

SAARC Training Workshop 'Power System Studies for Synchronization of Multiple Systems'

The Per Unit System

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The Per Unit System

- In power systems there are four base quantities required to define a per unit system
- These are:
 - Power
 - Voltage
 - Current
 - Impedance

Per Unit System

- Convenient way of representing system quantities, such as kilovolts, amps, ohms etc
- Per unit (pu) =
$$\frac{\text{the actual value (in any unit)}}{\text{the base of reference value in the same unit}}$$
- Benefits
 - equipment ratings are similar for different devices with respect to their own base, thus suspect data is easier to detect
 - physical turns ratio of transformers can be ignored
 - voltage magnitude throughout a given power system is relatively close to unity in per unit (pu) system for a system operating normally. Thus useful check on calculations
 - makes power system calculations simpler

Per Unit System (cont.)

How to convert to a per unit system:

- Choose voltage base and power base
- Calculate current base and impedance base
- Divide all actual quantities by their respective base values to get per unit (pu) quantity, thus

$$\text{Quantity per unit} = \frac{\text{actual quantity}}{\text{base value of quantity}}$$

$$S_{pu} = \frac{S}{S_B}, V_{pu} = \frac{V}{V_B}, I_{pu} = \frac{I}{I_B}, Z_{pu} = \frac{Z}{Z_B}$$

Per Unit System (cont.)

- For a balanced three-phase circuit star connected system:

$$\text{base current } I = \frac{\text{base power } S_{3\phi}}{\sqrt{3} \text{ base voltage } V_{LL}}$$

Calculated using line-line
base voltage and 3-phase
base power

$$\text{base impedance } Z = \frac{(\text{base voltage } V_{LL})^2}{\text{base power } S_{3\phi}}$$

- Base current and impedance for a delta connection:

$$\text{base current } I_{\Delta} = \frac{\text{base current } I}{\sqrt{3}}$$

$$\text{base impedance } Z_{\Delta} = 3 \text{ base impedance } Z$$

Change of Base

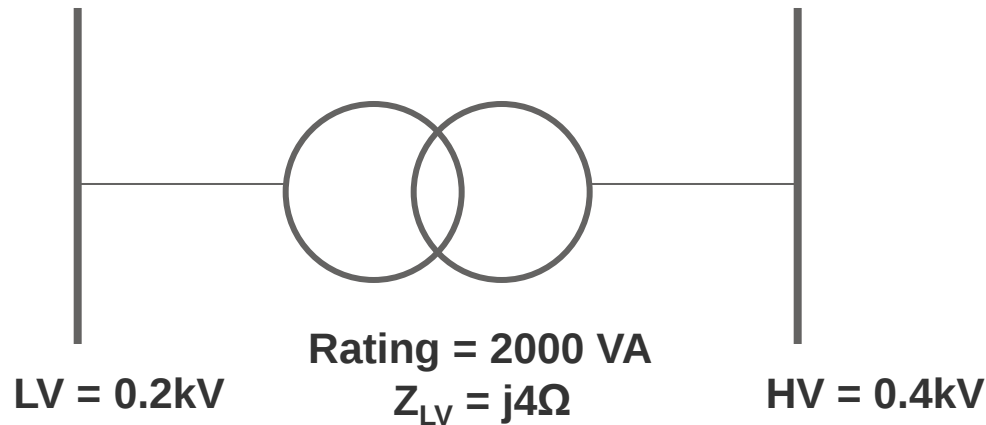
- Usually if none are specified, the pu values given are on nameplate ratings as base
- For example a generator whose impedance is 0.2 pu and whose ratings are 110MVA and 24kV, then the base MVA is assumed 110MVA and base line to line voltage is 24kV

Change of Base

- Often the base for the system is different from the base for each particular generator or transformer, hence it is important to be able to express the pu value in terms of different bases. This is derived below:

$$Z_{pu}^{new} = Z_{pu}^{old} \frac{S_B^{new}}{S_B^{old}} \left(\frac{V_B^{old}}{V_B^{new}} \right)^2$$

Transformers and Per Unit System



- The internal impedance of the transformer as seen from the high voltage side is:

$$Z_{HV} = Z_{LV} \left(\frac{V_2}{V_1} \right)^2 = j4.0 \times \left(\frac{0.4}{0.2} \right)^2 = j16.0\Omega$$

Transformers and Per Unit System

- Comparison of the bases and the per unit value on both sides of the transformer is shown below:

	Low voltage side	High voltage side
S_{base}	2000 VA	2000 VA
V_{base}	200 V	400 V
I_{base}	$S_{\text{base}}/V_{\text{base}} = 10\text{A}$	$S_{\text{base}}/V_{\text{base}} = 5\text{A}$
Z_{base}	$V_{\text{base}}^2/S_{\text{base}} = 20 \Omega$	$V_{\text{base}}^2/S_{\text{base}} = 80 \Omega$
Z_{pu}	$Z_{\text{LV}}/Z_{\text{base}} = j4/20=j0.2 \text{ p.u}$	$Z_{\text{HV}}/Z_{\text{base}} = j16/80=j0.2 \text{ p.u}$