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

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

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

Only within one voltage zone!

Changing Bases

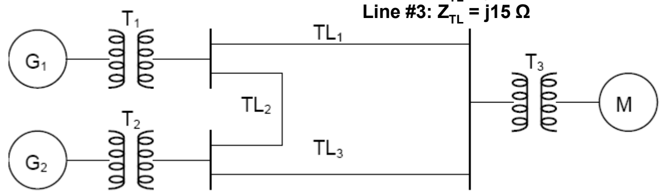
- Voltage, current, and impedance base values change at transformers as they step the voltage up or down.
- The power base remains the same across a transformer
- The pu values of impedance, voltage, and current across a transformer is independent of the reference side: primary or secondary

Example

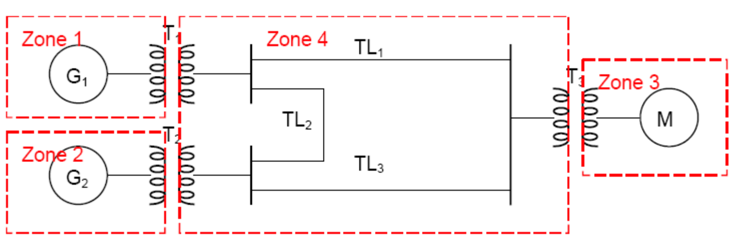
A one-line diagram of a three-phase power system is shown. Draw the impedance diagram of the power system, and mark all impedances in per unit. Use a base of 100 MVA and 138 kV for the transmission lines. All transformers are connected to step up the voltage of the generators to the transmission line 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:

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

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

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

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

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

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

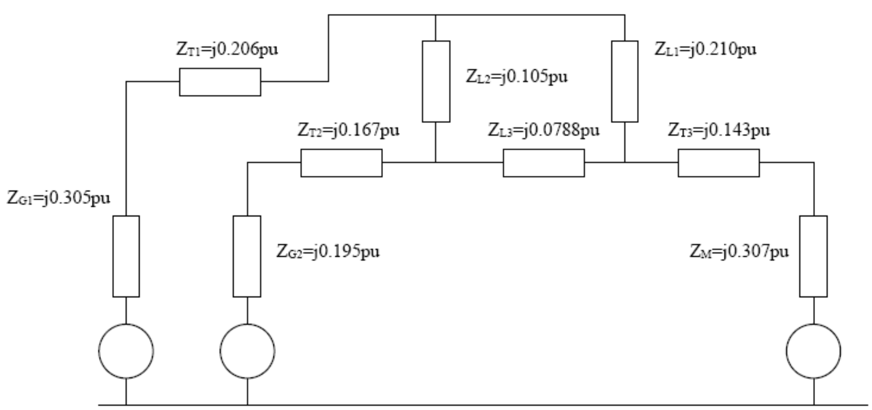
$$Z_{TL1} = \frac{j40\Omega}{190.4\Omega} = j0.210\,pu$$

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

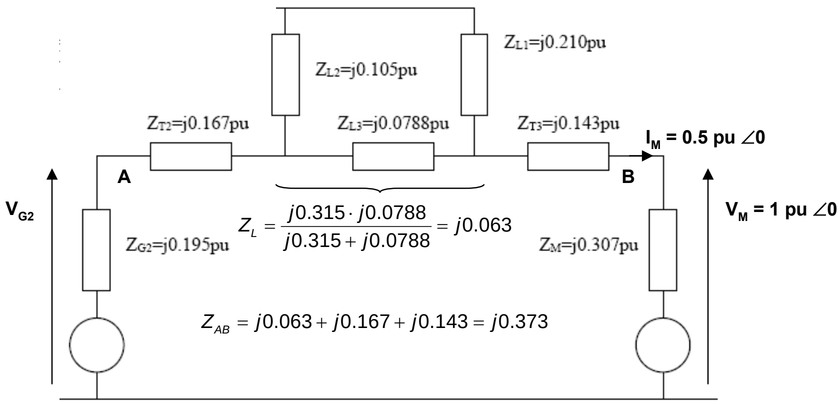
$$Z_{TL3} = \frac{j15\Omega}{190.4\Omega} = j0.0788\,pu$$

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

Example (cont)



Example (cont)

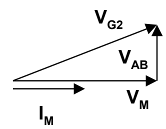


$$Z_L = \frac{j0.315 \cdot j0.0788}{j0.315 + j0.0788} = j0.063$$

$$Z_{AB} = j0.063 + j0.167 + j0.143 = j0.373$$

$$V_{AB} = I_M \cdot Z_{AB} = 0.5 \cdot j0.373 = 0.187\, pu\angle 90^\circ$$

$$V_{G2} = \sqrt{1 + 0.187^2}\,\angle \arctan(0.187) = 1.017\, pu\angle 10.6^\circ$$

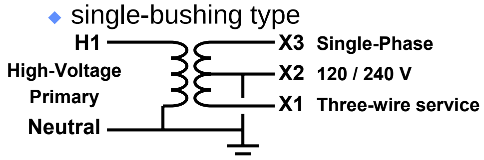


Load Calculations and Transformer Sizing

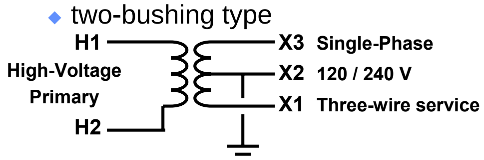
- **Load calculations determine the expected apparent power, S, of the load**
- **The expected load power is used to specify the power rating of the transformer**
- **Load balancing**
  - Single phase systems
    - three wire - 120 / 240 V residential service
  - Three phase systems
    - grounded-wye connection, four wire service
    - floating-wye connection, three wire service
    - delta connection, three wire service

Transformer Applications

- **Single-phase overhead transformers**
  - single-bushing type

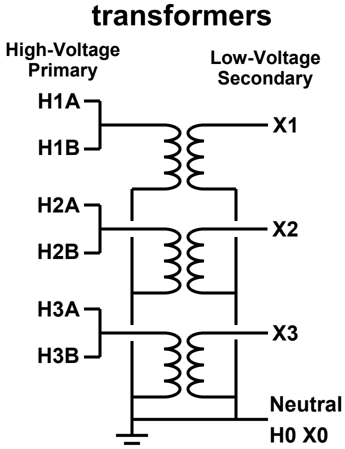


  - two-bushing type



Transformer Applications

- **Three-phase pad-mounted transformers**



Standard Transformer Ratings

- Overhead pole-type transformers

Single-phase (kVA)	Three-phase (kVA)
10	30
25	45
37.5	75
50	112.5
75	150
100	225
167	300
250	500
333	
500	

Example

A single-phase pole-mount transformer is to be used to supply the following estimated loads:

Load 1: 7 kW, 0.9 pf lagging, @ 120 V

Load 2: 12 kW, 0.9 pf lagging, @ 240 V

Load 3: 5 kW, 0.9 pf lagging, @ 120 V

Load 4: 23 kW, 0.8 pf lagging, @ 240 V

demand factor of all four loads: 0.72

The power distribution is one phase of a 12.47 kV, three-phase system. Specify the transformers voltage and power rating.

Example

$$V_{LL} = 12{,}470 \text{ V} \quad E_1 = V_{LN} = \frac{V_{LL}}{\sqrt{3}} = \frac{12{,}470}{\sqrt{3}} = 7200 \text{ V}$$

$$E_2 = 120 / 240 \text{ V}$$

$$Q = P\frac{\sqrt{1-PF^2}}{PF} = P\sqrt{1/PF^2 - 1}$$

$$P_1 = 7 \text{ kW} \quad Q_1 = 3.4 \text{ kVAr}$$

$$P_2 = 12 \text{ kW} \quad Q_2 = 5.8 \text{ kVAr}$$

$$P_3 = 5 \text{ kW} \quad Q_3 = 2.4 \text{ kVAr}$$

$$P_4 = 23 \text{ kW} \quad Q_4 = 17.25 \text{ kVAr}$$

$$S_{load} = (S_1 + S_2 + S_3 + S_4) \cdot df = (47 + j28.9 \text{ kVA}) \cdot 0.72$$

$$S_{load} = (55.1 \text{ kVA}) \cdot 0.72 = 39.7 \text{ kVA}$$

$$S_{xfmr\_rating} > 39.7 \text{ kVA}$$

a 12,470GrdY / 7,200V : 120 / 240V, 50 kVA transformer is required

Homework 4

See web site
http://www.eng.fsu.edu/~steurer/eel3216.html

Problems

3-10
3-22
in book

plus two extra problems