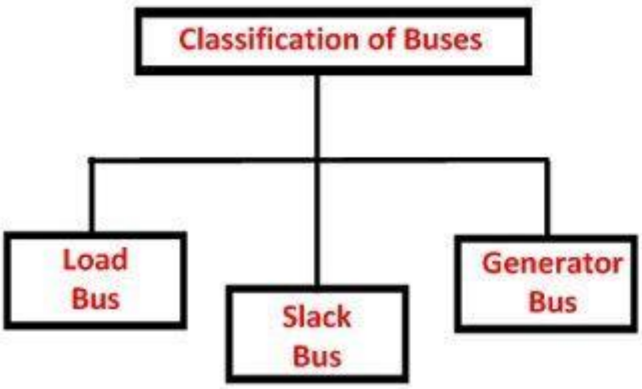
BUS CLASSIFICATION

A bus in a power system is defined as the vertical line at which the several components of the power system like generators, loads, and feeders, etc., are connected. The buses in a power system are associated with four quantities. These quantities are the magnitude of the voltage, the phase angle of the voltage, active or true power and the reactive power.

In the load flow studies, two variable are known, and two are to be determined. Depends on the quantity to be specified the buses are classified into three categories generation bus, load bus and slack bus.



The table shown below shows the types of buses and the associated known and unknown value.

Type of Buses	Know or Specified Quantities	Unknown Quantities or Quantities to be determined.
Generation or P-V Bus	P, | V |	Q, δ
Load or P-Q Bus	P, Q	| V |, δ
Slack or Reference Bus	| V |, δ	P, Q

Generation Bus or Voltage control bus

This bus is also called the P-V bus, and on this bus, the voltage magnitude corresponding to generate voltage and true or active power P corresponding to its rating is specified. Voltage magnitude is maintained constant at a specified value by injection of reactive power. The reactive power generation Q and phase angle δ of the voltage are to be computed.

Load Bus

This is also called the P-Q bus and at this bus, the active and reactive power is injected into the network. Magnitude and phase angle of the voltage are to be computed. Here the active power P and reactive power Q are specified, and the load bus voltage can be permitted within a tolerable value, i.e., 5 %. The phase angle of the voltage, i.e.δ is not very important for the load.

Slack, Swing or Reference Bus

Slack bus in a power system absorbs or emits the active or reactive power from the power system. The slack bus does not carry any load. At this bus, the magnitude and phase angle of the voltage are specified. The phase angle of the voltage is usually set equal to zero. The active and reactive power of this bus is usually determined through the solution of equations.

The slack bus is a fictional concept in load flow studies and arises because the I^2R losses of the system are not known accurately in advance for the load flow calculation. Therefore, the total injected power cannot be specified at every bus. The phase angle of the voltage at the slack bus is usually taken as reference or zero

Formulation of power flow problem in polar coordinates

The Newton-Raphson method can also be applied to the solution of power flow problem when the bus voltages are expressed in polar form. In fact, only polar form is used in practice because the use of polar form results in a smaller number of equations than the total number of equations involved in rectangular form.

For any i^{th} bus, we have

$$\mathbf{V}_i = V_i e^{j\delta_i}, \text{ then } \mathbf{V}_i^* = V_i e^{-j\delta_i},$$
$$\text{and } \mathbf{V}_k = V_k e^{j\delta_k} \qquad ...(6.114)$$
$$\text{and } \mathbf{Y}_{ik} = Y_{ik} e^{-j\theta_{ik}}$$

When δ is the phase angle of the bus voltages and θ_{ik} is and admittance angle.

Then according to Eq. 6.57(b) for any i^{th} bus –

$$\mathbf{S}_i^* = P_i - j\,Q_i = \mathbf{V}_i^* \sum_{k=1}^{n} \mathbf{Y}_{ik}\mathbf{V}_k \; ; \; i = 1, 2, \ldots n \qquad ...(6.115)$$

Substituting the values of V_i, V_k and Y_{ik} from Eq. (6.114) in Eq. (6.115) we have –

$$P_i - j\,Q_i = \sum_{k=1}^{n} V_i V_k Y_{ik}\, e^{-j(\theta_{ik} + \delta_i - \delta_k)} \qquad ...(6.116)$$

$$\text{Thus } P_i = \text{Real } \mathbf{V}_i^* \sum_{k=1}^{n} \mathbf{Y}_{ik}\mathbf{V}_k = \sum_{k=1}^{n} V_i V_k Y_{ik} \cos(\theta_{ik} + \delta_i - \delta_k)$$

$$= V_i V_i Y_{ii} \cos\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} V_i V_k Y_{ik} \cos(\theta_{ik} + \delta_i - \delta_k) \qquad ...(6.117)$$

$$\text{and } \quad Q_i = \text{Imaginary } \mathbf{V}_i^* \sum_{k=1}^{n} \mathbf{Y}_{ik}\mathbf{Y}_k = \sum_{k=1}^{n} V_i V_k Y_{ik} \sin(\theta_{ik} + \delta_i - \delta_k)$$

$$= V_i V_i Y_{ii} \sin\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} V_i V_k Y_{ik} \sin(\theta_{ik} + \delta_i - \delta_k) \qquad ...(6.118)$$

for $i = 2, 3, 4, \ldots n$ because bus 1 is slack bus

Now the linear equation in polar form becomes –

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} \qquad ...(6.119)$$

where J_1, J_2, J_3 and J_4 are the elements of Jacobian matrix and can be determined from power Eqs. (6.117) and (6.118) as follows:

The off-diagonal and diagonal elements of J_1 are –

$$\frac{\partial P_i}{\partial \delta_k} = V_i V_k Y_{ik} \sin(\theta_{ik} + \delta_i - \delta_k) \text{ for } k \neq i \qquad ...(6.120)$$

$$\text{and } \frac{\partial P_i}{\partial \delta_i} = -\sum_{\substack{k=1 \\ k \neq i}}^{n} V_i V_k Y_{ik} \sin(\theta_{ik} + \delta_i - \delta_k) \qquad ...(6.121)$$

The off-diagonal and diagonal elements of J_2 are –

$$\frac{\partial P_i}{\partial V_k} = V_i Y_{ik} \cos(\theta_{ik} + \delta_i - \delta_k) \text{ for } k \neq i \qquad ...(6.122)$$

and $$\frac{\partial P_i}{\partial V_i} = 2V_i Y_{ii} \cos\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} V_k Y_{ik} \cos(\theta_{ik} + \delta_i - \delta_k) \qquad ...(6.123)$$

The off-diagonal and diagonal elements of J_3 are –

$$\frac{\partial Q_i}{\partial \delta_k} = -V_i V_k Y_{ik} \cos(\theta_{ik} + \delta_i - \delta_k) \qquad ...(6.124)$$

and $$\frac{\partial Q_i}{\partial \delta_i} = \sum_{\substack{k=1 \\ k \neq i}}^{n} V_i V_k Y_{ik} \cos(\theta_{ik} + \delta_i - \delta_k) \qquad ...(6.125)$$

The off-diagonal and diagonal elements of J_4 are –

$$\frac{\partial Q_i}{\partial V_k} = V_i Y_{ik} \sin(\theta_{ik} + \delta_i - \delta_k) \text{ for } k \neq i \qquad ...(6.126)$$

and $$\frac{\partial Q_i}{\partial V_i} = 2V_i Y_{ii} \sin\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} V_k Y_{ik} \sin(\theta_{ik} + \delta_i - \delta_k) \qquad ...(6.127)$$

The elements of Jacobian matrix are computed with the latest voltage estimate and computed power. However, the procedure (i.e., algorithm, here) is the same as that of the rectangular coordinates. The formulation in the polar coordinates takes less computational efforts and also needs less memory space.