BUS CLASSIFICATION

INTRODUCTION

Load flow studies are one of the most important aspects of power system planning and operation. The load flow gives us the sinusoidal steady state of the entire system - voltages, real and reactive power generated and absorbed and line losses. Since the load is a static quantity and it is the power that flows through transmission lines, the purists prefer to call this Power Flow studies rather than load flow studies. We shall however stick to the original nomenclature of load flow.

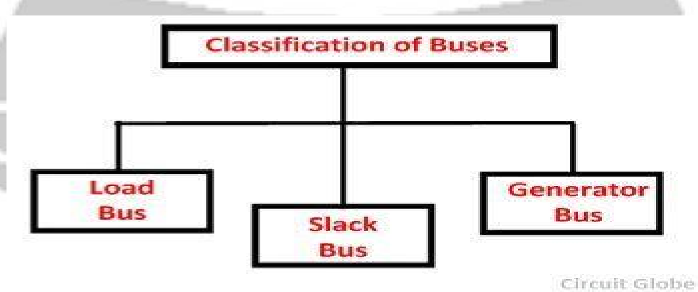
Through the load flow studies we can obtain the voltage magnitudes and angles at each bus in the steady state. This is rather important as the magnitudes of the bus voltages are required to be held within a specified limit. Once the bus voltage magnitudes and their angles are computed using the load flow, the real and reactive power flow through each line can be computed. Also based on the difference between power flow in the sending and receiving ends, the losses in a particular line can also be computed. Furthermore, from the line flow we can also determine the over and under load conditions.

The steady state power and reactive power supplied by a bus in a power network are expressed in terms of nonlinear algebraic equations. We therefore would require iterative methods for solving these equations. In this chapter we shall discuss two of the load flow methods. We shall also delineate how to interpret the load flow results.

CLASSIFICATION OF BUSES

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 variables 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

LOAD BUSES:

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.

In these buses no generators are connected and hence the generated real power PGi and reactive power QGi are taken as zero. The load drawn by these buses are defined by real power -PLi and reactive power -QLi in which the negative sign accommodates for the power flowing out of the bus. This is why these buses are sometimes referred to as P-Q bus. The objective of the load flow is to find the bus voltage magnitude |Vi| and its angle δi

Now consider a typical load flow problem in which all the load demands are known. Even if the generation matches the sum total of these demands exactly, the mismatch between generation and load will persist because of the line I 2R losses. Since the I 2R loss of a line depends on the line current which, in turn, depends on the magnitudes and angles of voltages of the two buses connected to the line, it is rather difficult to estimate the loss without calculating the voltages and angles. For this reason a generator bus is usually chosen as the slack bus without specifying its real power. It is assumed that the generator connected to this bus will supply the balance of the real power required and the line losses.

VOLTAGE CONTROLLED BUSES

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 are 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.

These are the buses where generators are connected. Therefore the power generation in such buses is controlled through a prime mover while the terminal voltage is controlled through the generator excitation. Keeping the input power constant through turbine-governor control and keeping the bus voltage constant using automatic voltage regulator, we can specify constant PGi and | Vi | for these buses. This is why such buses are also referred to as P-V buses. It is to be noted that the reactive power supplied by the generator QGi depends on the system configuration and cannot be specified in advance. Furthermore we have to find the unknown angle δi of the bus voltage.

SLACK OR SWING 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 I2R 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

Usually this bus is numbered 1 for the load flow studies. This bus sets the angular reference for all the other buses. Since it is the angle difference between two voltage sources that dictates the real and reactive power flow between them, the particular angle of the slack bus is not important. However it sets the reference against which angles of all the other bus voltages are measured. For this reason the angle of this bus is usually chosen as 0° . Furthermore it is assumed that the magnitude of the voltage of this bus is known.

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REAL AND REACTIVE POWER INJECTED IN A BUS

For the formulation of the real and reactive power entering a b us, we need to define the following quantities. Let the voltage at the i^{th} bus be denoted by

$$V_i = |V_i| \angle \delta_i = |V_i| (\cos \delta_i + j \sin \delta_i)$$

Also let us define the self admittance at bus- *i* as

$$Y_{ii} = |Y_{ii}| \angle \theta_{ii} = |Y_{ii}| (\cos \theta_{ii} + j \sin \theta_{ii}) = G_{ii} + jB_{ii}$$

Similarly the mutual admittance between the buses *i* and *j* can be written as

$$Y_{ij} = |Y_{ij}|\angle\theta_{ij} = |Y_{ij}|(\cos\theta_{ij} + j\sin\theta_{ij}) = G_{ij} + jB_{ij}$$

Let the power system contains a total number of *n* buses. The current injected at bus- *i* is given as

$$\begin{aligned} I_i &= Y_{i1}V_1 + Y_{i2}V_2 + \cdots + Y_{in}V_n \\ &= \sum_{k=1}^{n} Y_{ik}V_k \end{aligned}$$

It is to be noted we shall assume the current entering a bus to be positive and that leaving the bus to be negative. As a consequence the power and reactive power entering a bus will also be assumed to be positive. The complex power at bus- *i* is then given by

$$\begin{aligned} P_i - jQ_i &= V_i^* I_i = V_i^* \sum_{k=1}^{n} Y_{ik}V_k \\ &= |V_i|(\cos\delta_i - j\sin\delta_i)\sum_{k=1}^{n} |Y_{ik}V_k|(\cos\theta_{ik} + j\sin\theta_{ik})(\cos\delta_k + j\sin\delta_k) \\ &= \sum_{k=1}^{n} |Y_{ik}V_iV_k|(\cos\delta_i - j\sin\delta_i)(\cos\theta_{ik} + j\sin\theta_{ik})(\cos\delta_k + j\sin\delta_k) \end{aligned}$$

Note that

$$\begin{aligned} &(\cos\delta_i - j\sin\delta_i)(\cos\theta_{ik} + j\sin\theta_{ik})(\cos\delta_k + j\sin\delta_k) \\ &\quad = (\cos\delta_i - j\sin\delta_i)[\cos(\theta_{ik} + \delta_k) + j\sin(\theta_{ik} + \delta_k)] \\ &\quad = \cos(\theta_{ik} + \delta_k - \delta_i) + j\sin(\theta_{ik} + \delta_k - \delta_i) \end{aligned}$$

Therefore substituting in $P_I - jQ_i$ we get the real and reactive power as

$$P_i = \sum_{k=1}^{n} |Y_{ik}V_iV_k|\cos(\theta_{ik} + \delta_k - \delta_i)$$

$$Q_i = -\sum_{k=1}^{n} |Y_{ik}V_iV_k|\sin(\theta_{ik} + \delta_k - \delta_i)$$