DEE 3143 BASIC ELECTRICAL MACHINE & POWER SYSTEMS

CHAPTER 5
POWER SYSTEM REPRESENTATION

by
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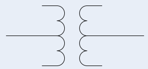
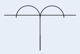
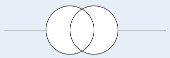
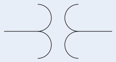
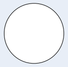
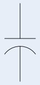
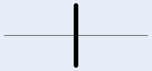
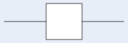
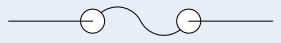
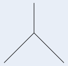
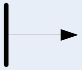
Topic Outcomes

- Calculate the per-unit value of any quantity in a three-phase power system.
- Develop the per-unit system to perform the steady-state analysis of power systems.
- Describe the advantages of per-unit system.

Single Line Diagram

- Represent the interconnection of the power system components.
- Also referred as Single-line Diagram
- Advantage: Simplicity
  - One phase represents all three phases of the balanced system.
  - Equivalent circuit of the components are replaced by their standard symbols
  - The completion of the circuit through the neutral is omitted.

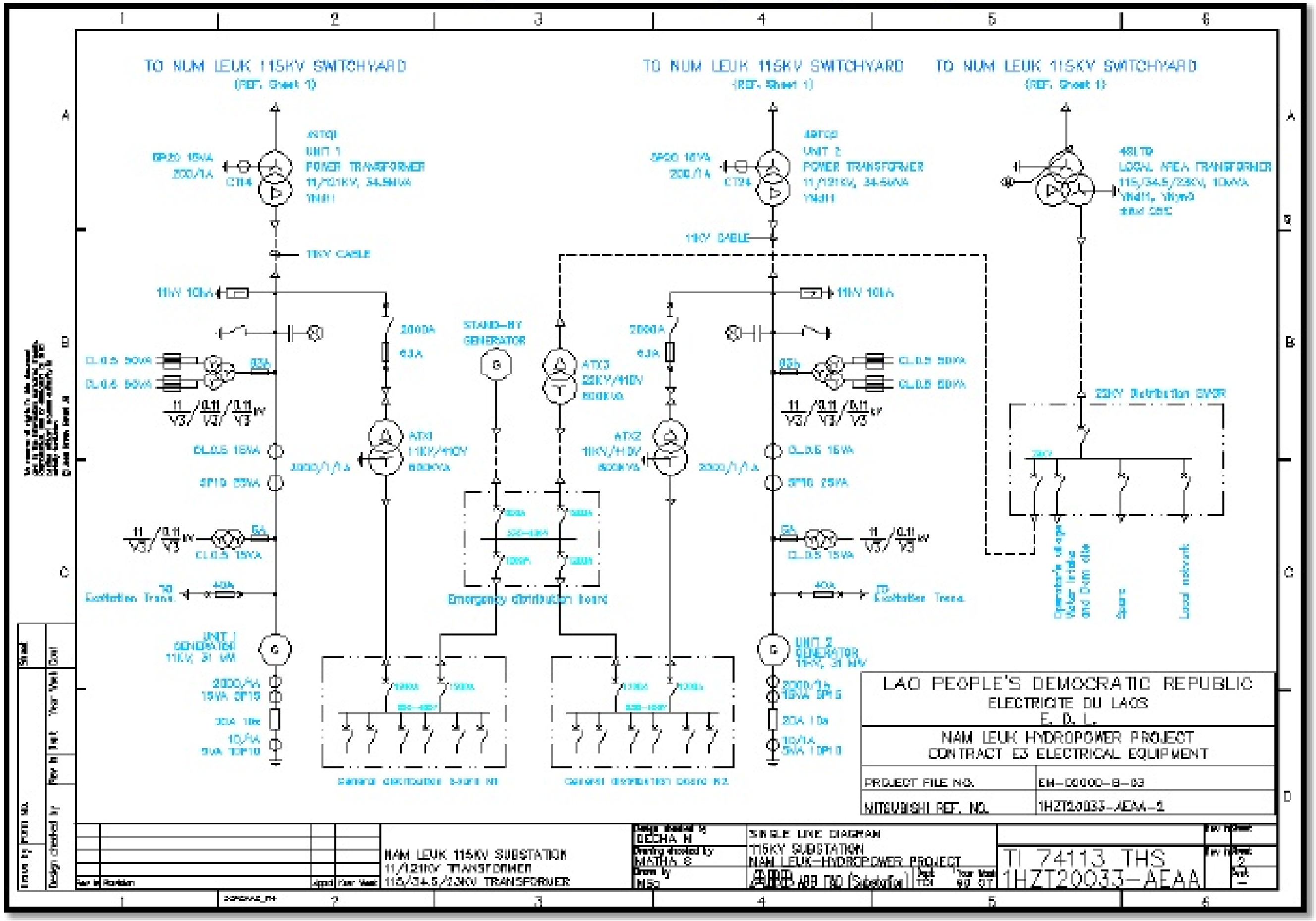
Single Line Diagram

	two-winding transformer		current transformer
	two-winding transformer		voltage transformer
	generator		capacitor
	bus		circuit breaker
	transmission line		circuit breaker
	delta connection		fuse
	wye connection		surge arrestor
	static load		disconnect

Symbol used in SLD

Source: http://cpacash.co/wiringdiagrams/electrical-line-diagram-symbols.html

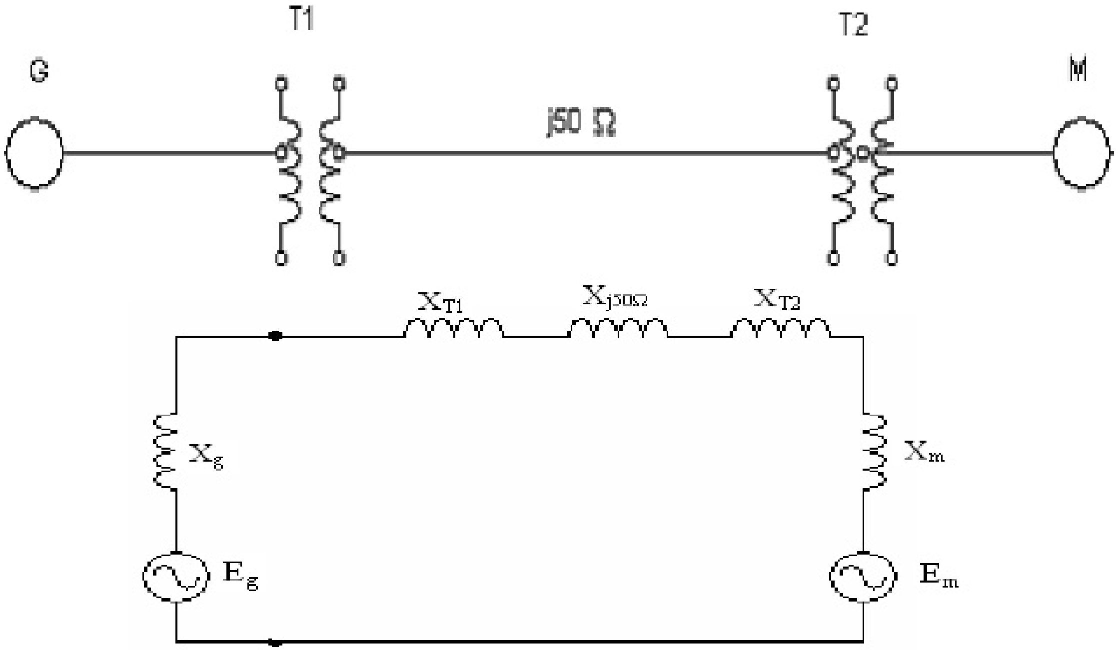
Single Line Diagram (cont.)



Source: https://www.slideshare.net/nanonon/step1-single-line-diagram

Reactance Diagram

REACTANCE DIAGRAM FOR THE GIVEN POWER SYSTEM NETWORK



Source: https://www.slideshare.net/Aisu/newton-raphson

Impedance Diagram

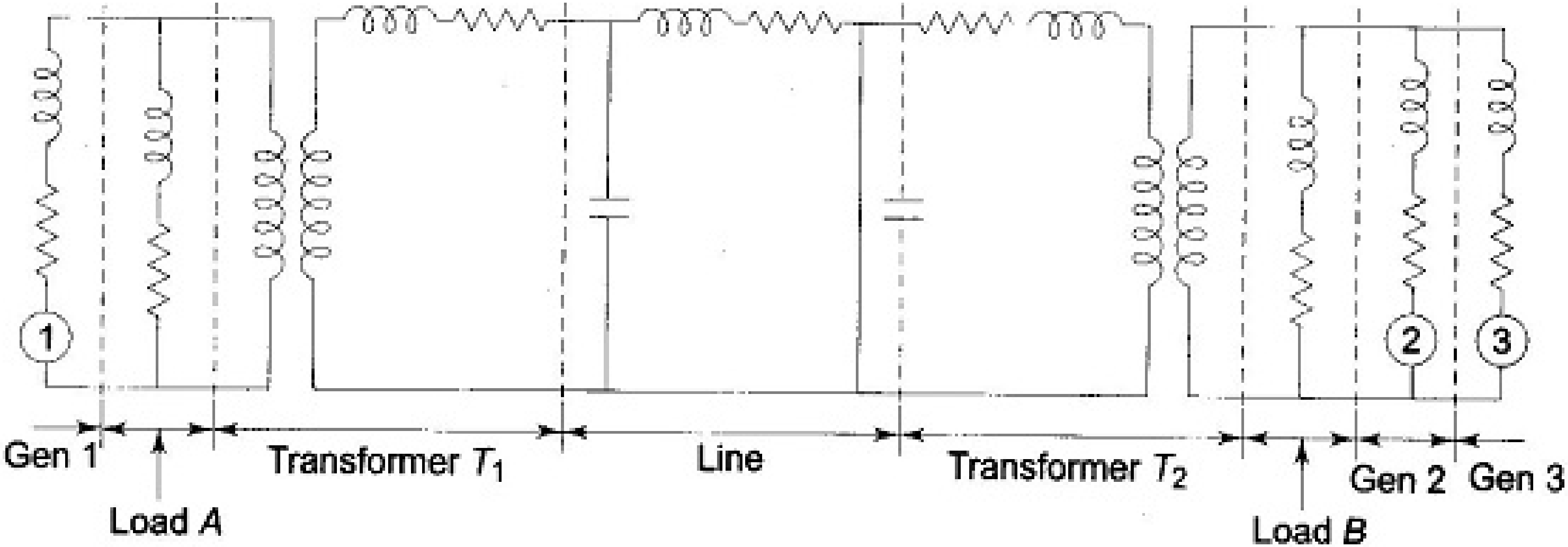


Fig. 4.6 Impedance diagram of the power system of Fig. 4.5

Source: http://www.eeeguide.com/power-system-impedance-diagram/

Per-unit System

- power, voltage, current and impedance are expressed in per-unit(pu) quantity.

$$\text{Per-unit Quantity} = \frac{\textit{Actual Quantity}}{\textit{Base Value Of Quantity}}$$

Phasor quantities/ complex values (Actual Quantity)

Real numbers (Base Value Of Quantity)

Per-unit System

- Need base value for all quantities – P,V, I,Z
- Base value do not have to be same for all equipment in the system.

$$S_{pu} = \frac{S}{S_B}$$

$$V_{pu} = \frac{V}{V_B}$$

$$I_{pu} = \frac{I}{I_B}$$

$$Z_{pu} = \frac{Z}{Z_B}$$

Per-unit System

Usually, the 3-phase base MVA$_B$(S_B) and the line-to-line base voltage kV$_B$(V_B).

Base Current:

$$S = IV$$ (in VA)

$$S_{pu} = I_{pu} V_{pu}$$ (in pu)

$$\frac{S}{S_B} = \frac{I}{I_B} \frac{V}{V_B}$$

$$I_B = \frac{S_B}{V_B}$$ 1-phase

$$I_B = \frac{S_B}{\sqrt{3} V_B}$$ 3-phase

Per-unit System

Usually, the 3-phase base $MVA_B(S_B)$ and the line-to-line base voltage $kV_B(V_B)$.

Base impedance:

$$V = ZI$$ ← (in V)

$$V_{pu} = Z_{pu} I_{pu}$$ ← (in pu)

$$\frac{V}{V_B} = \frac{Z}{Z_B}\frac{I}{I_B}$$

$$\frac{1}{V_B} = \frac{1}{Z_B}\frac{1}{I_B}$$

$$Z_B = \frac{V_B}{I_B} = \frac{V_B{}^2}{S_B}$$

Change of Base

If an impedance is expressed in a new base and an old base. We must have:

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

Expressing ZΩ to a new power base and a new voltage base

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

Change of Base

The relationship between the NEW and the OLD per-unit value

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

We usually have $V_{B,new} = V_{B,old}$ because a generator is almost always connected at its nominal voltage

$$Z_{pu}^{new} = Z_{pu}^{old} \frac{S_B^{new}}{S_B^{old}}$$

Choice of Base Value

- Need base value for all quantities – P,V, I,Z
- Base value do not have to be same for all equipment in the system.

Steady-state approach using per-unit approach

3-phase per-unit VOLTAGE

In the three-phase system, we have:

$$V_{LL} = \sqrt{3} V_{LN}$$

We would like to have:

$$V_{LL}^{pu} = V_{LN}^{pu} \Rightarrow \frac{V_{LL}}{V_{B,LL}} = \frac{V_{LN}}{V_{B,LN}}$$

$$\Rightarrow \quad V_{B,LL} = \sqrt{3} V_{B,LN}$$

Steady-state approach using per-unit approach

3-phase per-unit POWER

In the three-phase system, we have: $S_{3\phi} = 3S_{1\phi}$

We would like to have:

$$S_{3\phi}^{pu} = S_{1\phi}^{pu} \Rightarrow \frac{S_{3\phi}}{S_{B,3\phi}} = \frac{S_{1\phi}}{S_{B,1\phi}}$$

$$\Rightarrow S_{B,3\phi} = 3S_{B,1\phi}$$

Steady-state approach using per-unit approach

3-phase per-unit CURRENT

In the three-phase system, we have: $S = 3V_{LN}I_{LN} = \sqrt{3}V_{LL}I_{LL}$

We would like to have:

$$S^{pu} = V^{pu}I^{pu} \Rightarrow \frac{S}{S_{B,3\phi}} = \frac{V_{LL}}{V_{B,LL}}\frac{I_L}{I_B}$$

$$\Rightarrow I_B = \frac{S_{B,3\phi}}{\sqrt{3}V_{B,LL}}$$

Steady-state approach using per-unit approach

3-phase per-unit IMPEDANCE

In the three-phase system, we have:

$$V_{LN} = Z_{1\phi} I_L$$

We would like to have:

$$V^{pu} = Z^{pu} I^{pu} \Rightarrow \frac{V_{LN}}{V_{B,LN}} = \frac{Z_{1\phi}}{Z_B} \frac{I_L}{I_B}$$

$$\Rightarrow Z_B = \frac{V_{B,LN}}{I_B} = \frac{\dfrac{V_{B,LL}}{\sqrt{3}}}{\dfrac{S_{B,3\phi}}{\sqrt{3} V_{B,LL}}} = \frac{\left(V_{B,LL}\right)^2}{S_{B,3\phi}}$$

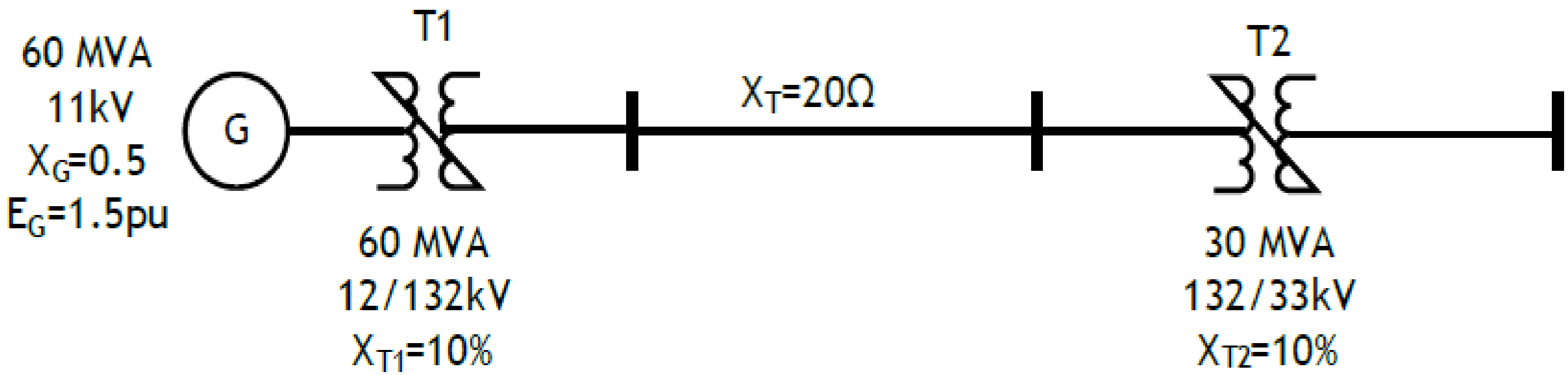
Steady-state approach using per-unit approach

Procedure for Per-unit Analysis

- Pick $|S_{BASE}|$ for the system.
- Pick V_{BASE} according to line-to-line voltage.
- Calculate Z_{BASE} for different regions/zones.
- Express all quantities in p.u.
- Draw the impedance diagram and solve for p.u quantities.
- Convert back to actual quantities if needed.

Example 1

Find the per unit value for X_{T1}, X_{T2} and X_T if the base value is 11 kV and 60 MVA.



Advantages of per-unit System

- Gives us a clear idea of relative magnitudes of various quantities, such as voltage, current, power and impedances.
- The per-unit impedance of equipment of equipment of the same general type based on their own rating fall in a narrow range regardless of the rating of the equipment. Whereas their impedance in ohms vary greatly with the rating.
- The per-unit values of impedance, voltage and current of a transformer are the same regardless of whether they are referred to the primary or the secondary side. This is a great advantage since the different voltage levels disappear and the entire system reduces to a system of simple impedance.
- The per-unit systems are ideal for the computerized analysis and simulation of complex power system problems.

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