LOAD FLOW STUDY

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INTRODUCTION

- For the ideal operation of power system, it is important that a steady state condition is always maintained.
- Three major problems encountered in the ideal operation of the power system are
  - Load flow problem;
  - Optimal load scheduling problem;
  - System control problem.
- Load flow study in power system parlance is the steady state solution of the power system network.
- Load flow study provides the information for the magnitudes and phase angles of load bus voltages, reactive power at generator buses, real and reactive power flow on transmission lines, other variables begin specified.

INTRODUCTION

- These information is essential for the continuous monitoring of the current state of the system and for analyzing the effectiveness of alternative plans for future system expansion to meet increased load demand.

INTRODUCTION

- Load flow studies are performed to calculate the magnitude and phase angle of voltage at the buses and also active power and reactive power flow for the given terminal or bus conditions.
- The following variable are associated with each bus or node:
    - Magnitude of voltage - $|V_i|$
    - Phase angle of the voltage - δ_i
    - Active power - P_i
    - Reactive power - Q_i
- Three types of buses or nodes are identified in a power system for load flow studies. In each bus two variable are known and two are to be determined.

LOAD FLOW PROBLEM

- Based in the specific variables, the buses are classified as
  - **Swing bus, reference bus or slack bus**
    - Voltage magnitude and phase of this bus is known. This bus is first to respond to a changing load conditions.
  - **Generator bus, voltage controlled bus or PV bus**
    - For this bus voltage magnitude and active power are specified. Often the upper and limits of reactive power are also specified. The phase angle of the voltage and reactive power are to be determined.
  - **Load bus or PQ bus**
    - Here the active power and reactive power are specified. Buses with neither generator nor load many be considered as load buses. If any bus in a power system network has both load and generator, then load is generally treated as negative generation.

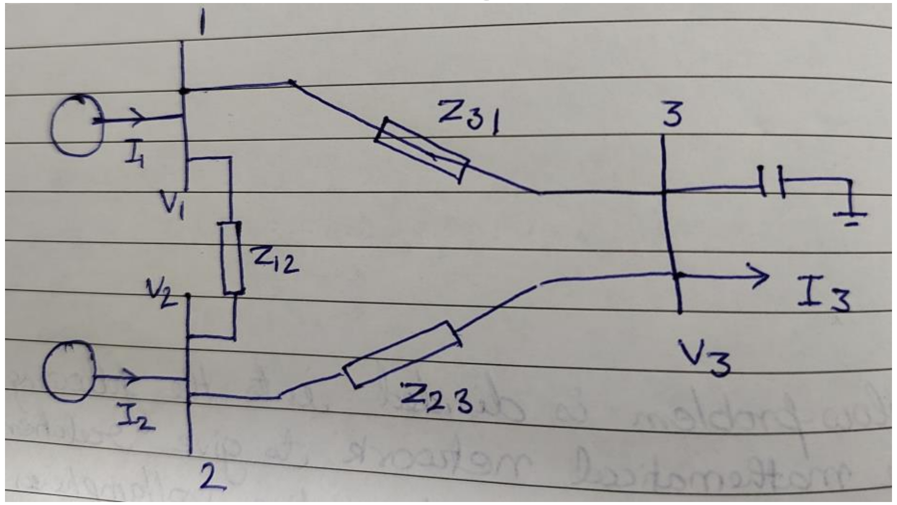
Bus types	Specified parameter	Unknow parameter
Reference bus or slack bus	$\lvert V_i \rvert; \delta_i$	$P_i; Q_i$
Generator bus or PV bus	$\lvert V_i \rvert; P_i$	$\delta_i; Q_i$
Load bus or PQ bus	$P_i; Q_i$	$\lvert V_i \rvert; \delta_i$

LOAD FLOW PROBLEM

- The load flow problem is divided into the following steps
  - A suitable mathematical network to give relationship between voltage, power and reactive power is formulated.
  - Power, vars & voltage are specified at various buses.
  - Numerical solution of the load flow problem subject to the restraints given in 2 is found to give the bus voltage.
  - Flow of power and vars is found in all the lines of the networks.

Y BUS MATRIX

- Consider a small power system network consisting of two generation station, one load and a static capacitor connected to load bus 3 (as shown in figure).



- The nodal equation can be determined and written in a matrix form as follows –

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}$$

Y BUS MATRIX

- The elements Y_{11}; Y_{22} and Y_{33}; the diagonal terms are called the self admittance.
- The self admittance of a node x is equal to the sum of admittance of all the elements connected to node x.
- In general, the diagonal element Y_{pp} of the bus admittance matrix is equal to the sum of admittance of all the element connected to bus p; i.e.

$$Y_{pp} = Y_{p1} + Y_{p2} + Y_{p3} + \ ... + Y_{pp}$$

- The elements Y_{12}; Y_{21} and Y_{23}; the off diagonal terms are called the mutual admittance.

Y BUS MATRIX

- For a network having 'n' nodes (buses) excluding ground, a set of following equation one for each node, can be written as

$$I_1 = Y_{11}.V_1 + Y_{12}.V_2 + \cdots + Y_{1n}.V_n$$
$$I_2 = Y_{21}.V_1 + Y_{22}.V_2 + \cdots + Y_{2n}.V_n$$
$$\vdots$$
$$I_n = Y_{n1}.V_n + Y_{n2}.V_n + \cdots + Y_{nn}.V_n$$

- This can be rewritten in a matrix form as follows –

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1n} \\ Y_{21} & Y_{22} & \cdots & Y_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ Y_{n1} & Y_{n2} & \cdots & Y_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{bmatrix}$$
$$I_{bus} = Y_{bus} \times V_{bus}$$

ADVANTAGE OF BUS ADMITTANCE MATRIX

- The advantage of bus admittance are –
  - Data preparation is simple.
  - Its formation and modification is easy
  - Since the bus admittance matrix is a spare matrix (most of its elements are zero), the computer memory required is less.
- Note – for a large power system more than 90 % of its off diagonal elements are zero. This is due to the fact that in power system network each node is connected to not more than three nods in general and an element Y_{pq} exists only if a transmission line is linked with a node p and q.

NUMERICAL PROBLEM

- **Problem statement –** Draw a single line diagram and determine the Y bus matrix for the five bus system.

Line	Series Impedance	Line	Series Impedance
1-2	0.2	4-5	0.25
2-3	0.25	1-5	0.2
3-4	0.3	1-4	0.5

- **Solution –**

$$\begin{bmatrix} -j12 & j5 & 0 & j2.0 & j5 \\ j5 & -j11.5 & j4 & 0 & j2.5 \\ 0 & j4 & -j7.33 & j3.33 & 0 \\ j2 & 0 & j3.33 & -j9.33 & j4 \\ j5 & j2.5 & 0 & j4 & -j11.5 \end{bmatrix}$$

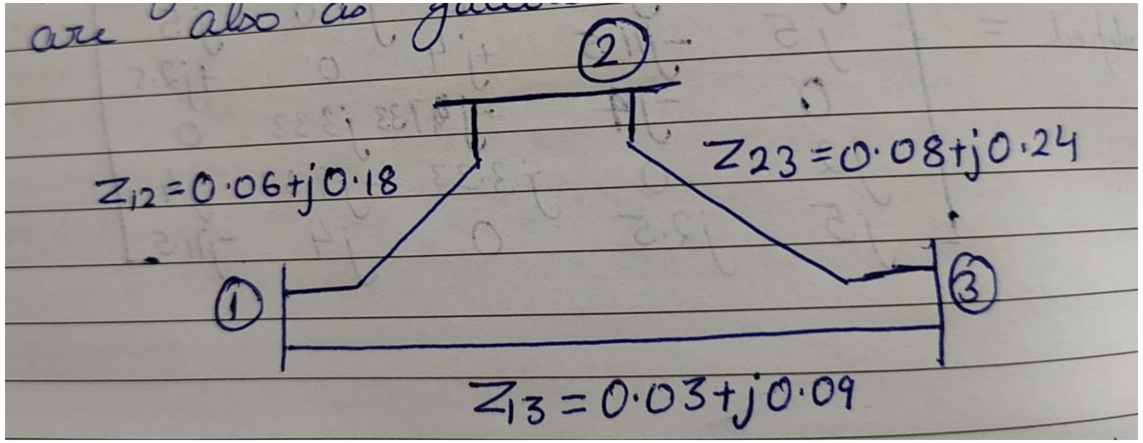
NUMERICAL PROBLEM

- **Problem statement –** In the previous example, if the line between 3 and 5 having impedance of j0.05; and 1 and 3 having impedance of j0.01 are connected; determine the modified bus admittance matrix.
- **Solution -**

$$\begin{bmatrix} -j112 & j5 & j100 & j2.0 & j5 \\ j5 & -j11.5 & j4 & 0 & j2.5 \\ j100 & j4 & -j127.33 & j3.33 & j20 \\ j2 & 0 & j3.33 & -j9.33 & j4 \\ j5 & j2.5 & j20 & j4 & -j31.5 \end{bmatrix}$$

NUMERICAL PROBLEM

- **Problem statement –** Determine Y Bus matrix of the system presented in the figure below.



- **Solution –**

$$\begin{bmatrix} 5 - j15 & -1.66 + j5 & -3.33 + j10 \\ -1.66 + j5 & 2.91 - j8.75 & -1.25 + j3.75 \\ -3.33 + j10 & 1.25 + j3.75 & 4.58 - j13.75 \end{bmatrix}$$

NUMERICAL PROBLEM

- **Problem statement –** In the previous example; if each line has a total shunt admittance of –j5 pu. Determine the modified admittance matrix.

$$\begin{bmatrix} 5 - j20 & -1.66 + j5 & -3.33 + j10 \\ -1.66 + j5 & 2.91 - j13.75 & -1.25 + j3.75 \\ -3.33 + j10 & 1.25 + j3.75 & 4.58 - j18.75 \end{bmatrix}$$

STATIC LOAD FLOW EQUATION (SLFE)

- The nodal current equation, the total current entering the i^{th} bus of an nth bus system is given by

$$I_i = Y_{i1}.V_1 + Y_{i2}.V_2 + \cdots Y_{in}.V_n = \sum_{k=1}^{n} Y_{ik}\,.V_k$$

- If $V_k = |V|_k \angle\, \delta_k$ and $Y_{ik} = Y_{ik}\, \angle(\theta_{ik})$

$$I_i = \sum_{k=1}^{n} |V|_k.Y_{ik}\angle(\theta_{ik}+\delta_k)$$

- If $V_i = |V|_i \angle\, \delta_i$; the active and reactive power delivered is given as

$$P_i = V_i \sum_{k=1}^{n} |V|_k.Y_{ik}\, sin\,(\delta_i - \theta_{ik} - \delta_k)$$

$$Q_i = V_i \sum_{k=1}^{n} |V|_k.Y_{ik}\cos(\delta_i\, - \theta_{ik} - \delta_k)$$

- The above two equation are known as static load flow equation.

STATIC LOAD FLOW EQUATION (SLFE)

- Both the equation provides ‘n’ power equations individually making a total of 2n equations.
- At each bus we have four variables ; a total of 4n variables are to be found.
- In order to find a solution at least two variable should be known at each bus which reduces the variable to 2n.
- The solution of the 2n variables are found by numerical methods because the above two equations are non linear.
- As there is no exact solution is possible for non linear equation; they are solved using iterative techniques which employ successive approximation which eventually convergence upon a solution.

GAUSS SEIDEL METHOD

- From the nodal current equation, the total current entering the Kth bus of a n bus system is given by

$$I_k = Y_{k1}.V_1 + Y_{k2}.V_2 + \cdots Y_{kn}.V_n = \sum_{i=1}^{n} Y_{ki}.V_i$$

- The complex power injected into the k^{th} bus is given as

$$S_k^* = P_k - j.Q_k = V_k^*.I_k$$

$$I_k = \frac{P_k - j.Q_k}{V_k^*}$$

$$\frac{P_k - j.Q_k}{V_k^*} = Y_{k1}.V_1 + Y_{k2}.V_2 + \cdots Y_{kn}.V_n$$

$$V_k = \frac{1}{Y_{kk}}\left[\frac{P_k - j.Q_k}{V_k^*} - \sum_{i=1;i\neq k}^{n} Y_{ik}.V_i\right]$$

GAUSS SEIDEL METHOD

- Considering the equation for bus 2

$$V_2 = \frac{1}{Y_{22}}\left[\frac{P_2 - j.Q_2}{V_2^*} - Y_{21}.V_1 - Y_{23}.V_3 \cdots Y_{2n}.V_n\right]$$

- The equation of the kth bus at a $(r+1)^{th}$ iteration is given as

$$V_k^{r+1} = \frac{1}{Y_{kk}}\left[\frac{P_2 - j.Q_2}{(V_k^r)^*} - \sum_{i=1;i\neq k}^{n} Y_{ik}\,.\,V_k^{r+1}\right]$$

- As $P_k;\ Q_k;\ Y_{kk};\ Y_{ki}$ are known and does not vary in the iteration, the above equation is approximated as

$$V_k^{r+1} = \frac{C_k}{(V_k^r)^*} - \sum_{i=1;i\neq k}^{n} D_{ik}\,.\,V_k^{r+1}$$

NEWTON RAPHSON METHOD

DECOUPLED LOAD FLOW METHOD

- In a power system operating in steady state, there is a strong interdependence between active power and bus voltage angle & reactive power and voltage magnitude.
- Thus, real power changes are less sensitive to changes in voltage magnitude and are mainly sensitive to changes in bus voltage angles.
- Similarly, the reactive power changes are less sensitive to changes in angle and are mainly sensitive to changes in voltage magnitude.
- This weak coupling in utilized in the development of decoupled load flow method in which P is decoupled from changes in voltage magnitude and Q is decoupled from changes in delta.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & 0 \\ 0 & L \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V / V \end{bmatrix}$$

FAST DECOUPLED LOAD FLOW (FDLF) METHOD

- In the case of fast decoupled load flow method following approximations are further made

$$\cos(\delta_i - \delta_k) \cong 1$$

$$\sin(\delta_i - \delta_k) \cong 0$$

$$G_{ik}\, sin\ \delta_{ik} \ll B_{ik}$$

$$Q_{ik} \ll B_{ii}|V_i|^2$$

- With these assumptions the Jacobian elements are

$$H_{ik} = L_{ik} = -V_i . V_k . B_{ik} \quad i \neq j$$

$$L_{ii} = H_{ii} = -B_{ii}|V_i|^2 \ i = j$$

DC LOAD FLOW METHOD

- $P_{ij} = \frac{V_i.V_j}{Z_{ij}} \sin(\delta_i - \delta_j)$
- Let us make assumption that

$$X_{ij} \approx Z_{ij}; V_i \approx 1; V_j \approx 1; \sin(\delta_i - \delta_j) \approx \delta_i - \delta_j$$

- $P_{ij} = \frac{\delta_i - \delta_j}{X_{ij}} \approx B_{ij}(\delta_i - \delta_j)$
- $[P] = [B][\delta]$
- $[\delta] = [B]^{-1}[P]$
- $[\delta] = [X][P]$