ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTING

DEPARTMENT OF ELECTRICAL POWER AND CONTROL ENGINEERING

POWER SYSTEMS I (EPCE - 3206)

CHAPTERS - TWO

REPRESENTATION OF POWER SYSTEM COMPONENTS

INSTRUCTOR :-Mekdes Gemechu

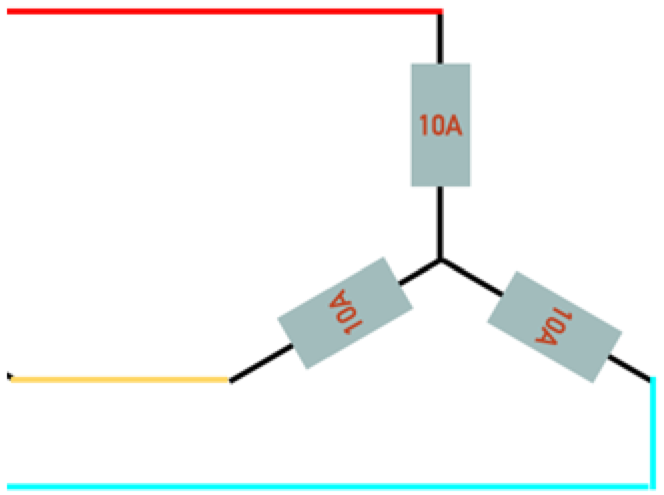
Out line

- Single Phase solution of balanced three phase network
- One Line Diagram
- Impedance / Reactance Diagram
- Per unit (pu) System.

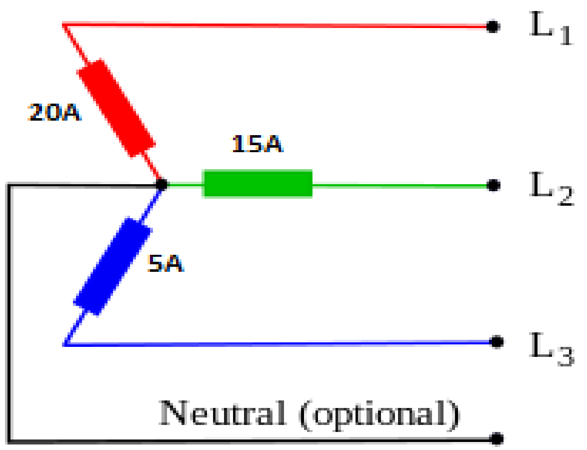
Single Phase solution of balanced three phase network

- ✓A three-phase system is **balanced if all the line loads are equal to each** other**.**
- ✓ A balanced three-phase network is one in which the **impedances in the three phases** are identical.
- ✓An **unbalanced load** refers to the condition when **unequal currents are carried by** the three phases. In this case, neutral carries the net current.

balanced

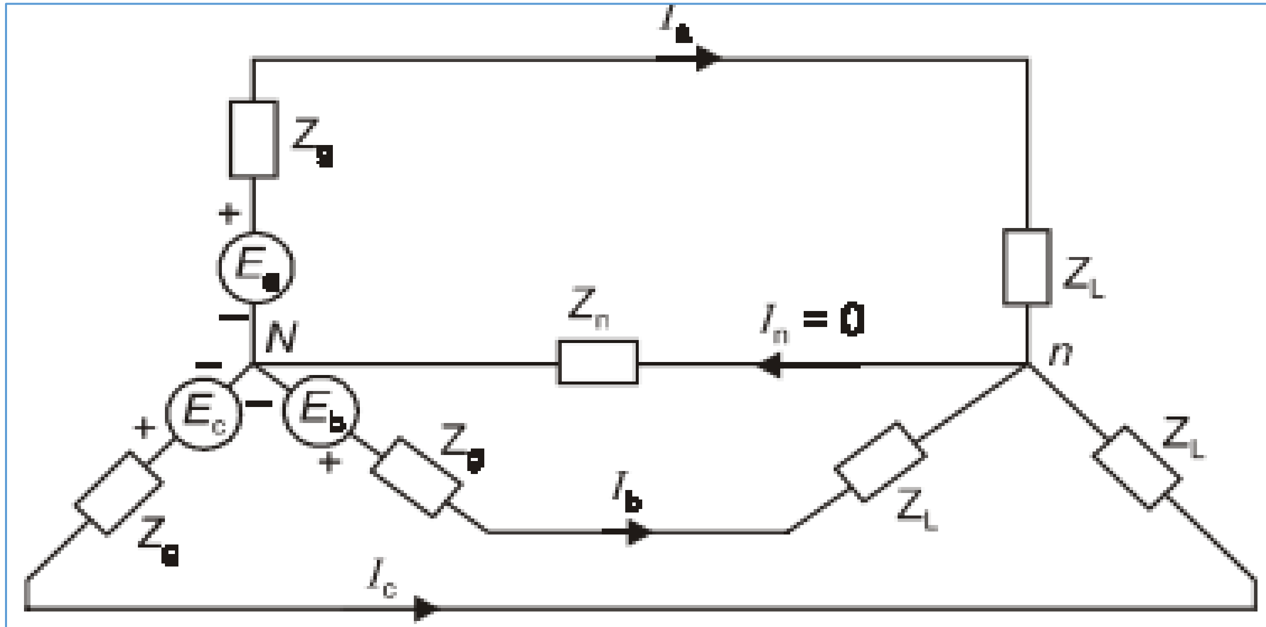


Unbalanced

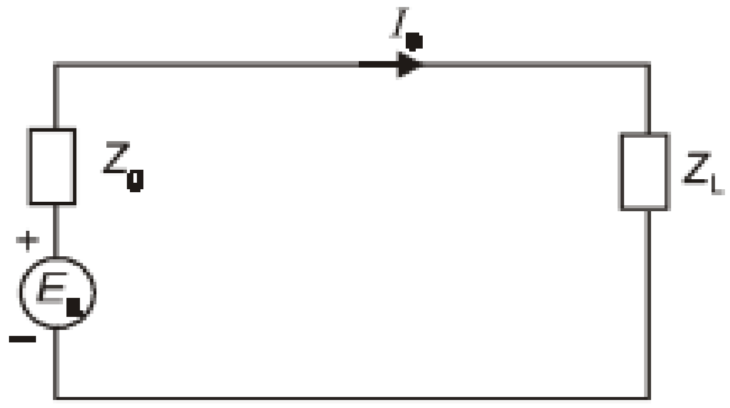


- ✓The solution of a balanced three phase circuit is easily carried out by solving the single-phase network corresponding to the reference phase.

Single phase representation of balanced three phase system



Balanced three phase network



Single phase representation of a balanced three phase network

- ✓For reference phase A;- **$E_a = (Z_g+Z_L) * I_a$**
- ✓**Voltage and current in Phase B and Phase C have the same magnitude but phase shift by 120^0**

Unbalanced System study

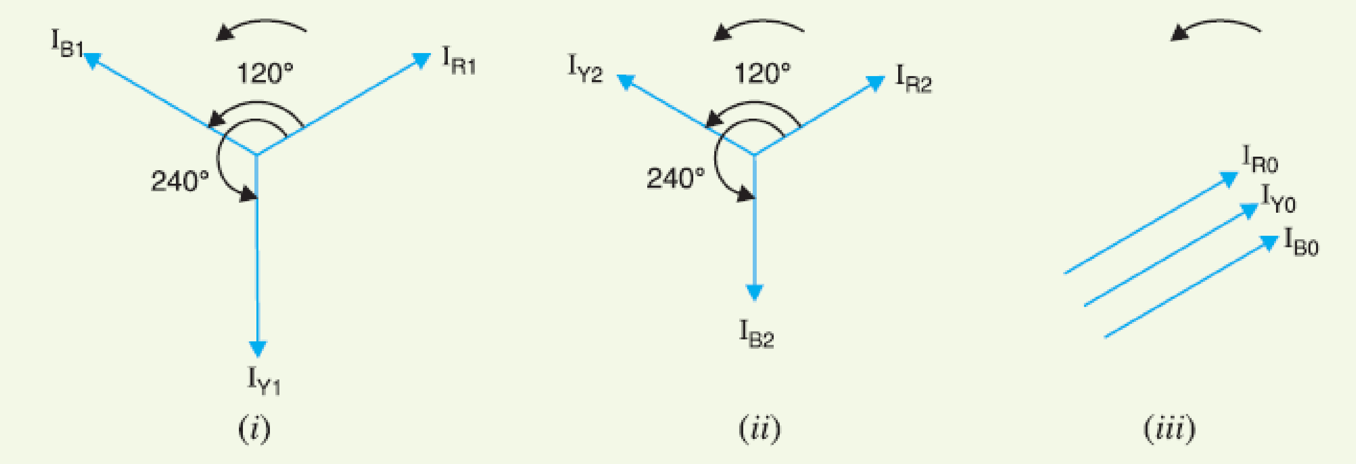
✓ **Un balanced three phase system can be studied by as being composed of thee separate sets of balanced vectors.**

(*i*) a balanced *system of 3-phase currents having positive† (or normal) phase sequence. These are called *positive phase sequence components.*

(*ii*) a balanced system of 3-phase currents having the opposite or negative phase sequence. These are called *negative phase sequence components.*

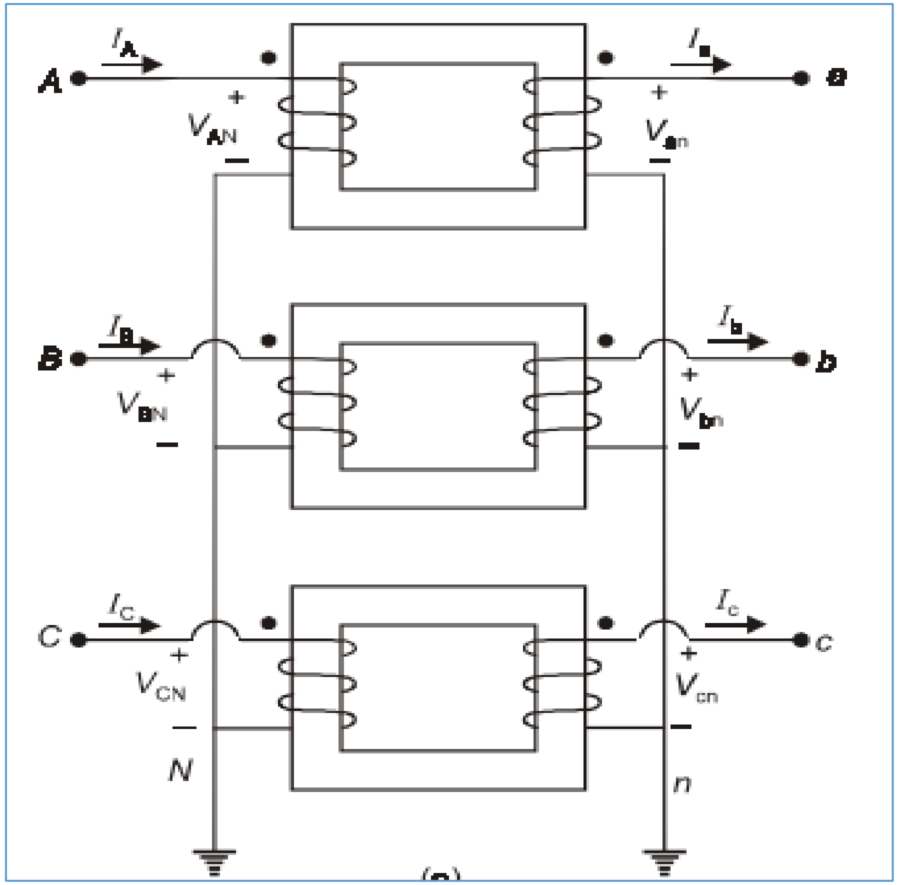
(*iii*) a system of three currents equal in magnitude and having zero phase displacement. These are called *zero phase sequence components.*

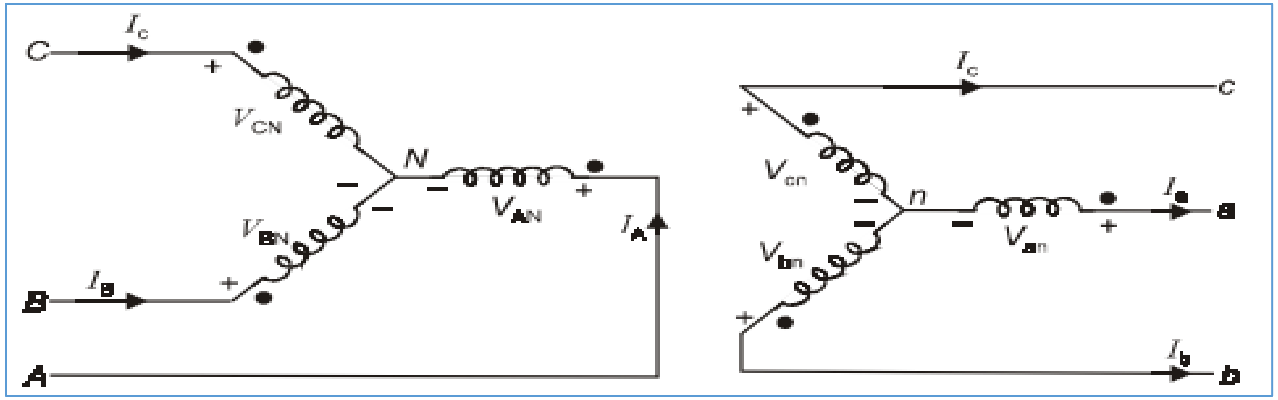
The positive, negative and zero phase sequence components are called the *symmetrical components* of the original unbalanced system. The term 'symmetrical' is appropriate because the unbalanced 3-phase system has been resolved into three sets of balanced (or symmetrical) components. The subscripts 1, 2 and 0 are generally used to indicate positive, negative and zero phase sequence



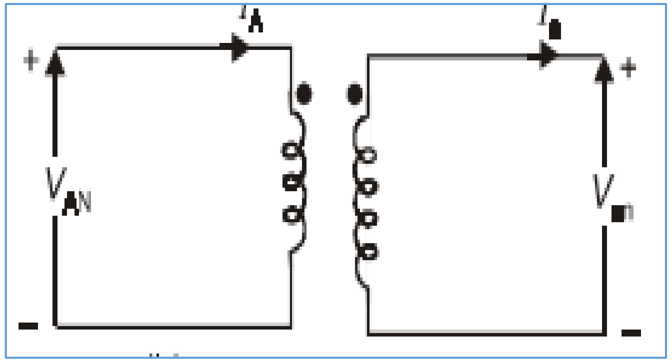
Three phase transformer

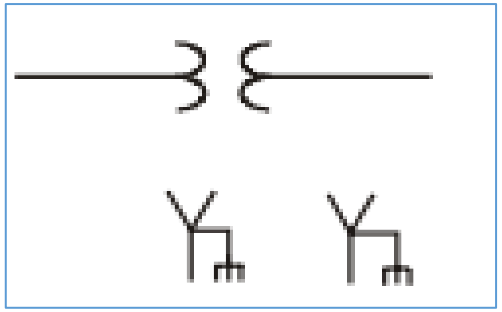
- ✓ Three identical single phase two winding transformer may be connected to form three phase transformer.
- ✓ The winding can be connected in four ways :- Δ –Δ , Y-Δ , Δ-Y and Y-Y.





(a) schematic representation of 3-phase Y-Y transformer



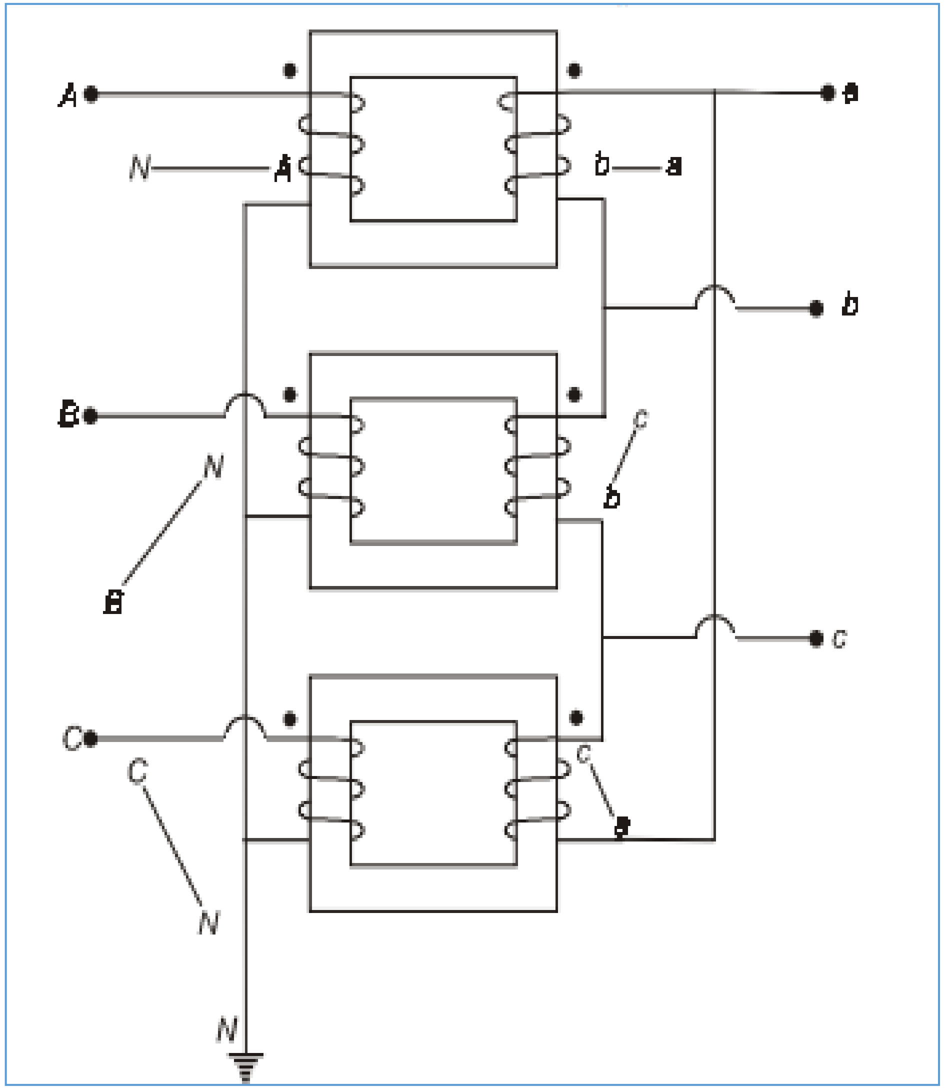


Three phase two winding transformer bank Y-Y,

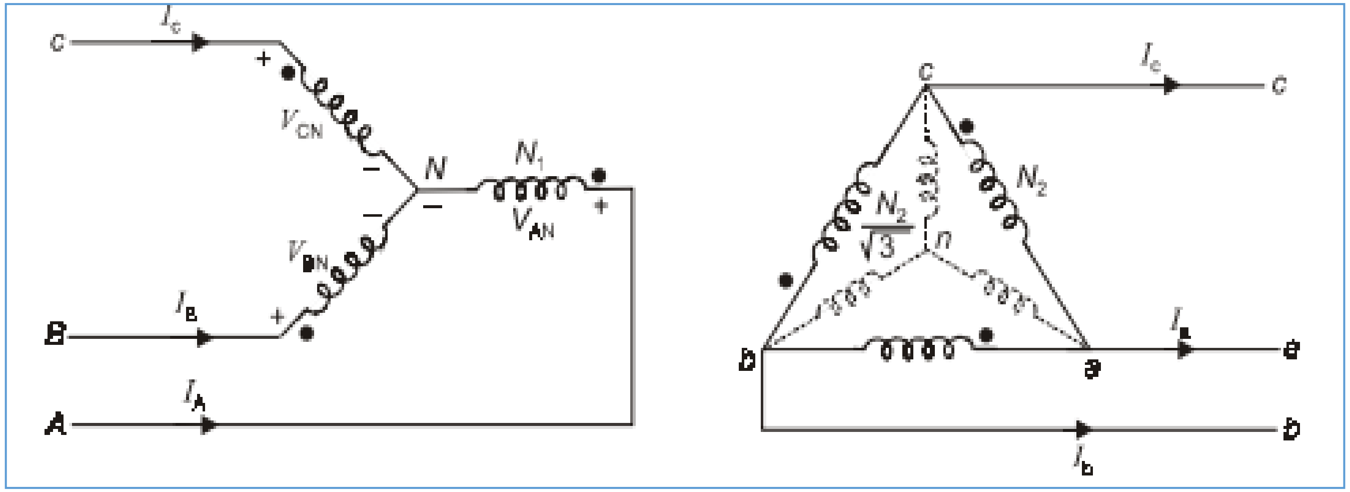
(b)single phase equivalent Y-Y transformer

(c) single line diagram

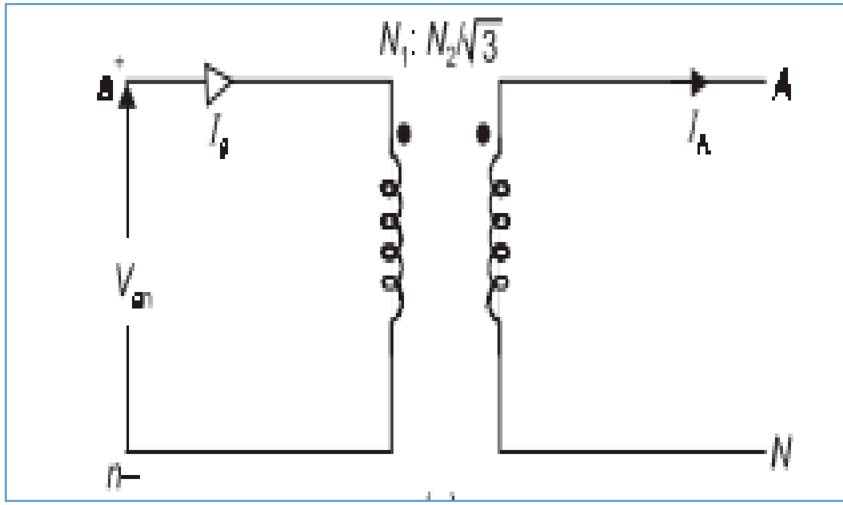
Y-Δ , Connection



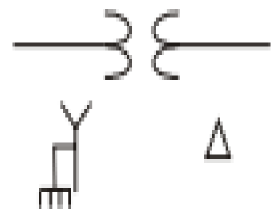
Three phase two winding transformer bank star- Delta,



(a) schematic representation of 3-phase Y-Δ transformer



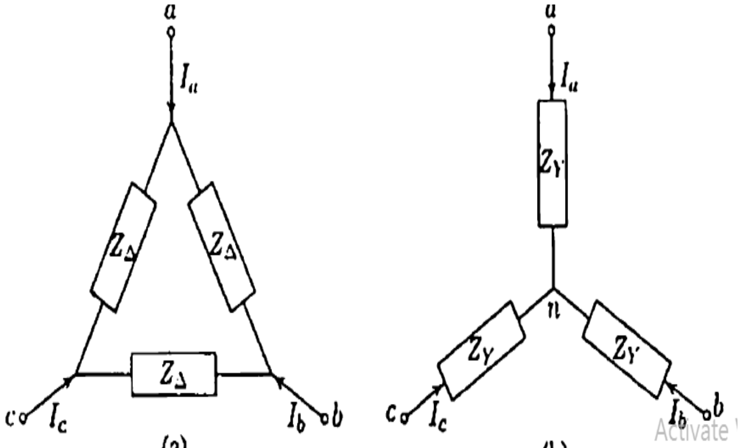
(b)single phase equivalent Y-Δ transformer



(c) single line diagram

Δ-Y transformation

- For analyzing network problems it is convenient to replace the Δ connected circuit with an equivalent Y connected circuit.



(a) (b)

$$I_a = \frac{V_{ab}}{Z_\Delta} + \frac{V_{ac}}{Z_\Delta} = \frac{V_{ab} + V_{ac}}{Z_\Delta}$$

$$I_a = \frac{3V_{an}}{Z_\Delta}$$

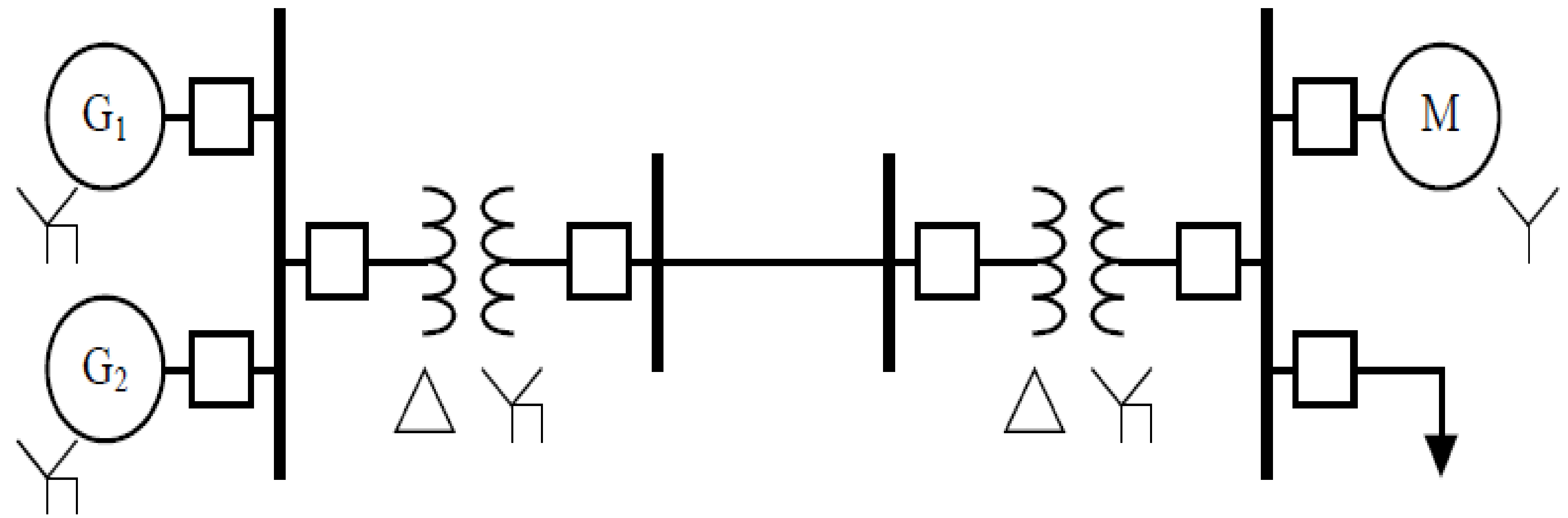
$$V_{an} = \frac{Z_\Delta}{3} I_a$$

The Δ-connected load is transformed into an equivalent Y. The impedance per phase of the equivalent Y is

$$Z_Y = \frac{Z_\Delta}{3}$$

A One-Line Diagram of a Portion of a Power System.

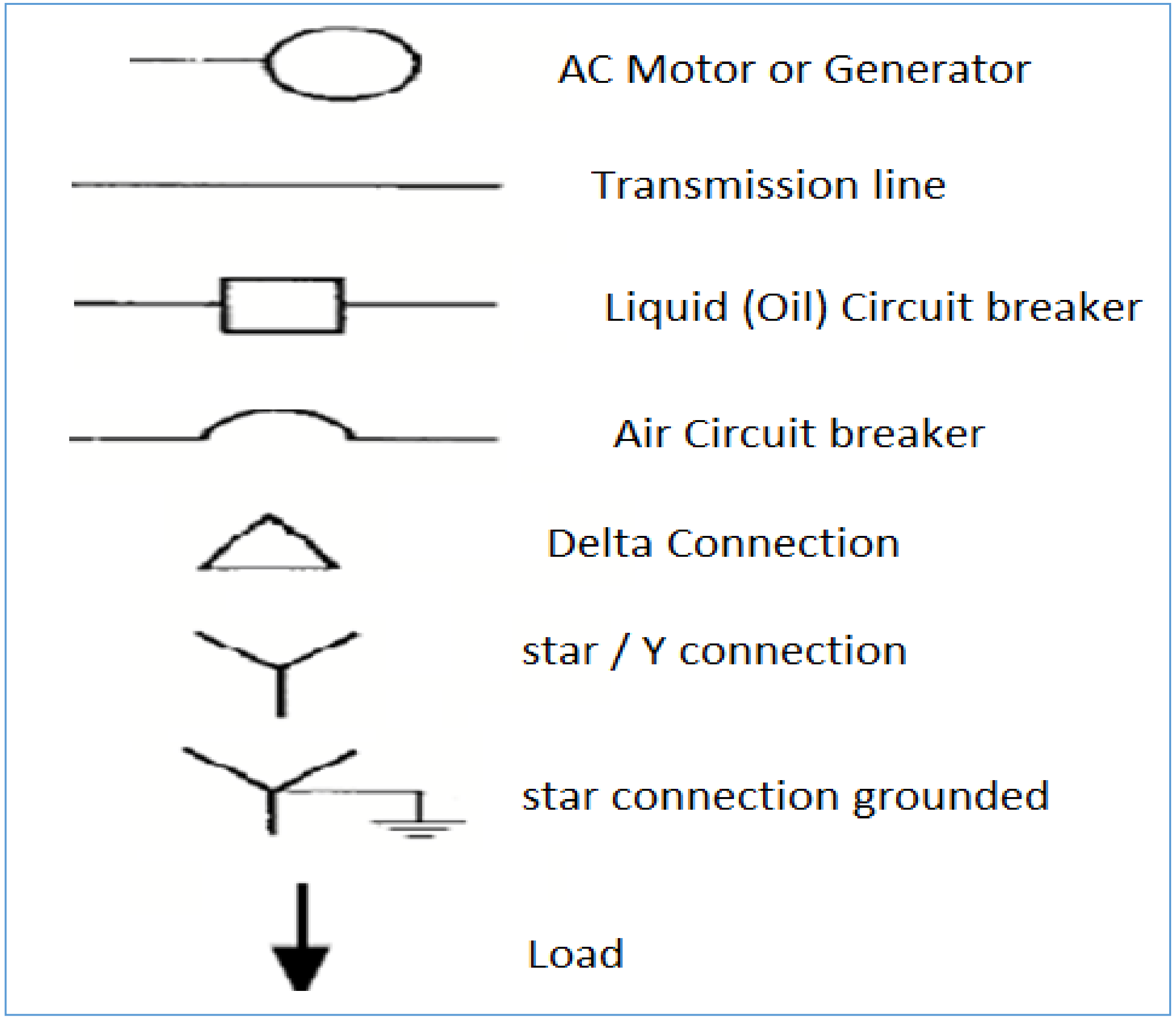
- ✓ In **power** engineering, a **single-line diagram** (**SLD**), also sometimes called one-**line diagram**, is a simplified notation for representing a three-phase **power system**.
- ✓ The one-**line diagram** has its largest application in **power** flow studies.

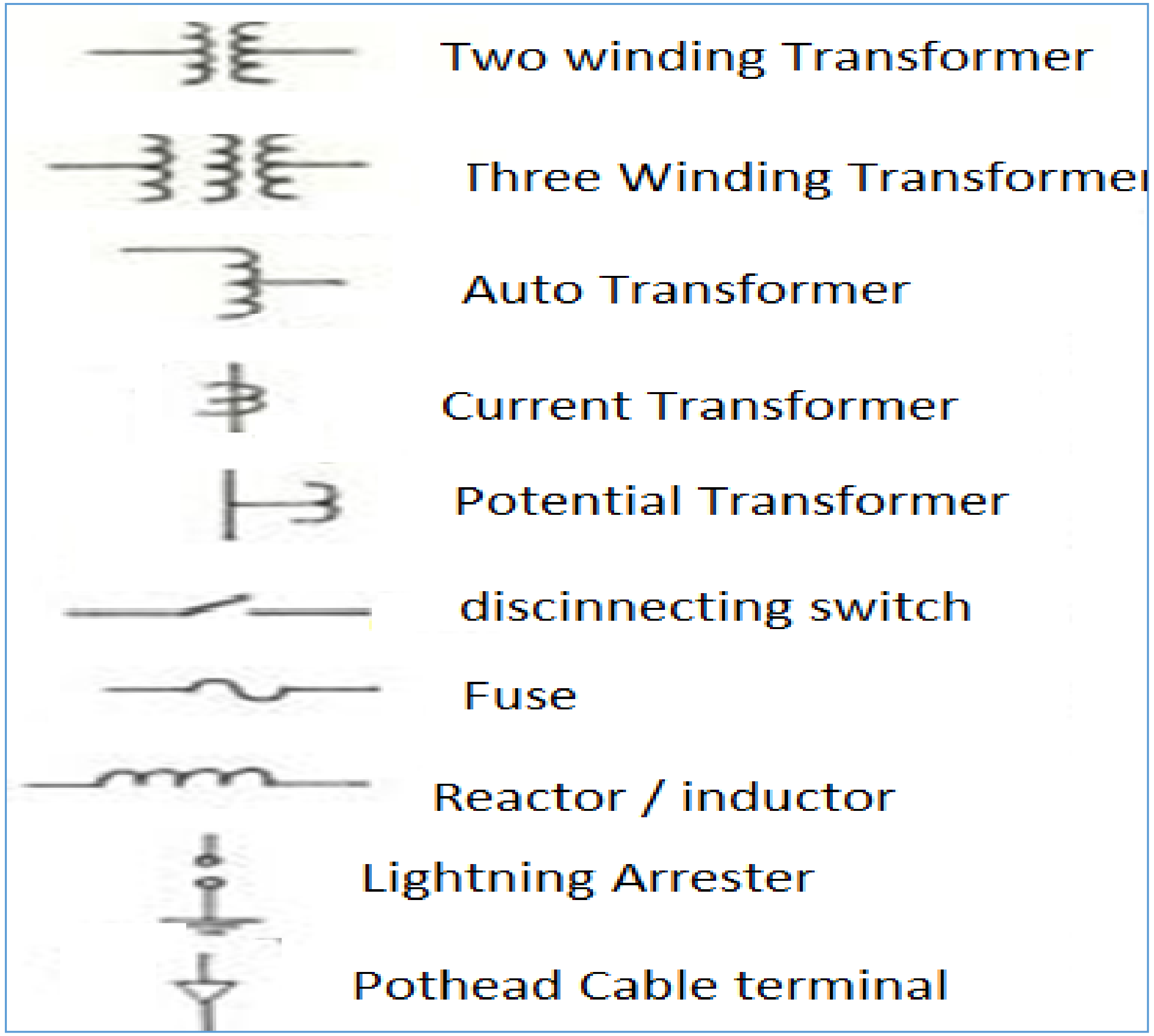


The components are: generators, transformers, transmission lines, and loads.

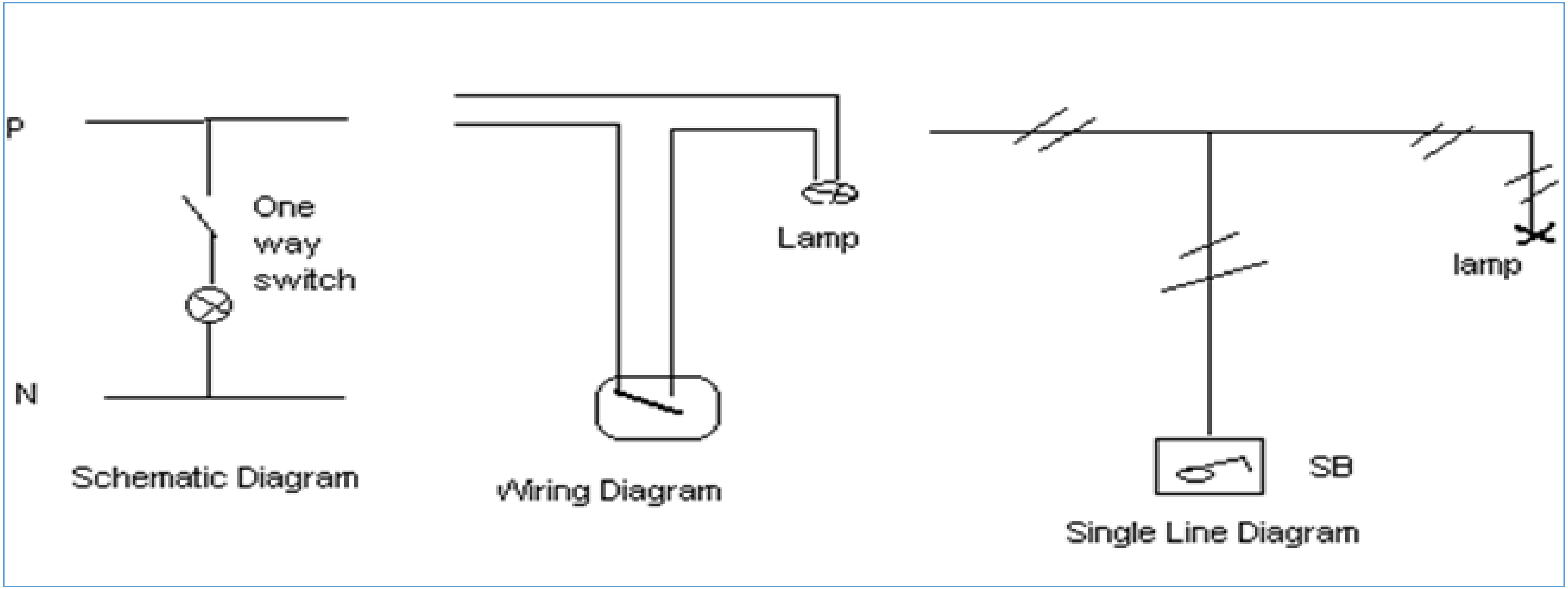
Power System Representation

- ✓The interconnections of the power system components can be represented by one-line diagram.
- ✓Symbolic Representation of Elements of a Power System:-





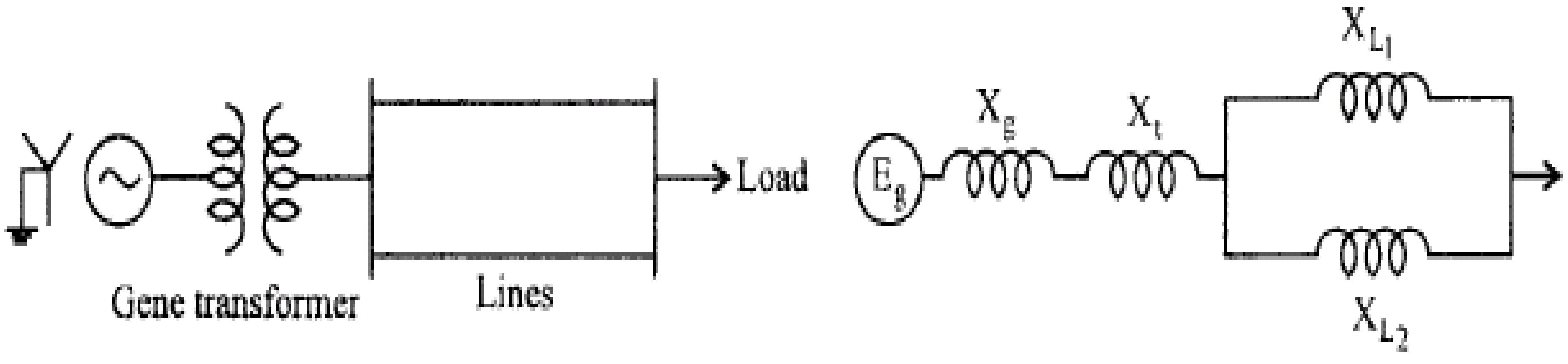
Representation of Electric Circuits



- ✓ A complete Circuit diagram of a power system for all three phase is very complicated. It is very much practical to represent a power system using simple symbols – for each component resulting is called single line diagram.

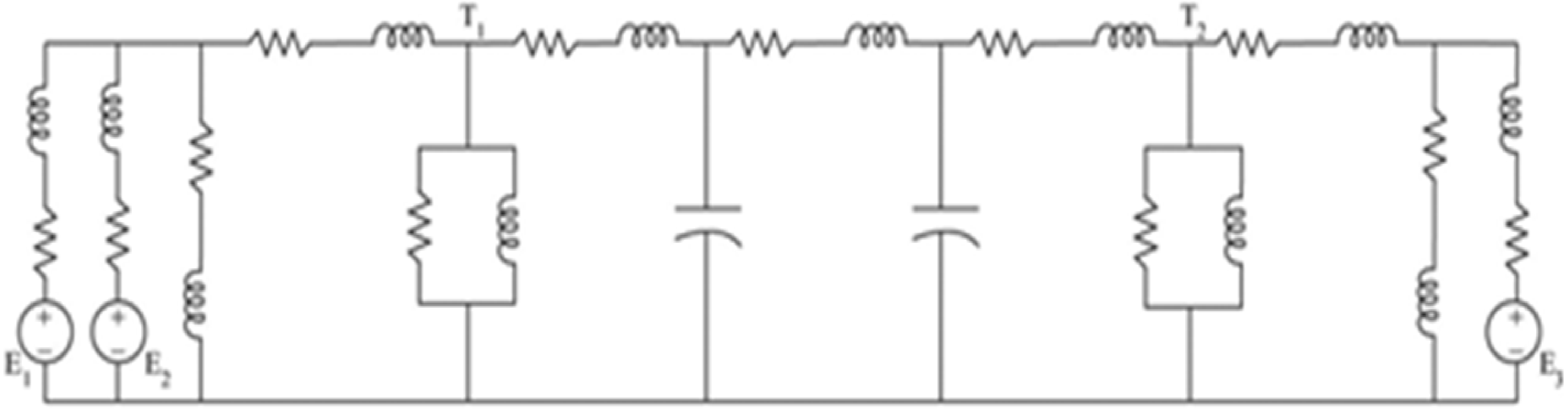
IMPEDANCE AND REACTANCE DIAGRAMS

- ✓In power system analysis it is necessary to draw an equivalent circuit for the system. This is an impedance diagrams.
- ✓Short-circuit analysis is sufficient to consider only reactance neglecting resistances.
- ✓For 3-phase balanced systems, it is simpler to represent the system by a single line diagram without losing the identity of the 3-phase system.
- ✓Thus, single line reactance diagrams can be drawn for calculation.



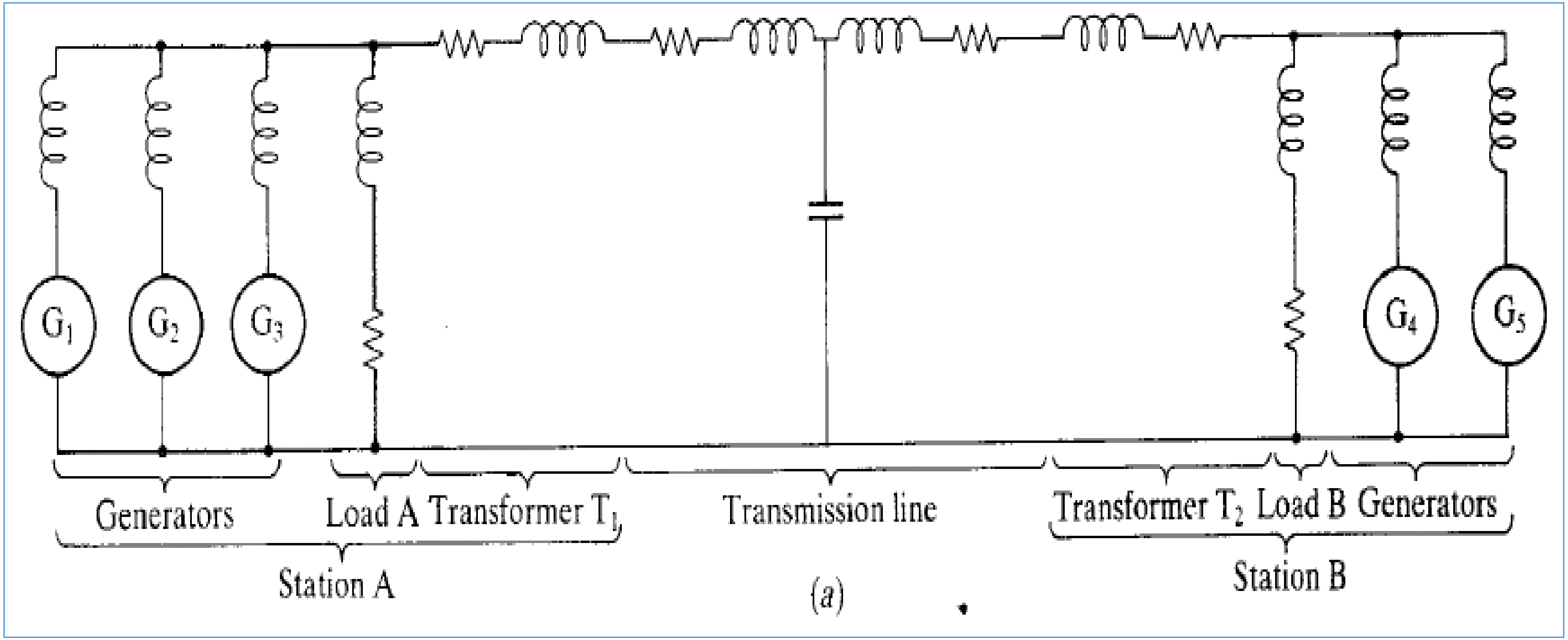
(a) A power system

(b) Equivalent single-line reactance diagram



a) Impedance diagram of Power System

- The one - line diagram may serve as the basis for a circuit representation components of the power system is *impedance diagram* or a *reactance diagram* if resistances are neglected.

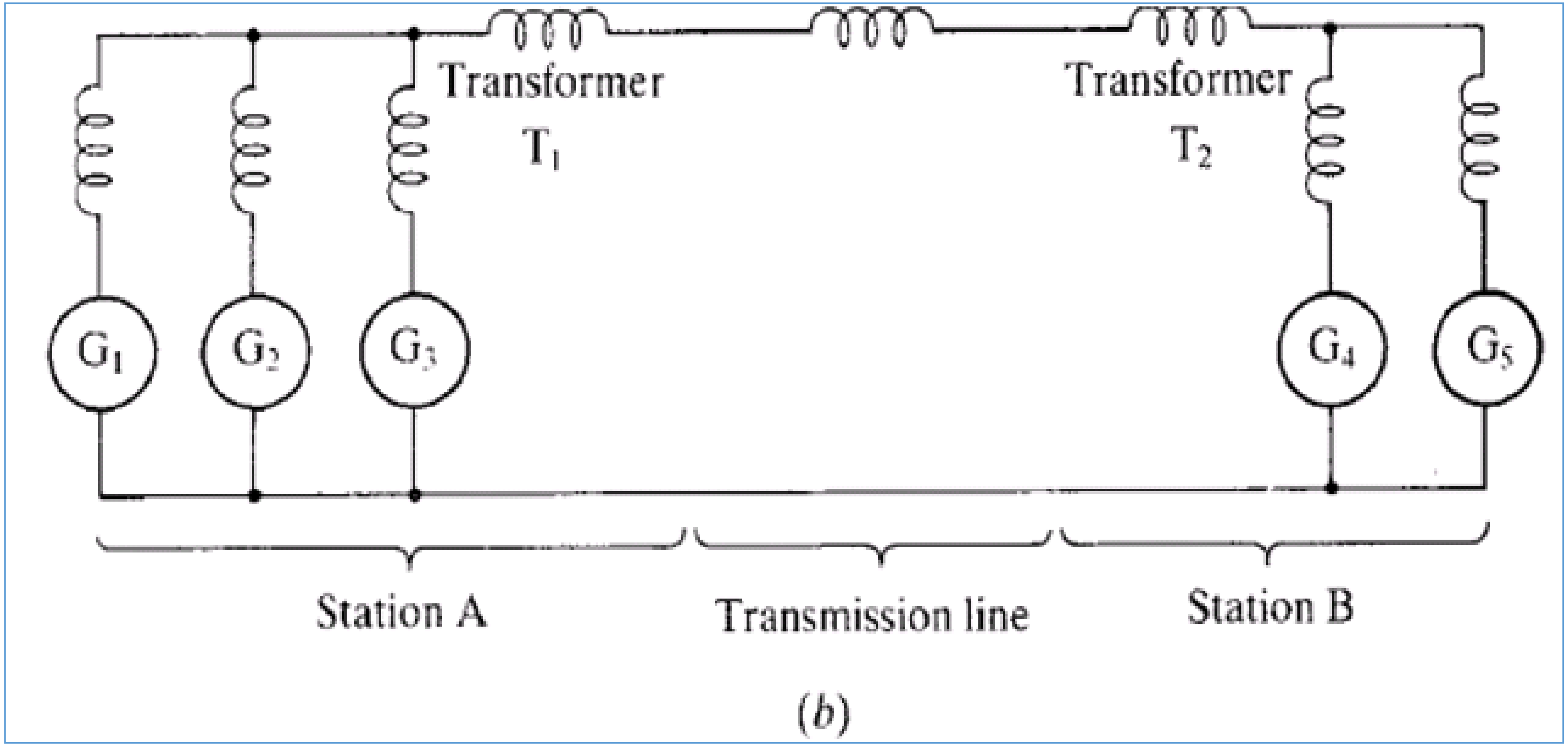


b) Impedance diagram of Power system.

The following assumptions have been incorporated in fig (b) above

- ✓A generator can be represented by a voltage source in series with an inductive reactance.
- ✓The internal resistance of the generator is negligible compared to the reactance.
- ✓The loads are inductive.
- ✓The transformer core is ideal, and the transformer may be represented by a reactance.
- ✓The transmission **line is a medium-length** line and can be denoted by a T or π circuit.
- ✓The delta-wye-connected transformer T1 may be replaced by an equivalent wye-wye-connected
- ✓Transformer (via a delta-to-wye transformation) so that the impedance diagram may be drawn on a per-phase basis.

- ✓ Neglecting all resistance , static loads and capacitance of the TL for the above CKT

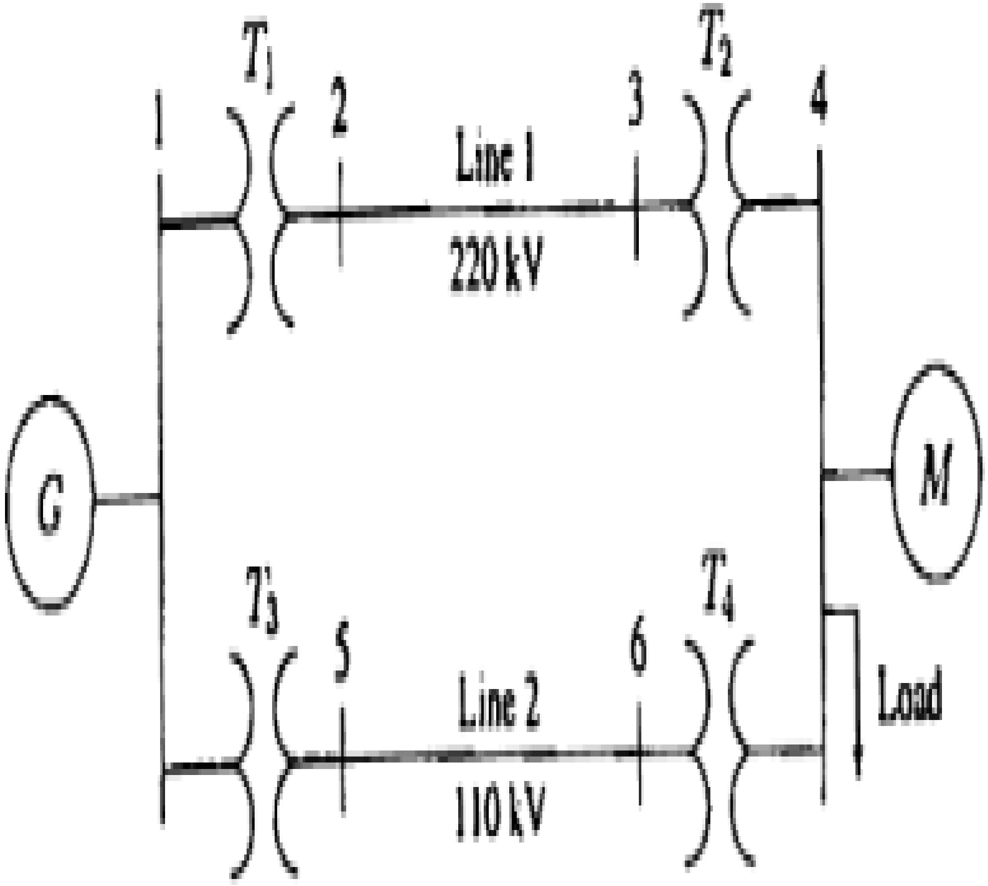


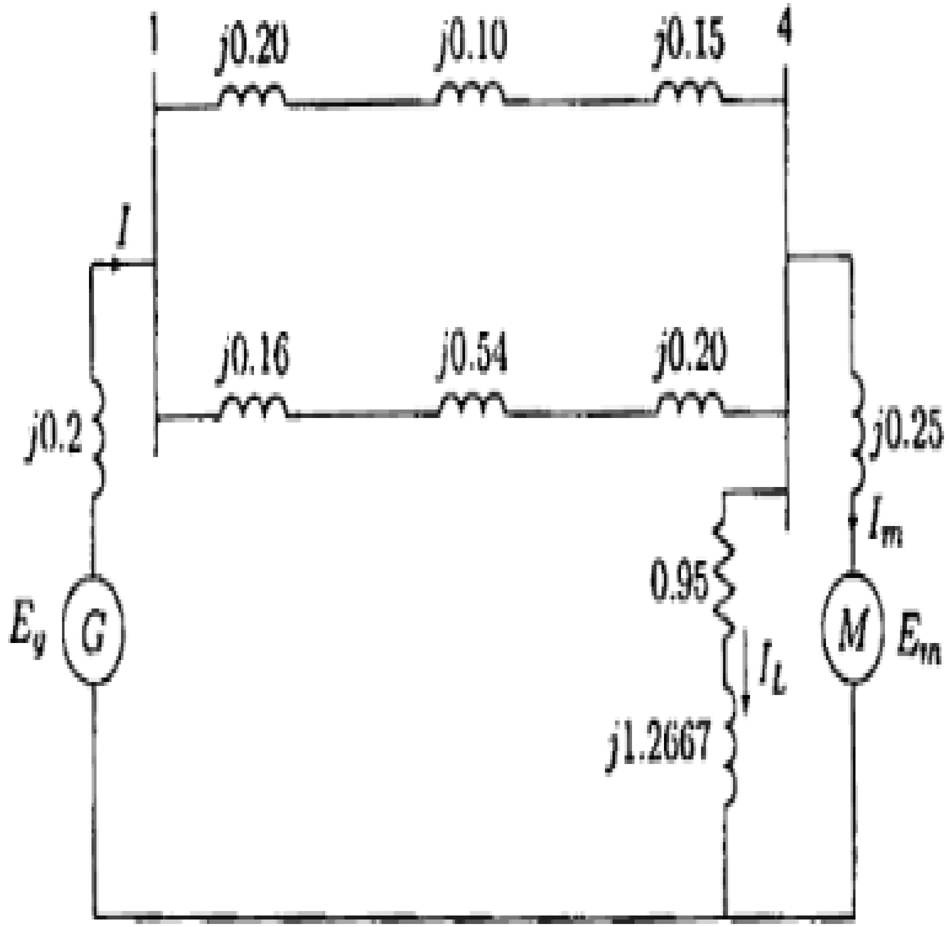
(b) Equivalent single-line reactance diagram

PER - UNIT REPRESENTATION

- ✓A **per-unit system** is the expression of system quantities as fractions of base unit quantity
- ✓Calculations are simplified because quantities expressed as per-unit do not change when they are referred from one side of a transformer to the other.
- ✓In an alternative and simpler system, a set of base values, or *base quantities,* is assumed for each voltage class, and each parameter is expressed as a decimal fraction of its respective base.
- ✓Per-unit and percent quantities and their bases exhibit the same relationships and obey the same laws (such as Ohm's law and Kirchhoff's laws) as do quantities in other systems of units.
- ✓A minimum of four base quantities(I, V, Z (Y) and S) are required to completely define a per-unit system.
- ✓ If two of them are set arbitrarily, then the other two become fixed.

Pu System


T1
T2
1
2
3
4
Line 1
220 kV
G
M
T3
T4
5
6
Line 2
110 kV
Load


1
j0.20
j0.10
j0.15
4
I
j0.16
j0.54
j0.20
j0.2
j0.25
Im
0.95
IL
j1.2667
Eg
G
M
Em

- ✓Base values can be determined by three ways:-
  - ❖Taking the largest value
  - ❖Taking the total sum
  - ❖Any arbitrary
- ✓Per unit quantity = Actual value in any units / base or reference value in the same units.
- ✓basic quantities of importance are voltage, current, impedance and power.
- ✓For all per unit calculations a base KVA or MVA and a base KV are to be chosen.

Per Unit Quantities

$$S_{pu} = \frac{S}{S_{base}} \qquad V_{pu} = \frac{V}{V_{base}} \qquad I_{pu} = \frac{I}{I_{base}} \qquad Z_{pu} = \frac{Z}{Z_{base}}$$

Base current $$I_{base} = \frac{V_{base} I_{base}}{V_{base}} = \frac{VA_{base}}{V_{base}}$$

Base Impedance $$Z_{base} = \frac{V_{base}}{I_{base}} = \frac{V^2{}_{base}}{I_{base} V_{base}} = \frac{V^2{}_{base}}{VA_{base}}$$

Base current $$I_{base} = \frac{MVA_{base}}{kV_{base}} \quad \text{in } kA, \qquad [\because 10^6/10^3 = 10^3]$$

Base Impedance $$Z_{base} = \frac{kV^2_{base}}{MVA_{base}} \quad \text{in } \Omega, \qquad [\because (10^3)^2/10^6 = 1]$$

For Single Phase system

For 3 Phase System

Base current $$I_{base} = \frac{VA_{3\phi base}}{\sqrt{3}V_{LLbase}}$$

Base Impedance $$Z_{base} = \frac{V^2_{LLbase}}{VA_{3\phi base}}$$

Base current $$I_{base} = \frac{MVA_{3\phi base}}{\sqrt{3}kV_{LLbase}} \quad \text{in } kA$$

Base Impedance $$Z_{base} = \frac{kV^2_{LLbase}}{MVA_{3\phi base}} \quad \text{in } \Omega$$

Change of base

✓The per unit (pu) impedance of the generator or transformer as supplied by the manufacturer is generally based on the rating of the generator or transformer itself.

✓Each per unit impedance referred to a new voltampere base with the equation .

✓The impedance of transmission line are expressed in ohms but can be converted to per unit values

$$Z_{p.u._{new}} = Z_{p.u._{old}}\left(\frac{S_{base_{new}}}{S_{base_{old}}}\right)\left(\frac{V_{base_{old}}}{V_{base_{new}}}\right)^2$$

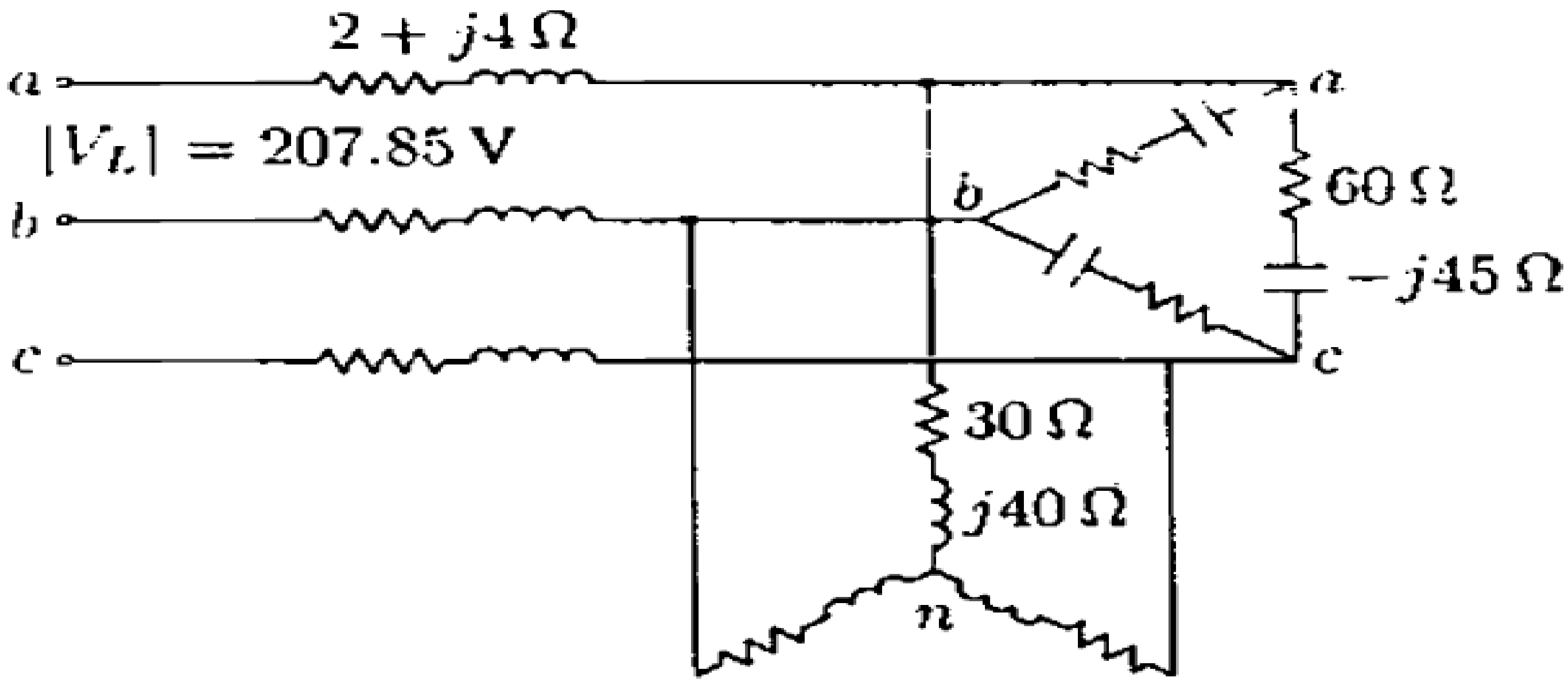
Refer Chapter 5 of D. DAS

Advantages of Per Unit System

- ✓ While performing calculations, referring quantities from one side of the transformer to the other side serious errors may be committed. This can be avoided by using per unit system.
- ✓Circuits are simplified.
- ✓Voltages have same range in **per unit** in all parts of the **system** from EHV **system** to distribution and utilization.
- ✓When expressed in the **per unit system**, apparatus parameters usually fall in narrow range regardless of apparatus size

Example 1

A three-phase line has an impedance of $2 + j4\ \Omega$



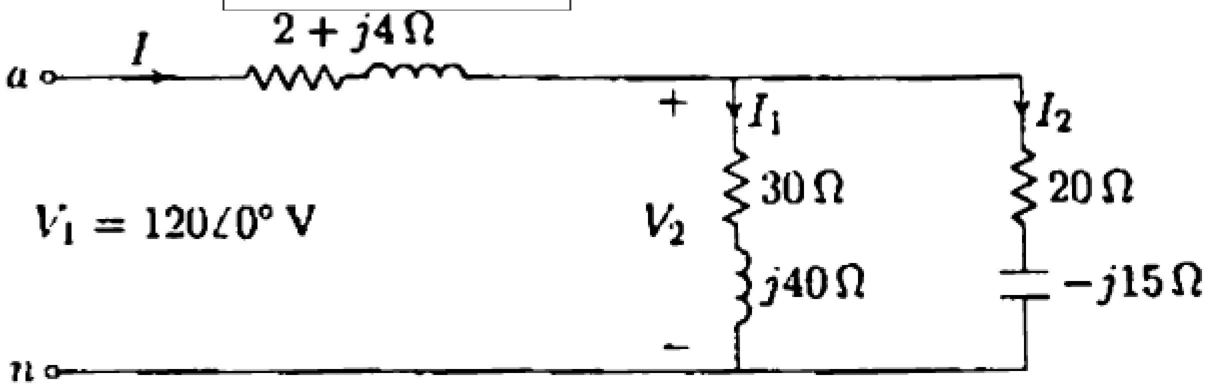
The line feeds two balanced three-phase loads that are connected in parallel. The first load is Y-connected and has an impedance of $30 + j40\ \Omega$ per phase. The second load is Δ-connected and has an impedance of $60 - j45\ \Omega$. The line is energized at the sending end from a three-phase balanced supply of line voltage 207.85 V. Taking the phase voltage V_a as reference, determine:

(a) The current, real power, and reactive power drawn from the supply.

(b) The line voltage at the combined loads.

(c) The current per phase in each load.

SOLUTIONS



$$I = \frac{V_1}{Z} = \frac{120\angle 0°}{24} = 5 \text{ A}$$

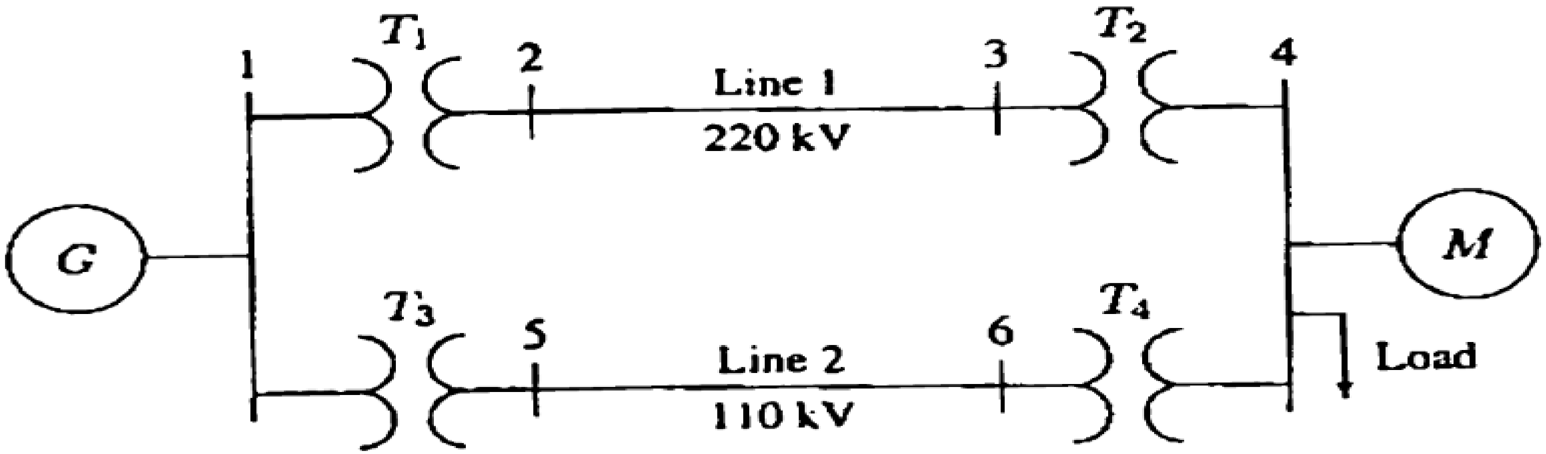
$$S = 3V_1 I^* = 3(120\angle 0°)(5\angle 0°) = 1800 \text{ W}$$

$$V_{2ab} = \sqrt{3}\angle 30°\ V_2 = \sqrt{3}\,(111.8)\angle 19.7° = 193.64\angle 19.7° \text{ V}$$

$$I_{ab} = \frac{I_2}{\sqrt{3}\angle -30°} = \frac{4.472\angle 26.56°}{\sqrt{3}\angle -30°} = 2.582\angle 56.56° \text{ A}$$

Example 2

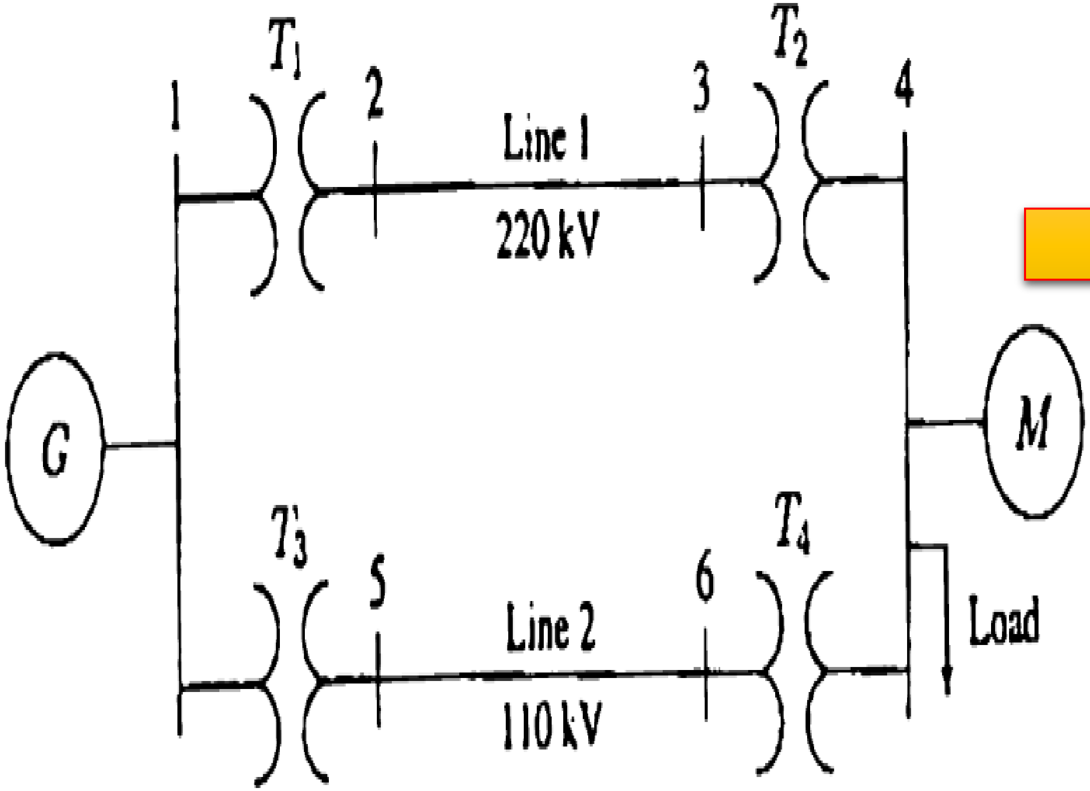
➢ The one line diagram of a three phase power is system shown in fig below. Select a common base of 100MVA and 22KV on the generator side. Draw an Impedance Diagram with all impedances marked in per unit. The manufacturer's data for each device is given as follows:-



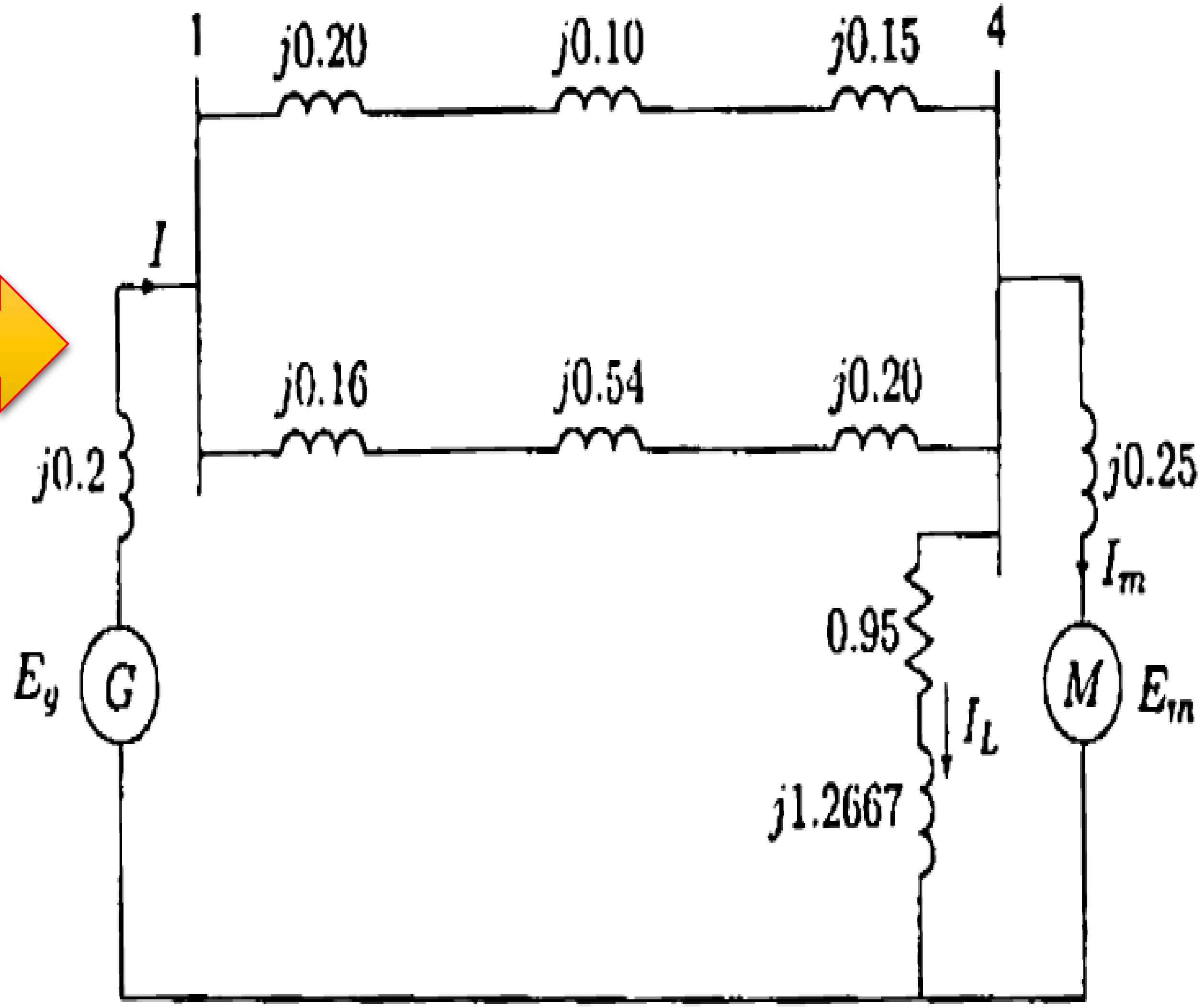
G:	90 MVA	22 kV	$X = 18$ %
T_1:	50 MVA	22/220 kV	$X = 10$ %
T_2:	40 MVA	220/11 kV	$X = 6.0$ %
T_3:	40 MVA	22/110 kV	$X = 6.4$ %
T_4:	40 MVA	110/11 kV	$X = 8.0$ %
M:	66.5 MVA	10.45 kV	$X = 18.5$ %

The three-phase load at bus 4 absorbs 57 MVA, 0.6 power factor lagging at 10.45 kV. Line 1 and line 2 have reactances of 48.4 and 65.43 Ω, respectively.

Answer:-



G
T1
T2
T3
T4
1
2
3
4
5
6
Line 1
220 kV
Line 2
110 kV
M
Load



1
4
j0.20
j0.10
j0.15
j0.16
j0.54
j0.20
I
j0.2
E_g
G
0.95
I_L
j1.2667
j0.25
I_m
M
E_m

Home Work

A single phase two-winding transformer is rated 25 kVA, 1100/440 volts, 50 Hz. The equivalent leakage impedance of the transformer referred to the low voltage side is $0.06\angle 78^\circ$ *Ω. Using transformer rating as base values, determine the per-unit leakage impedance referred to low voltage winding and referred to high voltage winding.*

Answer

$$\frac{V_{pB}}{V_{SB}} = \frac{V_{p,\,rated}}{V_{s,\,rated}} = \frac{1.1}{0.44} = 2.5.$$

Reference

1. D. Das Electrical Power Systems, New Age International (P) Ltd Publishers, 2006

1. Syed Nasar, Electrical Power Systems (Schaum‟s Outline Series), McGraw-hill Publishing Company,

Thank You!!!