

Power Systems Operation and Control

Lecture 1

Introduction to Power Systems

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Lecture learning outcomes:

At the end of this lecture, you will be able to:

- i. Understand the power systems
- ii. Identify the power systems components'
- iii. Understand the basic operation of conventional and non-conventional energy resources
- iv. Identify the types of Transmission lines
- v. Knows single phase and three phase power systems, and Per unit analysis

Content

1. Introduction
2. Elements of electric power systems
3. Transmission Systems
4. Distribution Systems and Load
5. Single and Three Phase Power System(STPS)
6. Per Phase Analysis
7. Power Flow Analysis
8. Operation of Power Plants

Summary

References

1. Introductions

- An electric power system is defined as a network of electrical components used to supply (generate), transmit, and consume electric power.
- An electric power system that supplies power to homes and industries for a sizeable region is called an electric grid

There are two types of electrical power such as:

- DC power - It is defined as the product of voltage and current, and is produced by DC sources like generators, batteries, fuel cells, etc.
- AC power - A flow of charge that exhibits a periodic change in direction is called AC power

2. Elements of electric power systems

An electric power system consists of four main subsystems:

- Generation
- Transmission
- Sub-transmission Systems and
- Distribution Systems.
- The generation subsystem converts primary energy sources into electrical energy.
- The transmission subsystem transfers power over long distances at high voltages.

EEPS

Cont.....

- Power System is a network of high tension wires/cables by which the generated Electrical power is transmitted and distributed throughout a region.
- **Power System consists of the following main components:**
 - a. Generation System- Energy Conversion Methods
 - b. Transmission System- Ultra-high, Extra-high, High and Medium Voltage levels
 - c. Distribution System- Low voltage levels
 - d. The Load or Energy sink- Resistive, Capacitive and inductive Electrical devices

2.1 Generation systems:

In the generation system, electricity is produced in power plants through:

- burning fossil fuels, using hydroelectric power plants or other Renewable energy(RE) resources.
- Power generation systems are simply the combination of a potential or stored energy converter providing kinetic energy, which, in turn, creates electric power for different applications

i. Types of Energy Resources:

- Oil, Natural Gas, Coal, Atomic energy (Fossil fuel resources)-Conventional resources
- Solar, Hydro, wind, hot water/spring, Biomass (RE Resources)

ii. Types of Energy conversions Techniques

- Classified as: Conventional and non-conventional as given in Table [1].

Table 1. Energy conversion Techniques. Url: <https://unacademy.com/content/upsc/study-material/environment/conventional-and-non-conventional-sources-of-energy/>

| Conventional | | Non-conventional |
|--|--|----------------------|
| Conventional non-RE | Conventional RE | 1. Solar energy |
| 1. Mostly fossil fuels found under the ground; | 1. Mostly non-fossil fuels found above the ground; | 2. Wind energy |
| a. Coal | a. Fire-wood | 3. Hydropower |
| b. Oil | b. Cattle dung | 4. Nuclear energy |
| c. Natural gas | c. Vegetable-wastes | 5. Geothermal energy |
| | d. Wood- charcoal | 6. Bio-gas |
| | | 7. Tidal Energy |

3. Transmission Systems(TSs)

- The bulk electrical energy is transmitted via this power system component from the generation stations where it is created to the primary load centers.

The components of the transmission system are:

- Step-up and step-down substations.
- Transmission Lines (Overhead or underground)
- Insulators
- Ground wires
- Mechanical structures

3.1 Characteristic and operation of Transmission lines

- Since transmission lines are often run with a balanced three-phase load, phase-by-phase analysis is possible.
- A transmission line can be thought of as **a two-port network on a phase-by-phase basis**.
- The voltage V_s and current I_s at the sending end are connected to the voltage V_R and current I_R at the receiving end by the use of ABCD constants, as follows:

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad \text{eqn.(1)}$$

- Transmission lines are divided into **three categories based** on the voltage levels and distance coverage they cover: ***short, medium, and long***.

- **Short transmission line:** A short transmission line has an operating voltage of less than 20 kV and a transmission distance of less than 80 km.
- In the case of a short transmission line, the effects of capacitance and conductance may be neglected
- All that is left to consider are the series resistance and inductance.
- While resistance and inductance are dispersed along the length of a line in reality, for short lines, the resistance and inductance are believed to be aggregated at a single location as presented in Fig.1[2].



Figure 1. Short transmission line representation.

URL: https://eeebooks4u.wordpress.com/wp-content/uploads/2017/03/short_line.png

TSs

Cont.....

- Based on the two-port network, the medium transmission line sending and receiving end parameters are related as:

$$I_S = I_R \quad \text{eqn.(2)}$$

$$V_S = I_R * Z + V_R$$

$$\begin{matrix} V_S \\ I_S \end{matrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{matrix} V_R \\ I_R \end{matrix} \quad \text{eqn.(3)}$$

- By substitution of eqn.2 in eqn.3:

$$\begin{matrix} V_S \\ I_S \end{matrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{matrix} V_R \\ I_R \end{matrix} \quad \text{eqn.(4)}$$

- **Medium transmission line:** A medium transmission line is one that has a voltage of between 20 and 100 kilovolts and a length of 80 to 250 km.
- It is necessary to take the capacitance effects into consideration.
- As a result, all admittances are combined at the sending, receiving, or center ends.
- Approximate line performance calculations have been performed using several different localized capacitance techniques.

The following techniques are employed more frequently presented in Figs. 2&3, respectively:

- Nominal T
- nominal π

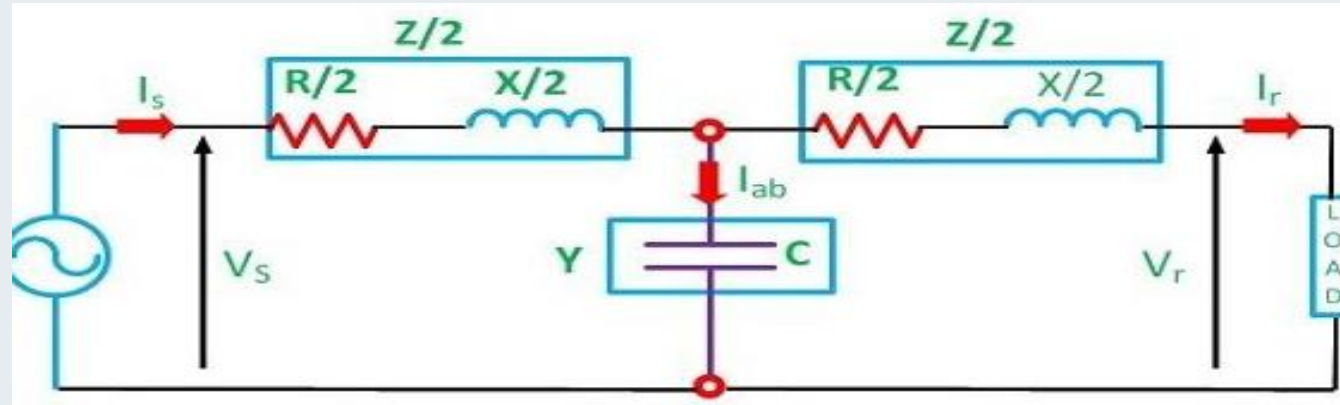


Figure 2: Nominal T-method Short Transmission line.

[url:https://circuitglobe.com/wp-content/uploads/2016/05/t2-model-compressor.jpg](https://circuitglobe.com/wp-content/uploads/2016/05/t2-model-compressor.jpg)

- The ABCD parameter is calculated as;
- Voltage at the mid-point of the line

$$V_{ab} = V_r + \frac{I_r Z}{2} \quad \text{eqn.(5)}$$

TSs

Cont.....

- Current in the capacitor,

$$I_{ab} = V_{ab}Y$$

eqn.(6)

- Then, the sending-end current and Voltage are given by:

$$I_S = I_r + I_{ab}$$

$$= I_r + V_{ab}Y$$

eqn.(7)

$$= I_r + \left(V_r + \frac{I_r Z}{2} \right) Y$$

$$= V_r Y + I_r \left(1 + \frac{ZY}{2} \right)$$

eqn.(8)

$$V_S = V_{ab} + \frac{I_S Z}{2}$$

$$= V_r \left(1 + \frac{ZY}{2} \right) + I_r \left(Z + \frac{ZY}{4} \right)$$

Nominal π method.

- According to this strategy, the complete resistance and inductive reactance are concentrated at the center of the line, while half of the total line capacitance is focused at each end as presented in Fig.3[3].

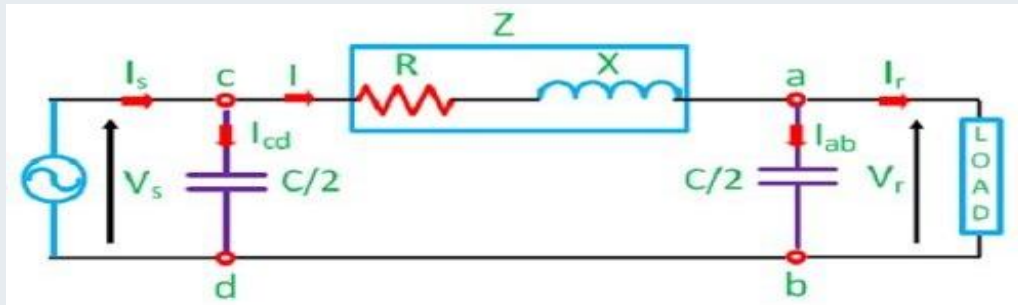


Figure 3. Nominal π method medium transmission line. url: <https://circuitglobe.com/wp-content/uploads/2016/05/pi-model-medium-line.jpg>

- Using the same procedures, the sending end voltage and current are given by:

$$V_s = \left(1 + \frac{ZY}{2}\right)V_r + ZI_r \quad \text{eqn.(9)}$$

$$I_s = \left(Y + \frac{ZY^2}{4}\right)V_r + \left(1 + \frac{ZY}{2}\right)I_r \quad \text{eqn.(10)}$$

- **Long Transmission Line:** Transmission lines that span more than **250 km (150 miles)** are considered lengthy.
- The approximation of the shunt admittance by two **constant capacitors at each end of the** line is insufficiently accurate for long lines.
- Rather, the series impedance and the shunt capacitance need to be thought of **as dispersed quantities**, and the differential equations of the line should be solved to determine the voltages and currents on it.
- On the other hand, a long transmission line can be modeled as a **π model with modified** shunt admittance Y' and series impedance Z' , and calculations can be done on that model using ABCD constants for Fig.4.

- The series impedance and shunt admittance adjusted values are:

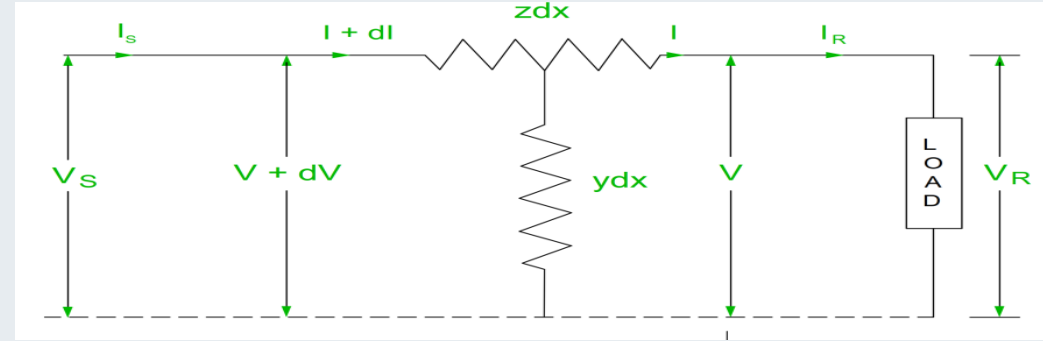


Figure 4. Long transmission line representation.

URL: https://www.myelectrical2015.com/2022/04/abcd-parameters-of-long-transmission.html#google_vignette

$$Z' = Z \frac{\sinh \gamma d}{\gamma d}$$

$$Y' = Y \frac{\tanh(\gamma d / 2)}{\gamma d / 2}$$

eqn.(11)

- Where, Z is the series impedance of the line; Y is the shunt admittance of the line; d is the length of the line; γ is the propagation constant of the line:

$$\gamma = \sqrt{yZ}$$

eqn.(12)

- Where, z is the series impedance per km and y is the shunt admittance per km.
- When γd decreases, the ratios tend to 1.0, transforming the model into a medium-length line model.
- For a long transmission line, the ABCD constants are;

$$A = \frac{Z'Y'}{2} + 1$$

$$B = Z'$$

$$C = Y' \left(\frac{Z'Y'}{4} + 1 \right)$$

$$D = \frac{Z'Y'}{2} + 1$$

eqn.(13)

4. Distribution Systems and Loads

- The distribution system gives out the energy from the medium voltage substations to customer s' location. It is composed of:
 - Medium Voltage (MV) lines (33kV, 15 kV)
 - MV/LV transformer substations (33/15/ kV to 400/380/220 V)
 - Distribution lines (33/15 kV, 380 V 3-phase and 220 v single phase

Load or Energy Sink:

- Load is the end equipment of the power system where the transmitted electrical energy is converted to other forms of useful energy.

- Finally, the overall power network diagram is presented in Fig.5

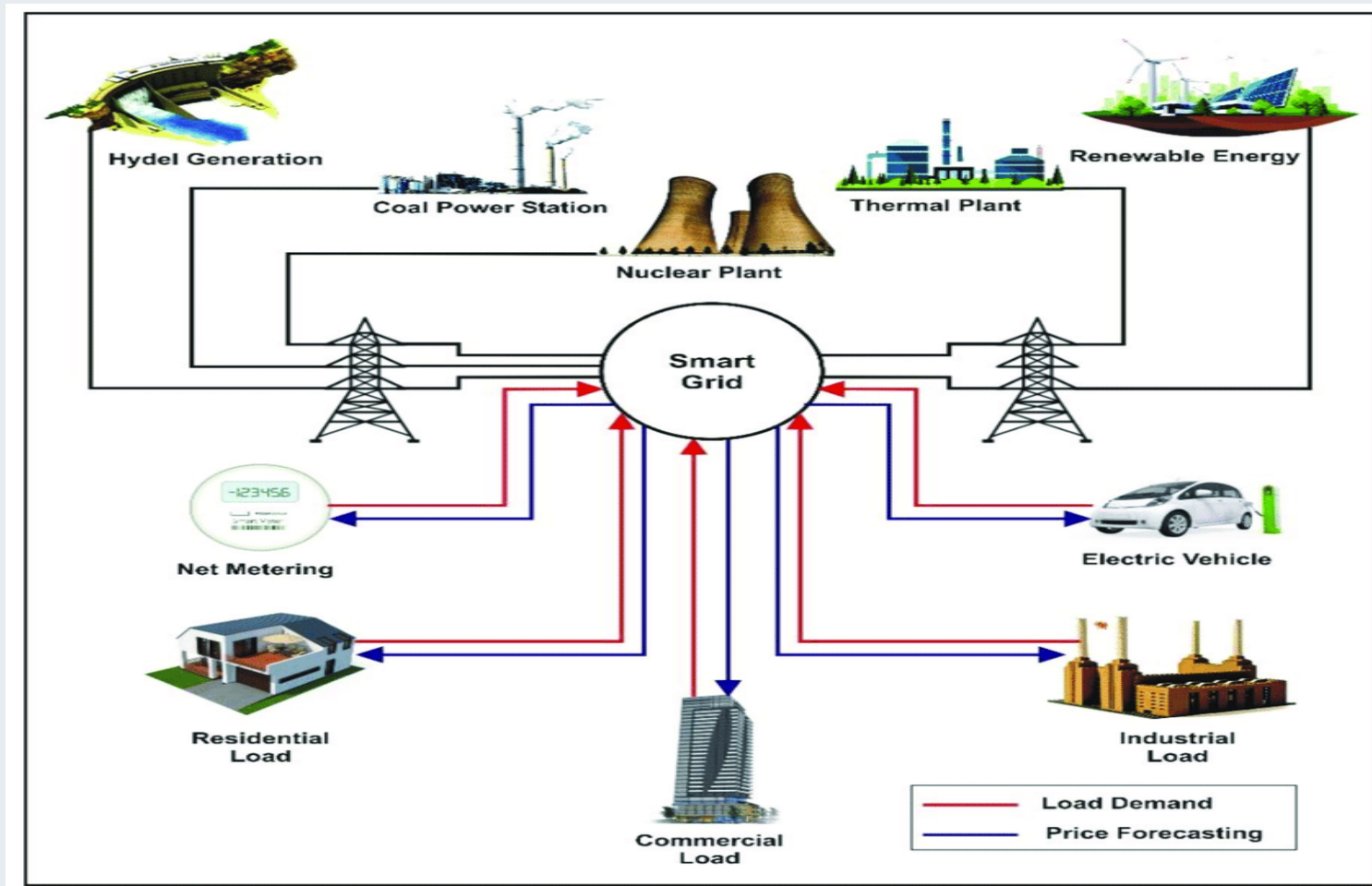


Figure 5: Modern power network structures[4].

5. Single and Three Phase Power System(STPS)

a. Single Phase Circuit Components

- Sources (voltage or current)
- Impedances (resistance, inductance, and capacitance)
- The components are connected in series or in parallel, presented in Fig.6

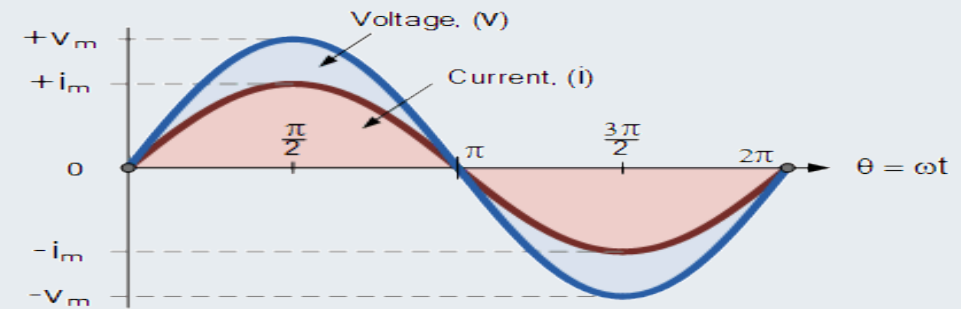
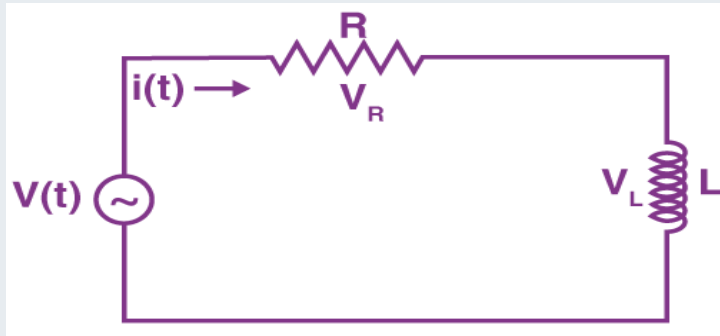


Figure 6. a. RL ckt. [url: https://cdn1.byjus.com/wp-content/uploads/2021/04/RL-Circuit-Series-Circuit.png](https://cdn1.byjus.com/wp-content/uploads/2021/04/RL-Circuit-Series-Circuit.png) b. RL circuit Phase shift. Url: <https://www.electronics-tutorials.ws/wp-content/uploads/2013/06/acp29.gif?fit=405%2C210?fit=355,226>

- The Phasor analysis is used to know the single phase power relations
- Goal of phasor analysis is to simplify the analysis of constant frequency AC systems

$$v(t) = V_{\max} \cos(\omega t + \theta_v) \quad \text{eqn.(14)}$$

$$i(t) = I_{\max} \cos(\omega t + \theta_i)$$

- Root Mean Square (RMS) voltage of sinusoid

$$V_{rms} = \sqrt{\frac{1}{T} \int_0^T v(t)^2 dt} = \frac{V_{\max}}{\sqrt{2}} \quad \text{eqn.(15)}$$

STPS

Cont.....

- Based on the Euler's identity;

$$e^{j\theta} = \cos\theta + j\sin\theta$$

eqn.(16)

- Accordingly, the phase notation is rewritten as :

$$V_{(t)} = \sqrt{2}|V|\cos(\omega t + \theta_v)$$

$$= \sqrt{2}|V|\operatorname{Re}[e^{j(\omega t + \theta_v)}]$$

eqn.(17)

Where, V is the r.m.s voltage.

- The r.m.s , cosine-referenced voltage is:

eqn.(18)

$$V = |V|e^{j\theta_v} = |V| \angle \theta_v$$

$$V_{(t)} = \operatorname{Re} \sqrt{2}V e^{j\omega t} e^{j\theta_v}$$

$$V = |V|\cos\theta_v + j|V|\sin\theta_v$$

$$I = |I|\cos\theta_I + j|I|\sin\theta_I$$

- Then, the power, P(t) is given as;

$$\begin{aligned} P_{(t)} &= V_{(t)} * I_{(t)} \\ &= \frac{1}{2} V_{\max} I_{\max} [\cos(\theta_V - \theta_I) + \cos(2\omega t + \theta_V + \theta_I)] \end{aligned} \quad \text{eqn.(20)}$$

- Then, the average power is given by:

$$\begin{aligned} P_{avg} &= \frac{1}{T} \int_0^T P(t) dt \\ &= \frac{1}{2} V_{\max} I_{\max} \cos(\theta_V - \theta_I) \\ &= |V| |I| \cos \phi \end{aligned} \quad \text{eqn.(22)}$$

- **Complex Power**

$$\begin{aligned} S &= |V| |I| [\cos(\theta_V - \theta_I) + j \sin(\theta_V - \theta_I)] \\ &= P + jQ \\ &= VI^* \end{aligned} \quad \text{eqn.(23)}$$

- Where, P is real power, Q is reactive power, S is apparent power and Φ is the power factor

Power flow or conservation of PF

- At every node (bus) in the system
 - ✓ Sum of real power in the node must be zero
 - ✓ Sum of reactive power in the node must be zero
- This is a direct consequence of Kirchhoff's current law, which states that the total current at each node must be equal to zero.
 - ✓ Conservation of power follows since $S = VI^*$

b. Balanced 3 Phase (ϕ) Systems

- Single phase is used primarily only in low voltage, low power settings, such as residential and some commercial
- A balanced three-phase system which is presented in Fig.7 has :
 - Three voltage sources with equal magnitude, but with an angle shift of 120°
 - Equal loads on each phase
 - Equal impedance on the lines connecting the generators to the loads
- Bulk power systems are almost exclusively three phase.

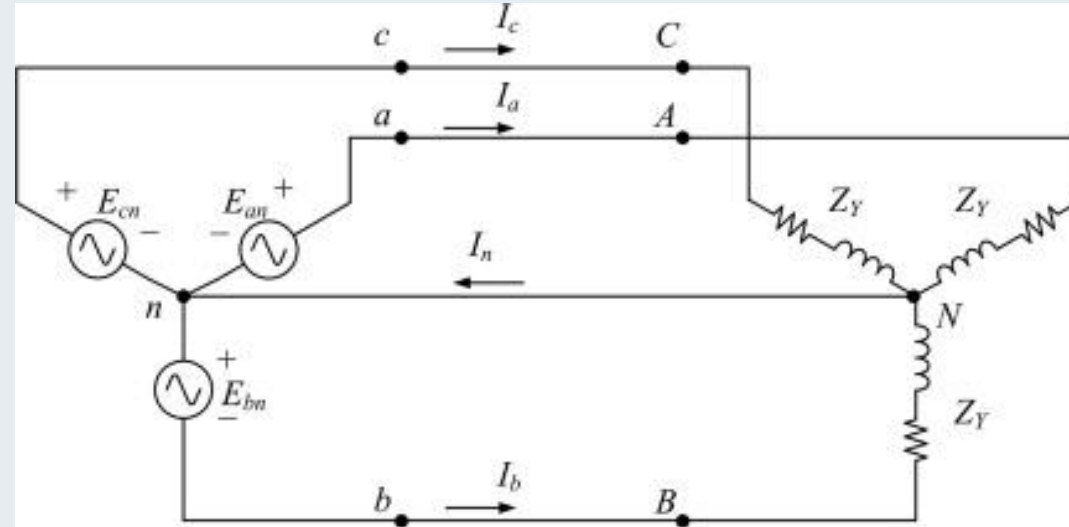


Figure 7. Balanced Three Phase system with No-Neutral current. url: <https://ars.els-cdn.com/content/image/1-s2.0-S1364032115017025-gr5.jpg>

$$I_n = I_a + I_b + I_c$$

$$I_n = \frac{V}{Z} (1 \angle 0^\circ + 1 \angle -120^\circ + 1 \angle 120^\circ) = 0$$

eqn.(24)

$$S = V_{an} I_{an}^* + V_{bn} I_{bn}^* + V_{cn} I_{cn}^* = 3 V_{an} I_{an}^*$$

- Balanced three phase system can transmit more power for same amount of wire, twice as much as single phase
- Torque produced by three-phase machines is constant
- Three phase machines use less material for same power rating
- Three phase machines start more easily than single phase machines

6. Per Phase Analysis

- Per phase analysis allows analysis of three phase systems with the same effort as for a single phase system
- For per-phase analysis:
 - a. All loads and sources Y connected
 - b. No mutual Inductance between phases
- All neutrals are at the same potential
- All phases are completely decoupled
- All system values are the same sequence as sources.
- The sequence order are phase b lags phase a and phase c lags phase b, known as “positive” sequence;

Per Phase Analysis

Cont....

Steps for per phase analysis

- Convert all Δ load/sources to equivalent Y's
- Solve phase "a" independent of the other phases
- Total system power $S = 3 V_a I_a^*$
- If desired, phase "b" and "c" values can be determined by inspection (i.e., $\pm 120^\circ$ degree phase shifts)
- If necessary, go back to original circuit to determine line-line values or internal Δ values.

Per Phase Analysis

Cont....

- **Per Unit values** : The ratio of the actual value in any value to the chosen base value of the same unit is known as; per unit value, it has a unit less quantities
- A key problem in analyzing power systems is the large number of transformers.
- It would be very difficult to continually have to refer impedances to the different sides of the transformers
- This problem is avoided by a normalization of all variables.
- This normalization is known as per unit analysis

$$Quantity_{pu} = \frac{\textit{Actual value}}{\textit{Base value}}$$

eqn.(25)

Per Phase Analysis

Cont....

- Referring quantities from one side of the transformer to the other side serious errors may be committed, which can be avoided using per unit system.
- Voltages, currents and impedances expressed in per unit do not change when they are referred
- Per unit impedances of electrical equipment of similar type usually lie within a narrow range, when the equipment ratings are used as base values.
- Transformer connections do not affect the per unit values.

- In power systems the 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.

The following are some of the **guide** lines for selection of base values.

- Rating of the largest plant or unit for base MVA or KVA.
- The total capacity of a plant or system for base MVA or KVA.
- Any arbitrary value.

Per Phase Analysis

Cont....

- Once the base values or reference values are chosen. the other quantities can be obtained as;
 1. Pick a 1- Φ VA base for the entire system, S_B
 2. Pick a voltage base for each different voltage level, V_B . Voltage bases are related **by transformer turns ratios. V is phase voltage for 1- Φ**
 3. Calculate the current base, $I_B = S_B/V_B$
 4. Calculate the impedance base, $Z_B = (V_B)^2/S_B$
 5. Convert actual values to per unit
 6. Convert back to actual as necessary

Per Phase Analysis

Cont....

I. Pick a 3- Φ VA base for the entire system,

$$S_B^{3\phi}$$

II. Pick a voltage base for each different voltage level, V_B . Voltages are line to line.

III. Calculate the current base, I_B

$$I_B^{3\phi} = \frac{S_B^{3\phi}}{\sqrt{3} V_{B,LL}} = \frac{3 S_B^{1\phi}}{\sqrt{3} \sqrt{3} V_{B,LN}} = \frac{S_B^{1\phi}}{V_{B,LN}} = I_B^{1\phi}$$

IV. Calculate the impedance base

$$Z_B = \frac{V_{B,LL}^2}{S_B^{3\phi}} = \frac{(\sqrt{3} V_{B,LN})^2}{3 S_B^{1\phi}} = \frac{V_{B,LN}^2}{S_B^{1\phi}}$$

Per Phase Analysis

Cont....

Per Unit Change to Common MVA Base

- Parameters for equipment are often given using power rating of equipment as the MVA base
- To analyze a system all per unit data must be on a common power base

$$\begin{aligned} Z_{Pu}^{Newbase} &= Z_{Pu}^{Originalbase} * \frac{V_{base}^2}{S_{Base}^{Originalbase}} \\ &= Z_{Pu}^{Originalbase} * \frac{S_{Base}^{Newbase}}{S_{Base}^{Originalbase}} \end{aligned} \quad \text{eqn.(26)}$$

Example A 50 MVA transformer has a leakage reactance of 4%. What is the reactance on a 100 MVA base?

$$X_{Pu}^{New} = 0.04 * \frac{100}{50} = 0.08$$

7. Power Flow Analysis

- Power is very important for the development of any country. It has the following characteristics:
 - It can be easily converted to and from other forms of energy.
 - It can be transmitted and distributed over large area and long distance.
 - It can be easily controlled
- It is economical, because it can be generated in large quantities at one location and distributed to sites where the energy is needed.
- used for planning and controlling a system

- Power flow analysis begins with understanding the power network structure as presented in Fig.8 , which is drawn using power world simulator software.

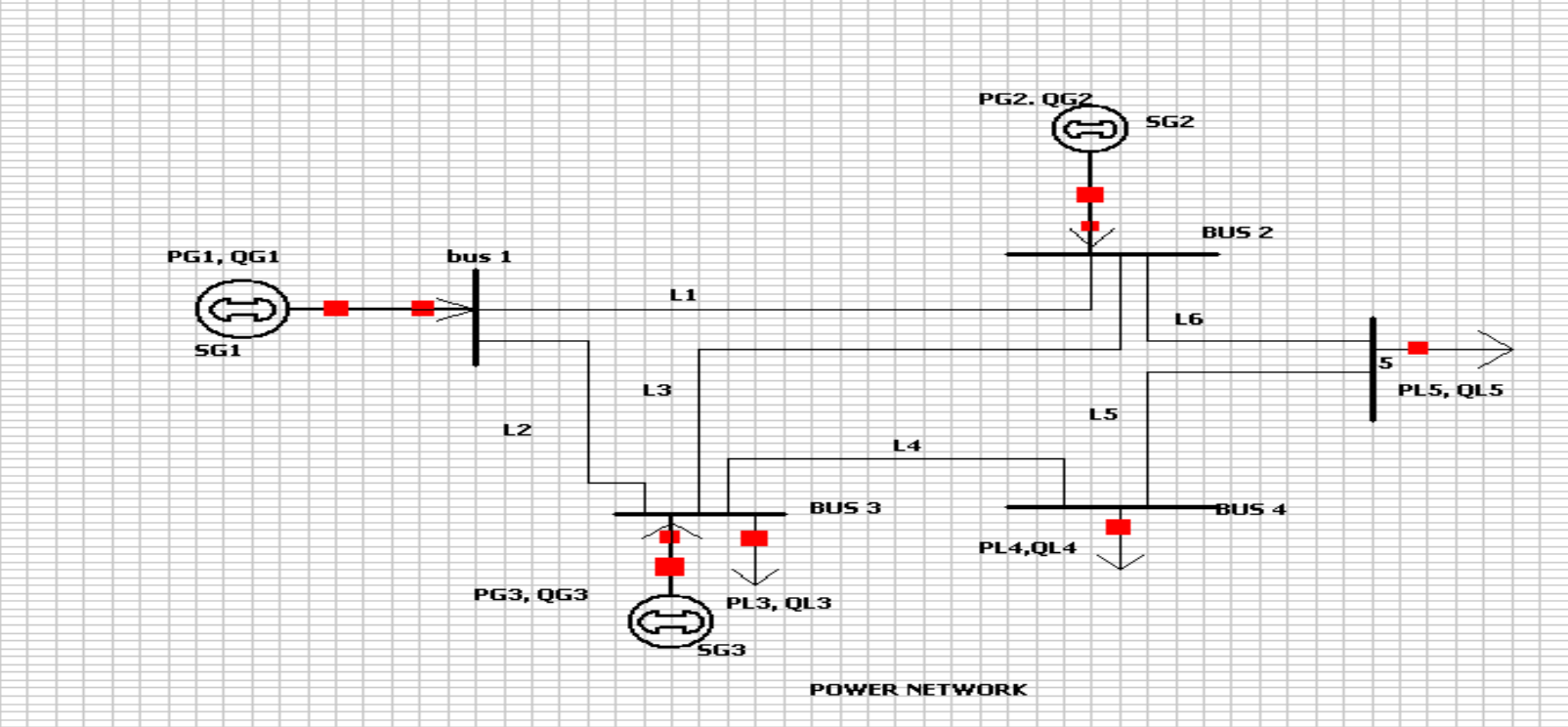
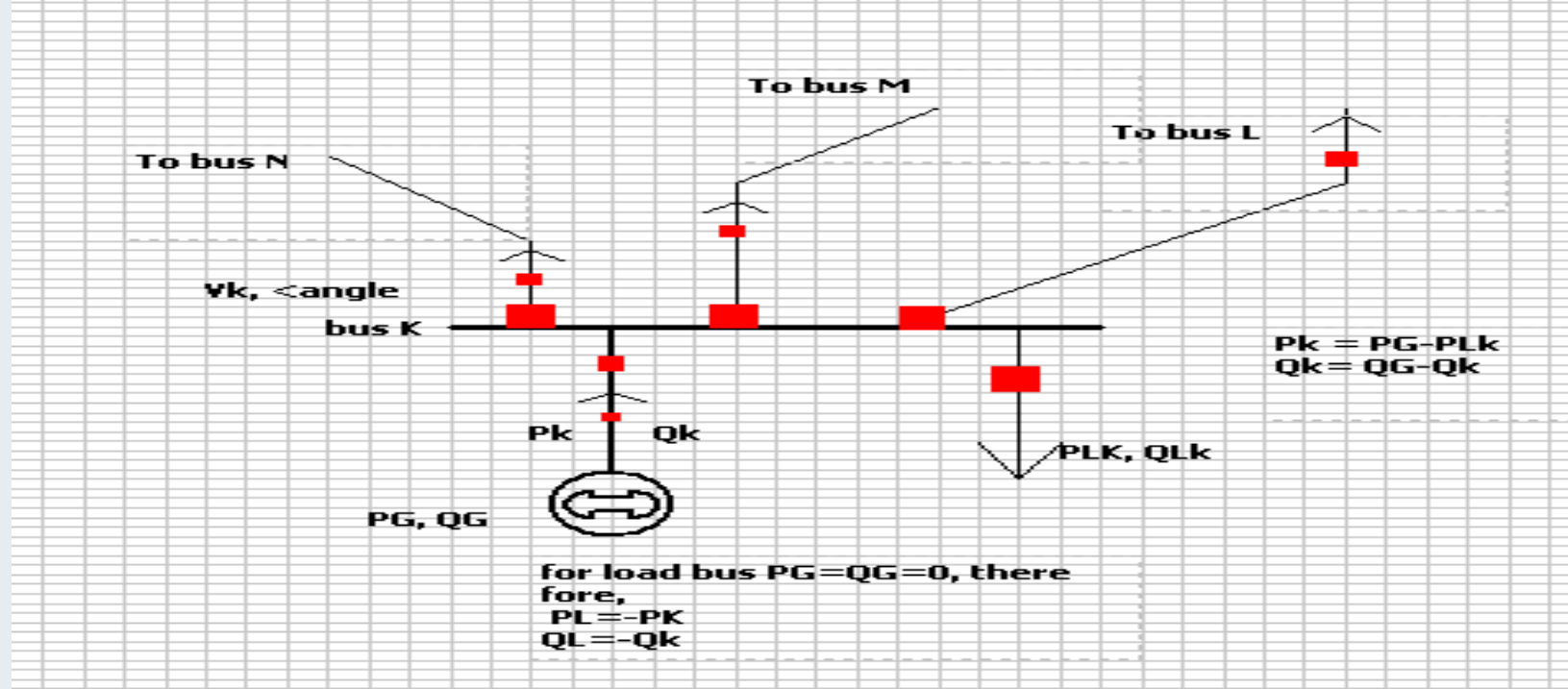


Figure 8. Power Network Sample

Power Flow Analysis

Cont.....

- If, only bus k is considered from Fig.8, the power flow equation is given as;



$$P_K = P_{KL} + P_{KM} + P_{KN}$$

$$Q_K = Q_{KL} + Q_{KM} + Q_{KN}$$

eqn.(27)

Power Flow Analysis

Cont.....

Significance of power flow are:

- To find out the voltage magnitude and its phase angle at each bus
- To determine the active and reactive power flow in each line
- Thus, each bus has four state variables:
 - voltage magnitude
 - voltage phase angle
 - real power injection
 - reactive power injection
- In order to perform the analysis, two parameters out of four state variables should be defined or given.

Power Flow Analysis

Cont.....

General objectives of power flow are;

- For the successful operation of static power flow analysis ;
 - Generation must supplies demand (load) and loss.
 - Node voltage magnitudes must be remain close to rated values.
 - Generator must operates within specified real and reactive power limits.
 - lines and transformers should not be overloaded

Power Flow Analysis

Cont.....

- Bus Admittance matrix formulation . It's formulated based on eqn.28.

$$S_K = I^* V$$
$$S_K = P_K + jQ_K$$

eqn.(28)

- Considering long transmission line and KCL at each node for Fig.9, the admittance is:

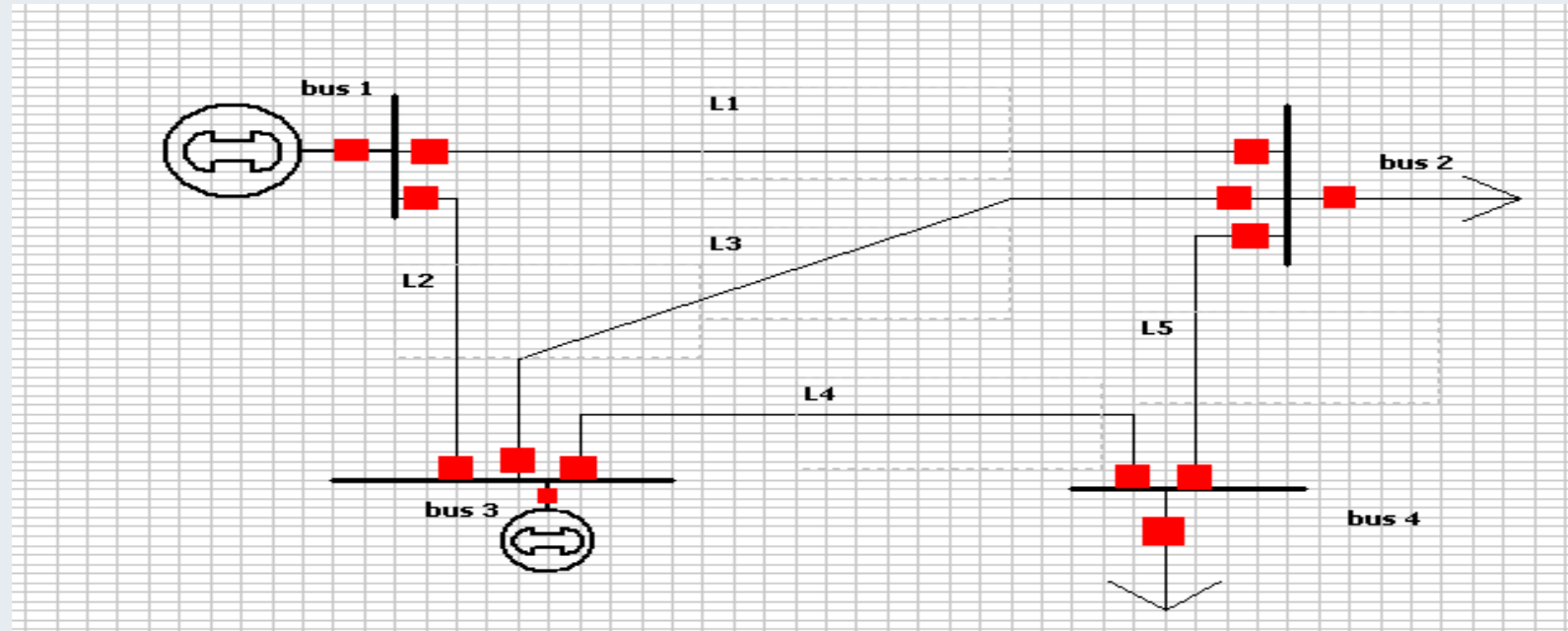


Figure 9. Single line representation of Five bus system

Power Flow Analysis

Cont.....

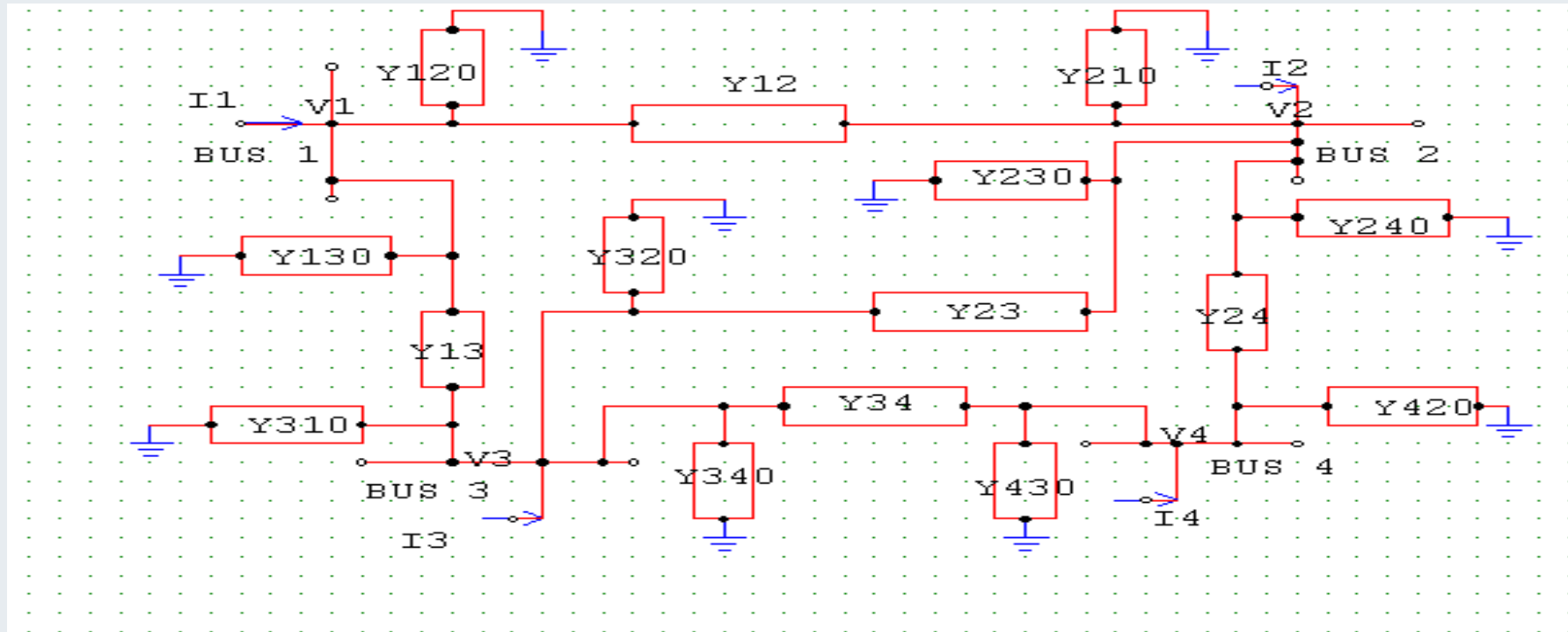


Figure 10. The π model five-bus long transmission line representation

Power Flow Analysis

Cont.....

➤ To find out the current 'I' flowing into bus I, apply KCL at each bus is presented in Eqn.29

$$\mathbf{I}_1 = \mathbf{V}_1 (\mathbf{Y}_{120} + \mathbf{Y}_{130} + \mathbf{Y}_{12} + \mathbf{Y}_{13}) - \mathbf{V}_2 * \mathbf{Y}_{12} - \mathbf{V}_3 * \mathbf{Y}_{13}$$

$$\mathbf{I}_2 = \mathbf{V}_2 (\mathbf{Y}_{210} + \mathbf{Y}_{230} + \mathbf{Y}_{240} + \mathbf{Y}_{12} + \mathbf{Y}_{23} + \mathbf{Y}_{24}) - \mathbf{V}_1 * \mathbf{Y}_{12} - \mathbf{V}_3 * \mathbf{Y}_{23} - \mathbf{V}_4 * \mathbf{Y}_{24} \quad \text{eqn.(29)}$$

$$\mathbf{I}_3 = \mathbf{V}_3 (\mathbf{Y}_{310} + \mathbf{Y}_{320} + \mathbf{Y}_{340} + \mathbf{Y}_{31} + \mathbf{Y}_{23} + \mathbf{Y}_{34}) - \mathbf{V}_1 * \mathbf{Y}_{13} - \mathbf{V}_2 * \mathbf{Y}_{23} - \mathbf{V}_4 * \mathbf{Y}_{34}$$

$$\mathbf{I}_4 = \mathbf{V}_4 (\mathbf{Y}_{420} + \mathbf{Y}_{430} + \mathbf{Y}_{43} + \mathbf{Y}_{42}) - \mathbf{V}_3 * \mathbf{Y}_{43} - \mathbf{V}_2 * \mathbf{Y}_{42}$$

Power Flow Analysis

Cont.....

- The current I in matrix and Y bus matrix forms are given in eqn.30 and eqn.31, respectively. ;

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & -Y_{12} & -Y_{13} & -Y_{14} \\ -Y_{21} & Y_{22} & -Y_{23} & -Y_{24} \\ -Y_{31} & -Y_{32} & Y_{33} & -Y_{34} \\ -Y_{41} & -Y_{42} & -Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} \quad \text{eqn.(30)}$$

$$I = YV \Rightarrow I_i = \sum_{j=1}^n Y_{ij} V_j$$

$$Y = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \quad \text{eqn.(31)}$$

Power Flow Analysis

Cont.....

- The diagonal element Y_{11} , Y_{22} , Y_{33} and Y_{44} are called self (driving point) admittance which is the sum of all admittances connected to the node identified by the repeated subscripts
- The other admittances are called mutual (transfer) admittance of the nodes which is negative of admittances connected directly between two nodes.
- Diagonal elements of Y bus matrix is the summation of all elements connected to bus i
- Off-diagonal elements of Y bus matrix is simply obtained as negative of the magnitude of admittance connected between i and j

Power Flow Analysis

Cont.....

➤ **Power flow equations** : Based on the known and unknown variables, buses can be classified as;

| Types of bus | specified variables | Variables to be computed |
|--------------------------|---------------------|--------------------------|
| Load bus(uncontrolled) | P, Q | $ V , \delta$ |
| Generator (V controlled) | $P, V $ | Q, δ |
| Slack (Swing) | $ V , \delta$ | P, Q |

Load bus: A load bus is a bus that has only loads connected to it; no generation is present.

- Real power (P_{Di}) and reactive power (Q_{Di}) are pulled from the supply at this bus.
- Since generated powers P_{Gi} and Q_{Gi} are presumed to be positive, P_{Di} and Q_{Di} in a power balancing equation are viewed **as negative** numbers.

PV or Voltage controlled bus/ generator bus: A voltage controlled bus is any bus in the system where the voltage magnitude can be controlled.

- The real power(P) and Voltage (V) are known, whereas, its phase angle and the reactive power (Q) are to be determined.
- The limits on the value of the reactive power are also specified.

Slack bus: The place where total energy balance or power mismatch is determined using eqn. 32.

$$P_L = \sum_{i=1}^N P_{Gi} - \sum_{i=1}^N P_{Di} \quad \text{eqn.(32)}$$
$$Q_L = \sum_{i=1}^N Q_{Gi} - \sum_{i=1}^N Q_{Di}$$

➤ **In order to determine an unknown variables,** a power flow equations is needed. Thus,

➤ applying KCL at each node I is presented in eqn.33;

$$\mathbf{I}_i = \sum_{j=1}^N \mathbf{Y}_{ij} \mathbf{V}_j, \quad i=1,2,\dots,N \quad \text{eqn.(33)}$$

Power Flow Analysis

Cont.....

- The complex apparent power injected to bus 'i' is given as;

$$\begin{aligned} S_i &= P_i + jQ_i \\ &= V_i I_i^* \end{aligned}$$

eqn.(34)

- Substituting 'i' in eqn.(34), **the complex power (s) is given as;**

Where,

$$P_i + jQ_i = V_i \left[\sum_{j=1}^N Y_{ij} V_j \right]$$

eqn.(35)

$$V_i = V_i e^{j\delta_i}$$

$$V_j = V_j e^{j\delta_j}$$

$$Y_{ij} = Y_{ij} e^{j\theta_{ij}}$$

- Note that, the power flow is given by:

$$P_i + jQ = V_i \left[\sum Y_{ij} V_j e^{j(\delta_i - \delta_j - \theta_{ij})} \right]$$

eqn.(36)

Power Flow Analysis

Cont.....

- Separating the real and reactive power from eqn.36, is given as;

$$P_i = V_i \left[\sum_{j=1}^N Y_{ij} V_j \cos(\delta_i - \delta_j - \theta_{ij}) \right] \quad \text{eqn.(37)}$$

$$Q_i = V_i \left[\sum_{j=1}^N Y_{ij} V_j \sin(\delta_i - \delta_j - \theta_{ij}) \right]$$

- Eqn.37, reveals the polar form of the load **flow equations or static load flow equations**.
- They are usually expressed in the following forms as mathematical models of the load flow problem.
- But during operating condition all the power system variables are not kept constant at rated values and iterative solution is needed, considering eqn.38.

$$\Delta P_i = P_{i,sched} - P_{i,calculated} \Rightarrow (P_{Gi} - P_{Di}) - P_{i,calculated} \quad \text{eqn.(38)}$$
$$\Delta Q_i = Q_{i,sched} - Q_{i,calculated} \Rightarrow (Q_{Gi} - Q_{Di}) - Q_{i,calculated}$$

- In case of iterative techniques, the soln. is obtained in an orderly fashion starting from its **initial approximate** soln. for initial guess.
- The number of steps needed to obtain real soln. depends on the *initial guess's* , *problem size and the iterative technique* used.
- Thus, based on the named constraints, the approximate soln. may **converge, diverge or oscillate**.
- The round-off error in this case goes on getting corrected in each step.
- Commonly used iterative load flow techniques are;
 - i. Gauss–Seidel method
 - ii. Newton–Raphson method
 - iii. Fast decoupled method

8. Operation of Power Plants(OPPs)

a. Operation of Conventional Power Plants (OCPPs):

- The primary characteristics of CPPs, such as **thermal or hydro generation**, which aid in frequency **regulation and load shifting**, are output stability and controllability[5].
- CPPs often have ***bulk generation and are based on fossil fuels***, both of which are bad for the environment.
- They may, like a hydro plant that **ruins the local topology**, occupy and have an impact on a big geographic area.
- Because CPPs are located close to the raw material source, energy may be lost during transmission, leading to greater generation and further environmental pollution.

b. Operation of Non-Conventional Power Plants (ONCPPs)

- Non-Conventional Power Plants: Non-conventional power plants utilize renewable energy sources that are naturally replenished and practically inexhaustible
- N-CPPts are located near to grid with reduced transmission power loss compared to CPPTs.
- However, their intermittent characteristics compared to CPPTs needs daily operation and control aspects with respect to load variations and climate change
- Specifically, their resources needs to be adjusted per seconds

Summary

- In summary, the basics of power systems is discussed in this lecture.
- The structure of power systems, its components and operation is well presented.
- Besides this, the three types of power transmission lines and their two-port network equation is also discussed.
- On top of it, the basics of power flow analysis is also discussed
- Finally, the basic operation of conventional and non-conventional power plant is also mentioned.

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Thank you !