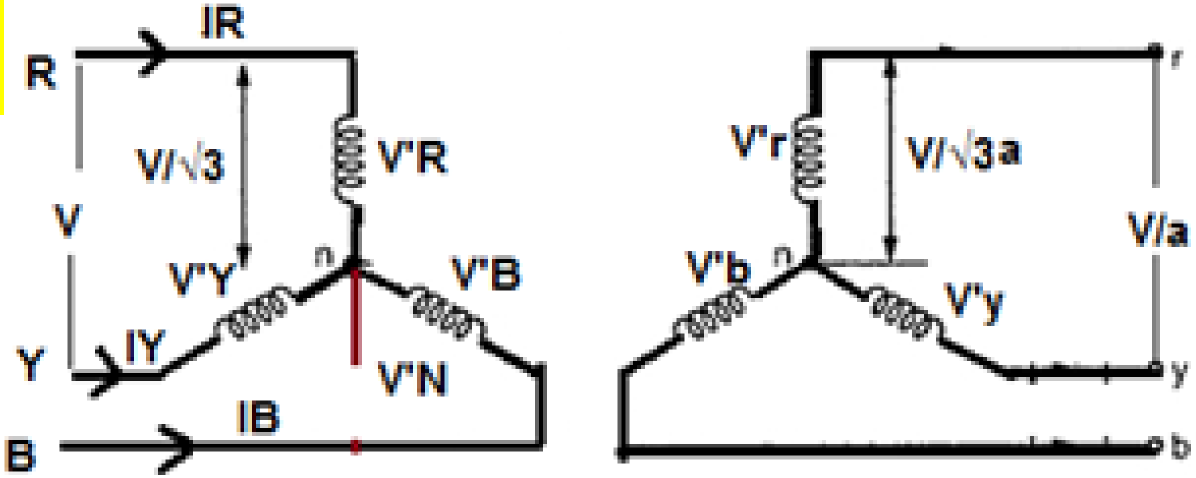
Connection Type

Four possible connections for three phase transformer:



Star-star (Y-Y) Connection

$$V_{\phi P} = \frac{V_{LP}}{\sqrt{3}}$$



$$V_{LS} = \sqrt{3} V_{\phi S}$$

Source: https://electricalnotes.wordpress.com/2012/04/30/star-star-connection-of-transformer/

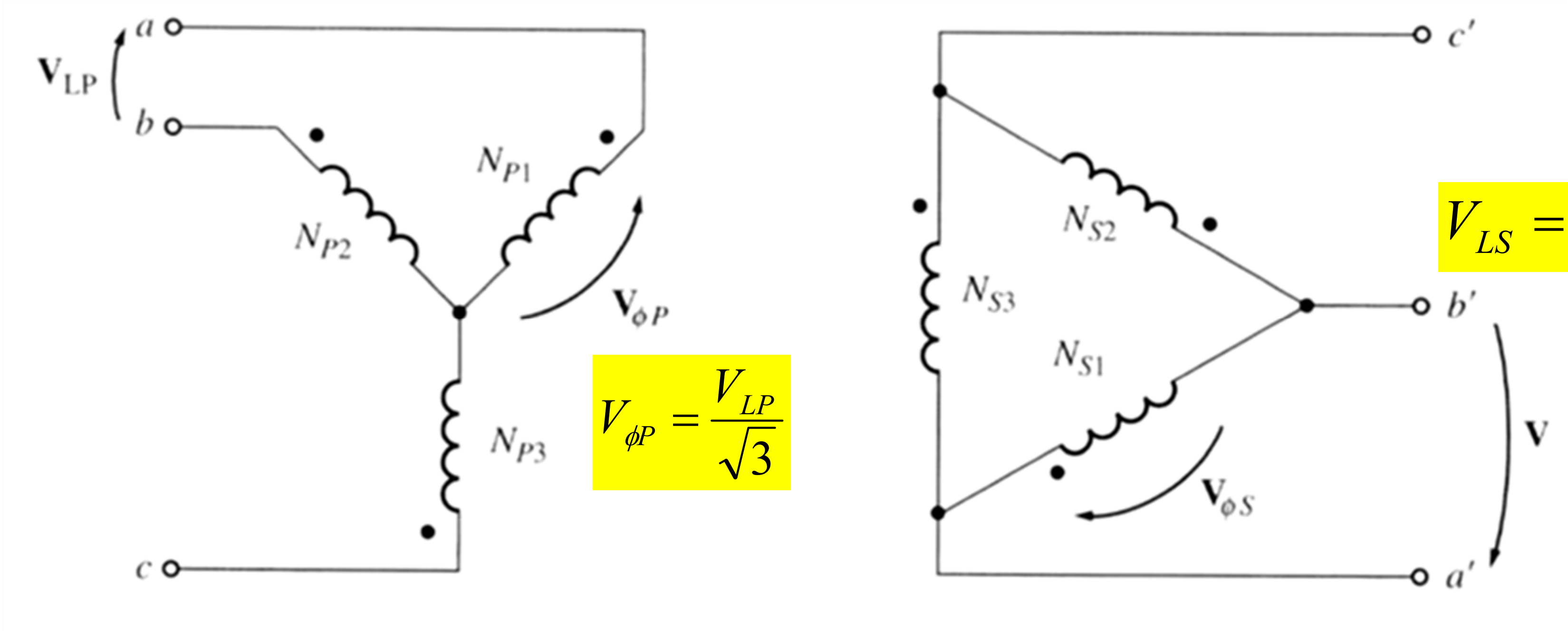
- $V_{ØS}$ = secondary-phase voltage
- V_{LP} = primary-line voltage
- V_{LS} = secondary-line voltage

$$\frac{V_{LP}}{V_{LS}} = \frac{\sqrt{3} V_{\phi P}}{\sqrt{3} V_{\phi S}} = a$$

Star-star (Y-Y) Connection

Advantages	Disadvantages
• Economic: less number of turns and quantity of insulation. • The windings able to handle heavy loads and short circuit.	• Unbalanced voltage. • The presence of third harmonic voltage.

Star-delta (Y-Δ) Connection



$$V_{\phi P} = \frac{V_{LP}}{\sqrt{3}}$$

$$V_{LS} = V_{\phi S}$$

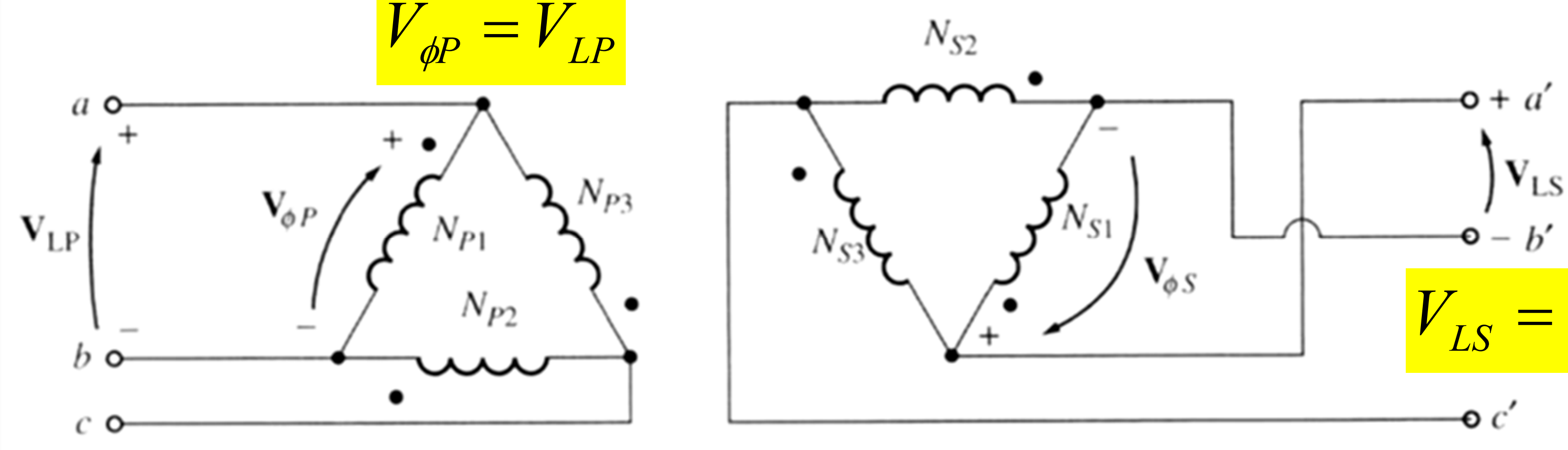
$$\frac{V_{LP}}{V_{LS}} = \frac{\sqrt{3}V_{\phi P}}{V_{\phi S}} = \sqrt{3}a$$

Star-delta (Y-Δ) Connection

Advantages	Disadvantages
• Economic: less number of turns and quantity of insulation. • No third harmonic voltage problem. • Stable with respect to unbalanced load.	• The secondary voltage is shifted 30° from the primary one.

Delta-delta (Δ–Δ) CONNECTION

$$V_{\phi P} = V_{LP}$$



$$V_{LS} = V_{\phi S}$$

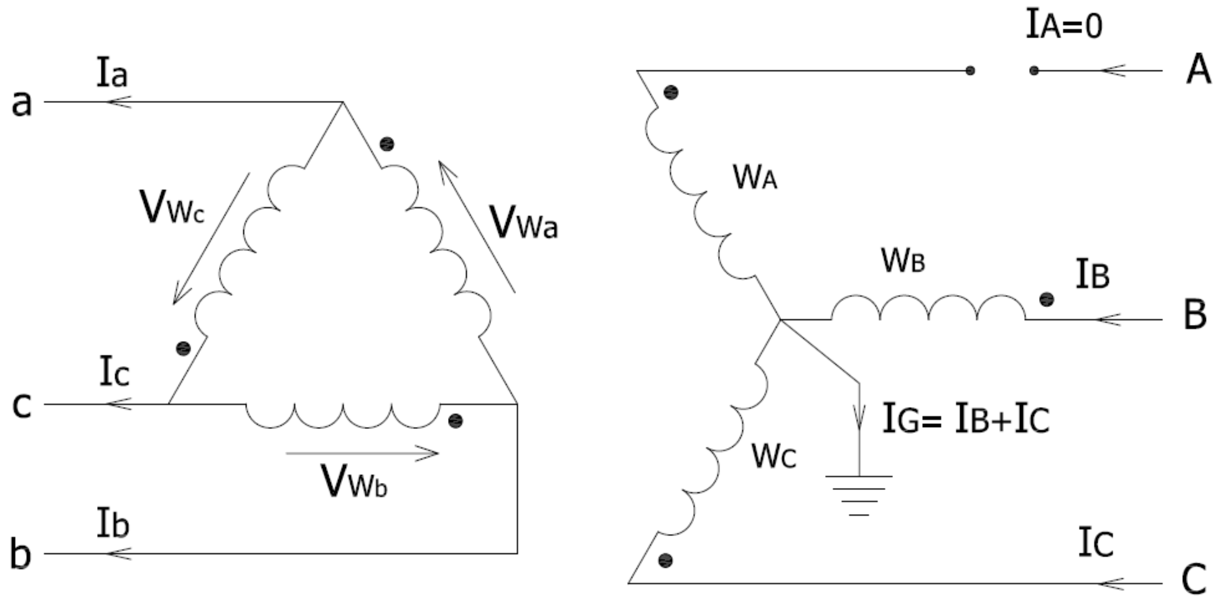
$$\frac{V_{LP}}{V_{LS}} = \frac{V_{\phi P}}{V_{\phi S}} = a$$

Delta-delta (Δ–Δ) CONNECTION

Advantages	Disadvantages
• Economic: cross-section of the winding is low. • No third harmonic voltage problem. • Stable with respect to unbalanced load.	• It is not possible for 3-phase four wire system because neutral point is absent.

Delta-star (Δ –y) Connection

$$V_{\phi P} = V_{LP}$$



$$V_{LS} = \sqrt{3} V_{\phi S}$$

Fig. 9. Open Phase in a Y_g-Δ Transformer

Source: http://generalpac.com/transformers/open-phase-condition-in-transformers

$$\frac{V_{LP}}{V_{LS}} = \frac{V_{\phi P}}{\sqrt{3} V_{\phi S}} = \frac{\sqrt{3}}{a}$$

Delta-star (Δ–y) Connection

Advantages	Disadvantages
• No third harmonic voltage problem. • Stable with respect to unbalanced load.	• The secondary voltage is shifted 30° from the primary one.

Applications

CONNECTION TYPES	APPLICATIONS
STAR-STAR	Most economical for small high voltage transformers
STAR-DELTA	Commonly used in a step-down transformer (i.e. employed at the substation)
DELTA-DELTA	Suitable for large, low voltage transformers
DELTA-STAR	Commonly used in a step-up transformer (i.e. at the beginning of a HT transmission line)

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Research interest: Reliability, Distribution network, smart grid, risk asessment