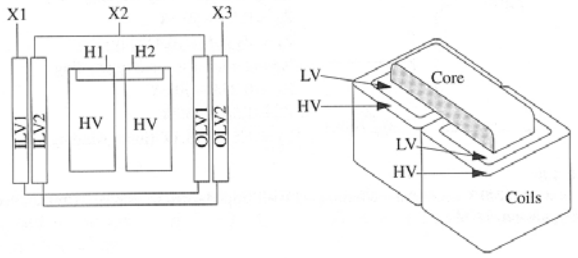
Three-phase transformers

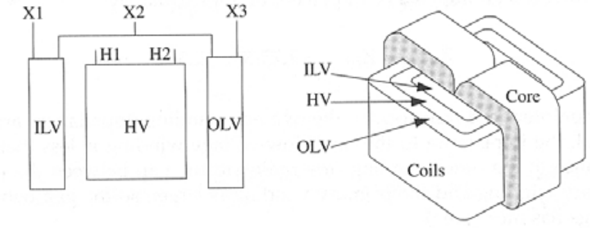
- **Core arrangements**
  - Transformer bank => three 1~ transformers (core type or shell type)
  - 3~ transformer (3, 4, 5 legged core-type)
- **Winding arrangements**
  - Y-Y
  - Δ-Δ
  - Δ-Y
  - Y-Δ
  - With tertiary

Core Type vs. Shell Type



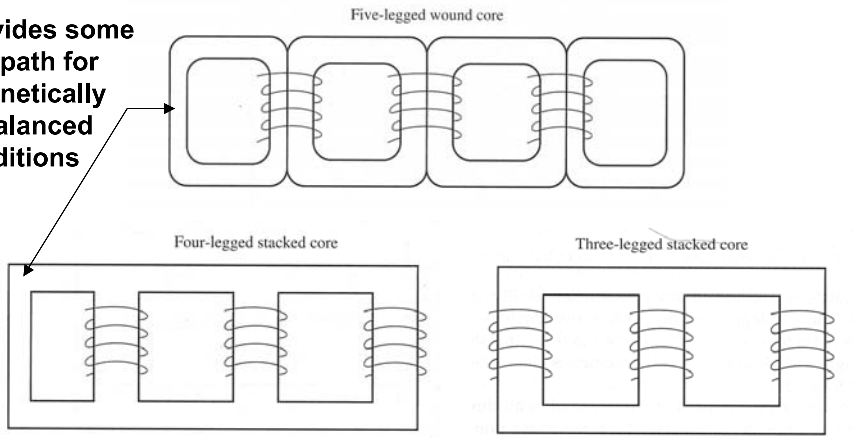
Core type

Shell type

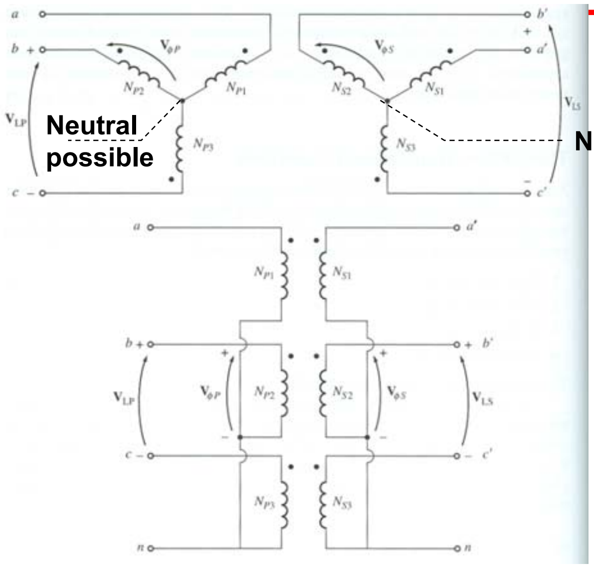


Three-phase transformer core forms

Provides some flux path for magnetically unbalanced conditions



Y-Y connection



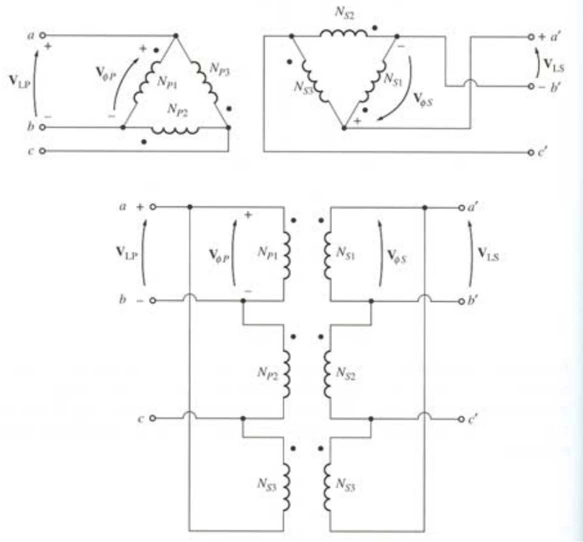
Neutral possible

Neutral possible

Magnitudes

$$\frac{V_{LP}}{V_{LS}} = a$$

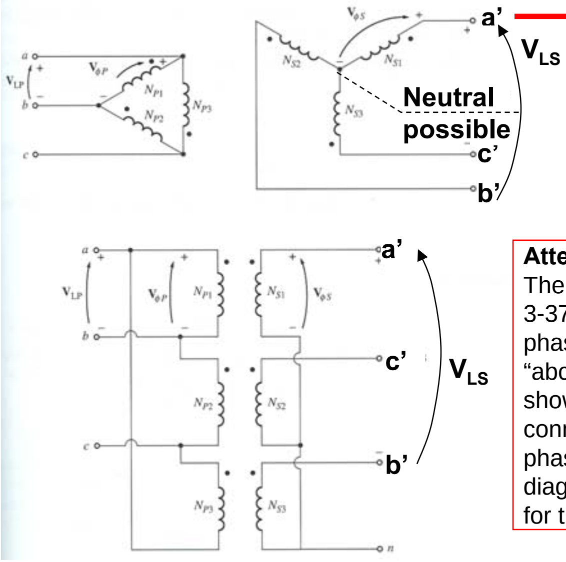
Δ-Δ connection



Magnitudes

$$\frac{V_{LP}}{V_{LS}} = a$$

Δ-Y connection



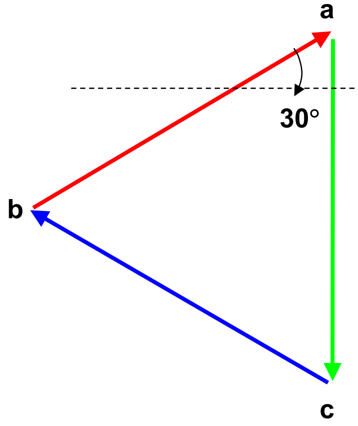
Magnitudes

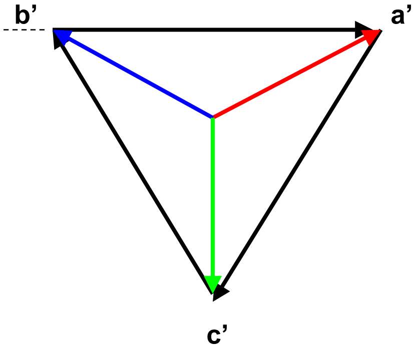
$$V_{LS} = \frac{V_{LP}}{a}\sqrt{3} \qquad \frac{V_{LP}}{V_{LS}} = \frac{a}{\sqrt{3}}$$

Attention
The terminal connections in Figure 3-37(c) in Textbook leads to a phase transposition (“acb” => “abc”). Therefore, this diagram here shows the corrected terminal connections that do not lead to a phase transposition. The phasor diagram on the next slide is drawn for this connection.

Δ-Y connection – Phasor diagram

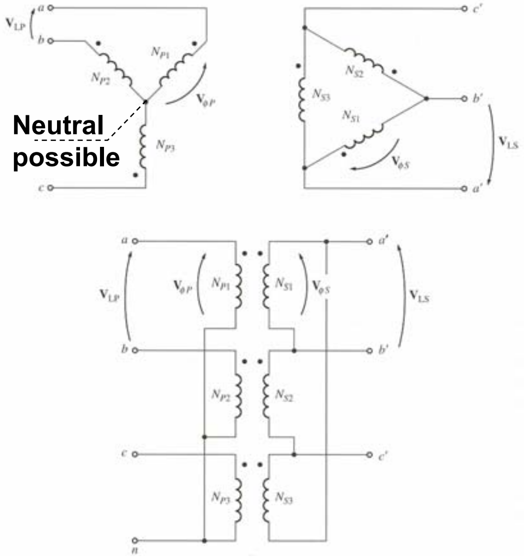
The respective phase-phase voltages on the secondary side lag those on the primary side by 30°





The acb sequence was chosen here arbitrarily. However, the corrected terminal connections now retain the sequence on the secondary side.

Y-Δ connection



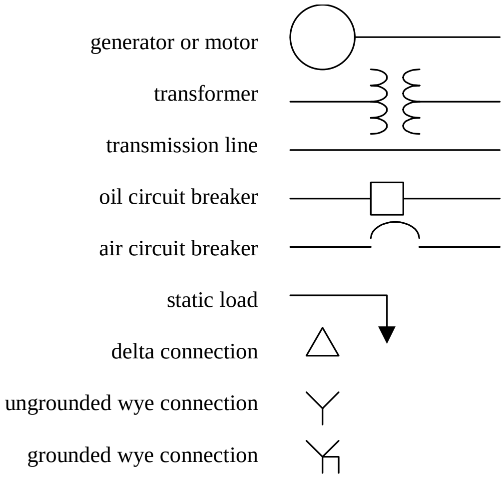
Neutral possible

Magnitudes

$$V_{LP} = \sqrt{3}\,aV_{LS}$$

$$\frac{V_{LP}}{V_{LS}} = \sqrt{3}\,a$$

Power System Representation



generator or motor

transformer

transmission line

oil circuit breaker

air circuit breaker

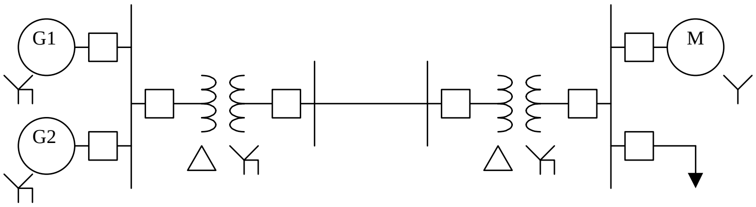
static load

delta connection

ungrounded wye connection

grounded wye connection

Power System Representation



One Line Diagram

Changing Bases

- The impedances of generators, transformers, transmission lines, and loads are supplied by the manufacturers in per unit based on the equipment's own rating.
- When placing the equipment into a system, the impedance must be converted to the system base

$$Z_{pu} = \frac{Z_{p-Actual}}{Z_{Base}} = \frac{\left(Z_{p-Actual}\right)\left(S_{3\phi-Base}\right)}{\left(V_{LL-Base}\right)^2}$$

$$Z_{new-pu} = Z_{old-pu}\left(\frac{S_{3\phi-Base-new}}{S_{3\phi-Base-old}}\right)\left(\frac{V_{LL-Base-old}}{V_{LL-Base-new}}\right)^2$$

Only within one voltage zone!

Changing Bases

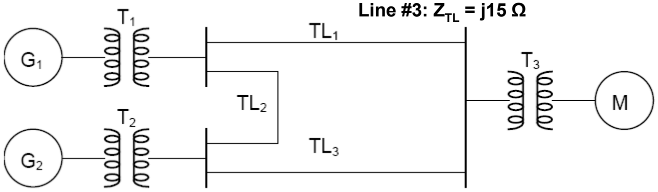
- The pu impedance of a transformer is independent of the reference side: primary or secondary.
- Voltage, current, and impedance base change at transformers as they step the voltage up or down.
- The power base remains the same across a transformer

Example

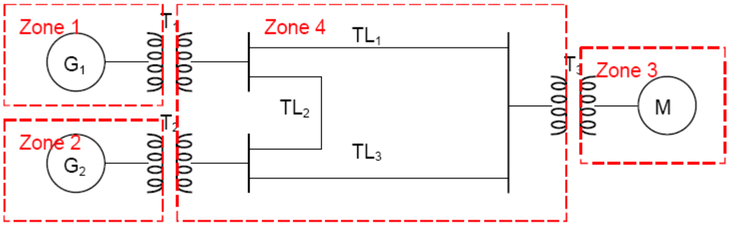
A one-line diagram of a three-phase power system is shown. Draw the impedance diagram of the power system, and mark all impedances in per unit. Use a base of 100 MVA and 138 kV for the transmission lines. All transformers are connected to step up the voltage of the generators to the transmission line voltages. Calculate the terminal voltage of G2 (in pu) if G1 is out of service and the motor draws 50 MW of power with 1 pu voltage at its terminals.

Equipment Ratings:
G1: 45 MVA 13.2 kV Xg = 0.15 pu
G2: 55 MVA 18 kV Xg = 0.12 pu
Motor : 75 MW, PF=1, 11.6 kV Xg = 0.23 pu

T1: 50 MVA 13.8 / 138 kV Xt = 0.10 pu
T2: 60 MVA 19.05 / 138 kV Xt = 0.10 pu
T3: 70 MVA 138 / 11.6 kV Xt = 0.10 pu
Line #1: Z_{TL} = j40 Ω
Line #2: Z_{TL} = j20 Ω
Line #3: Z_{TL} = j15 Ω



Example (cont)



Voltage Zones:
Zone 1: V_{Base} = 13.8 kV S_{Base} = 100MVA
Zone 2: V_{Base} = 19.05 kV S_{Base} = 100MVA
Zone 3: V_{Base} = 11.6 kV S_{Base} = 100MVA
Zone 4: V_{Base} = 138 kV S_{Base} = 100MVA

Example (cont)

Impedances:

$$Z_{G1} = j0.15\left(\frac{100MVA}{45MVA}\right)\left(\frac{13.2kV}{13.8kV}\right)^2 = j0.305\,pu$$

$$Z_{G2} = j0.12\left(\frac{100MVA}{55MVA}\right)\left(\frac{18kV}{19.05kV}\right)^2 = j0.195\,pu$$

$$Z_{M} = j0.23\left(\frac{100MVA}{75MVA}\right)\left(\frac{11.6kV}{11.6kV}\right)^2 = j0.307\,pu$$

$$Z_{T1} = j0.10\left(\frac{100MVA}{50MVA}\right)\left(\frac{138kV}{138kV}\right)^2 = j0.200\,pu$$

$$Z_{TL1} = \frac{j40\Omega}{190.4\Omega} = j0.210\,pu$$

$$Z_{T2} = j0.10\left(\frac{100MVA}{60MVA}\right)\left(\frac{138kV}{138kV}\right)^2 = j0.167\,pu$$

$$Z_{TL2} = \frac{j20\Omega}{190.4\Omega} = j0.105\,pu$$

$$Z_{T3} = j0.10\left(\frac{100MVA}{70MVA}\right)\left(\frac{138kV}{138kV}\right)^2 = j0.143\,pu$$

$$Z_{TL3} = \frac{j15\Omega}{190.4\Omega} = j0.0788\,pu$$

$$Z_{Base} = \frac{(138kV)^2}{100MVA} = 190.4\Omega$$