Interconnected Power System

LOAD FLOW STUDIES

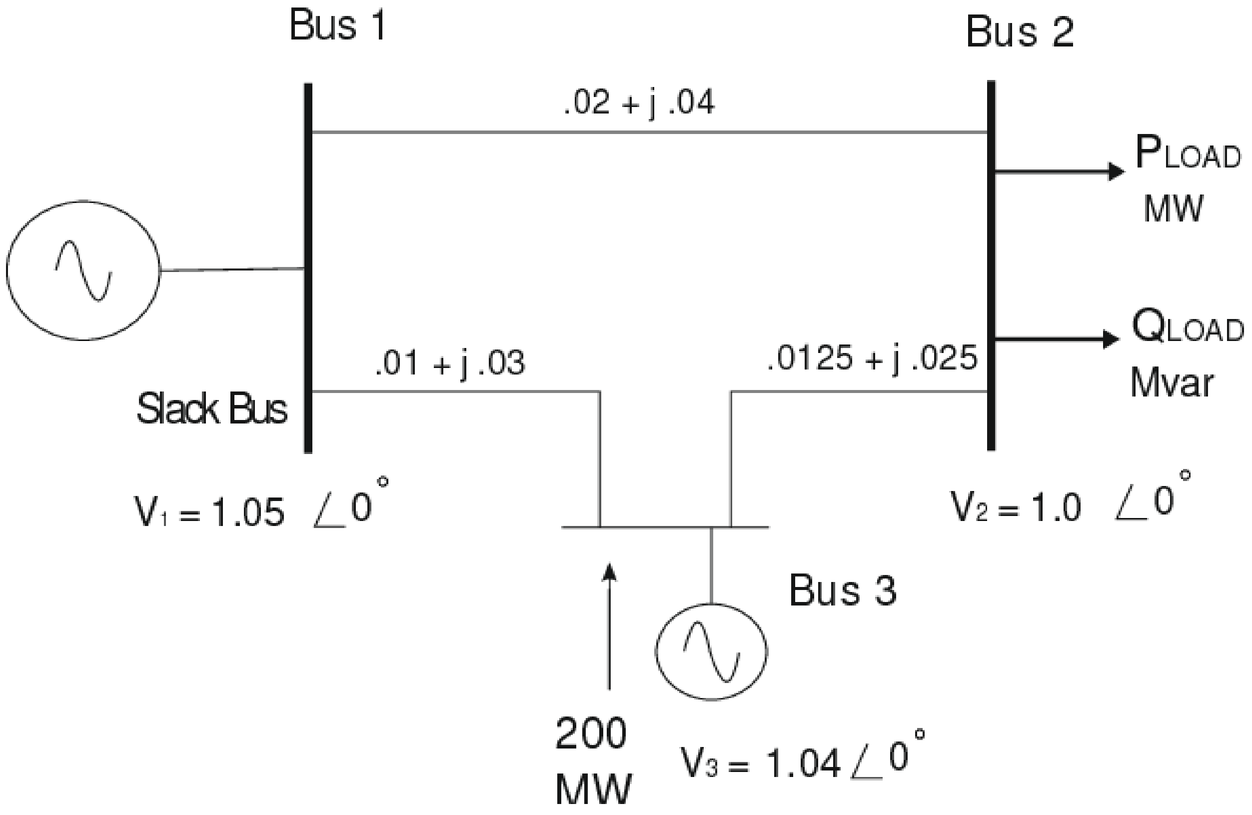
Prof. K. R. Chaudhari
Asst. Prof., EED
RNGPIT, Bardoli

What is Load Flow Analysis…?

- It is the planning the new system or the extension of an existing system.
- A knowledge of power system operation is essential to ensure supply of active power and reactive power demanded by various loads with the frequency and various bus voltages maintained within specific tolerances.
- It is the determination of the power system operating condition based on the previous knowledge of the system parameters.
- It is used for continuous monitoring of power system.

What is Load Flow Analysis…?

- Load flow is a set of non liner simultaneous algebraic equation and thus it is have multiple solution.
- Parameter to be monitored:
  - Bus Voltage Magnitude (V)
  - Bus Voltage Phase Angles (δ)
  - MW and MVAR flows in the lines (P & Q)



Necessity of Load Flow Analysis…

- To keep voltage level of certain buses within tolerances by proper reactive power scheduling.
- To determined the best location for capacitor or voltage regulation for improvement of voltage regulation.
- The total active power generation is equal to the load demand plus losses. Load flow studies used to maintain the above ratio.
- To analyse the effectiveness of alternative plans for future system expansion to meet the increased load demand or for designing a new system.

Static Load Flow Equation (SLFE)

- The complex power injected by source into p^{th} bus of power system is given by,

$$S_p = P_p + j\,Q_p = V_p I_p^*, \quad p = 1, 2, \ldots, n$$ Eq. (1)

where, V_p = voltage at the p^{th} bus w.r.t. ground

I_p^* = source current injected into p^{th} bus

$$S_p^* = P_p - j\,Q_p = V_p^* I_p, \quad p = 1, 2, \ldots, n$$ Eq. (2)

$$I_p = \sum_{q=1}^{n} Y_{pq} V_q, \quad p = 1, 2, \ldots, n$$ Eq. (3)

$$\therefore P_p - j\,Q_p = V_p^* \sum_{q=1}^{n} Y_{pq} V_q, \qquad p = 1, 2, \ldots, n$$ Eq. (4)

Static Load Flow Equation (SLFE)

$$\therefore P_p - jQ_p = V_p^* \sum_{q=1}^{n} Y_{pq} V_q, \qquad p = 1, 2, \ldots, n \qquad \text{Eq. (4)}$$

Equating real and imaginary parts of Eq. (4), we get,

$$\therefore P_p(real/active\ \ power) = \mathrm{Re}\left\{ V_p^* \sum_{q=1}^{n} Y_{pq} V_q \right\}, \qquad p = 1, 2, \ldots, n \qquad \text{Eq. (5)}$$

$$\therefore Q_p(reactive\ \ power) = -\mathrm{Im}\left\{ V_p^* \sum_{q=1}^{n} Y_{pq} V_q \right\}, \qquad p = 1, 2, \ldots, n \qquad \text{Eq. (6)}$$

Static Load Flow Equation (SLFE)

In polar form,

$$\left.\begin{aligned}
V_p &= |V_p| \angle \delta_p = |V_p| \left(\cos \delta_p + j \sin \delta_p \right) \\
V_p^* &= |V_p| \angle -\delta_p = |V_p| \left(\cos \delta_p - j \sin \delta_p \right) \\
Y_{pq} &= |Y_{pq}| \angle \theta_{pq} = |Y_{pq}| \left(\cos \theta_{pq} + j \sin \theta_{pq} \right)
\end{aligned}\right\} \quad \text{Eq. (7)}$$

Static Load Flow Equation (SLFE)

We know,

$$
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\end{aligned}\right\}
$$

Eq. (7)

We know,

$$P_p - jQ_p = \sum_{q=1}^{n} V_p^* \, Y_{pq} \, V_q, \qquad p = 1, 2, \ldots, n$$

Eq. (4)

$$= \sum_{q=1}^{n} |V_p||Y_{pq}||V_q| \angle -\delta_p + \theta_{pq} + \delta_q$$

Static Load Flow Equation (SLFE)

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$$= \sum_{q=1}^{n} |V_p||Y_{pq}||V_q| \cos\left(-\delta_p + \theta_{pq} + \delta_q\right) + j\sum_{q=1}^{n} |V_p||Y_{pq}||V_q| \sin\left(-\delta_p + \theta_{pq} + \delta_q\right)$$

$$= \sum_{q=1}^{n} |V_p||Y_{pq}||V_q| \cos\left(\theta_{pq} + \delta_q - \delta_p\right) + j\sum_{q=1}^{n} |V_p||Y_{pq}||V_q| \sin\left(\theta_{pq} + \delta_q - \delta_p\right)$$

Static Load Flow Equation (SLFE)

$$P_p - jQ_p = \sum_{q=1}^{n} |V_p||Y_{pq}||V_q| \cos(\theta_{pq} + \delta_q - \delta_p) + j\sum_{q=1}^{n} |V_p||Y_{pq}||V_q| \sin(\theta_{pq} + \delta_q - \delta_p)$$

Real and Reactive Powers can now be expressed as below and they are known as SLFE for n - bus system,

$$P_p = \sum_{q=1}^{n} |V_p||Y_{pq}||V_q| \cos(\theta_{pq} + \delta_q - \delta_p), \quad p = 1, 2, \ldots, n \qquad \text{Eq. (8.a)}$$

$$Q_p = -\sum_{q=1}^{n} |V_p||Y_{pq}||V_q| \sin(\theta_{pq} + \delta_q - \delta_p), \quad p = 1, 2, \ldots, n \qquad \text{Eq. (8.b)}$$

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.
  - Bus Voltage Magnitude (V)
  - Bus Voltage Phase Angles (δ)
  - MW and MVAR flows in the lines (P & Q)
- 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.

Classification of Buses

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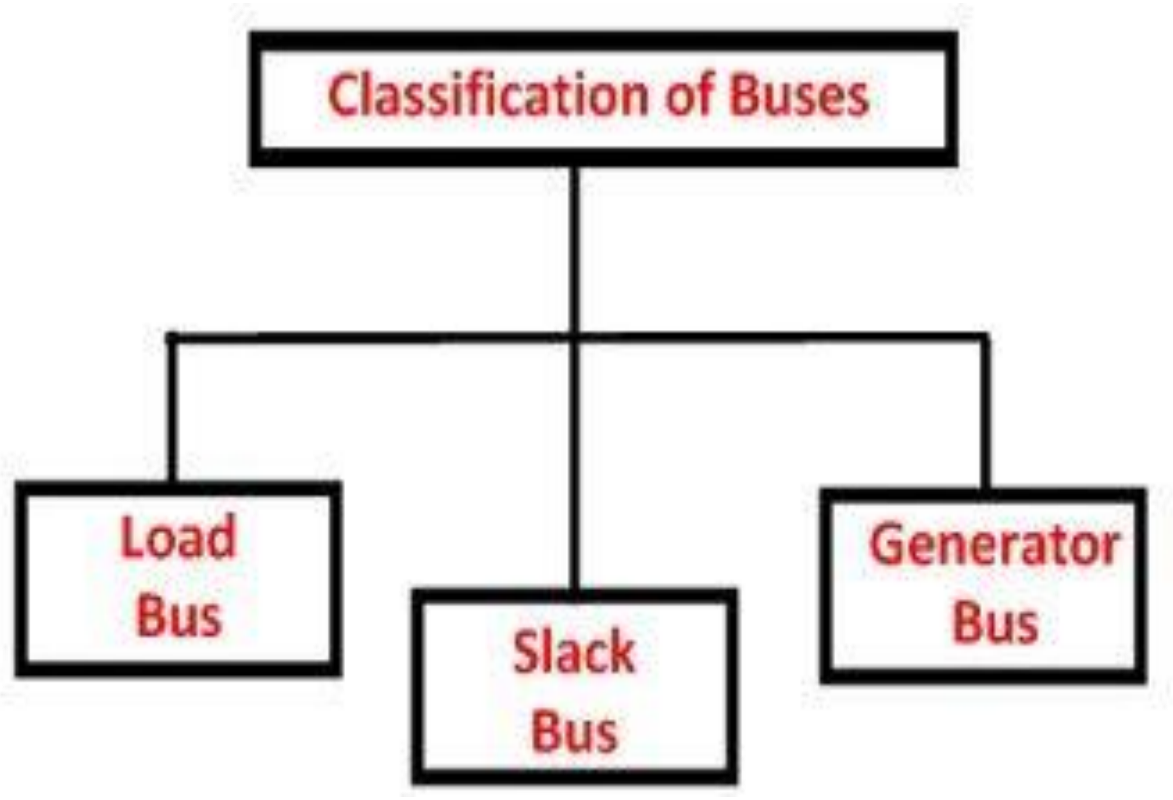
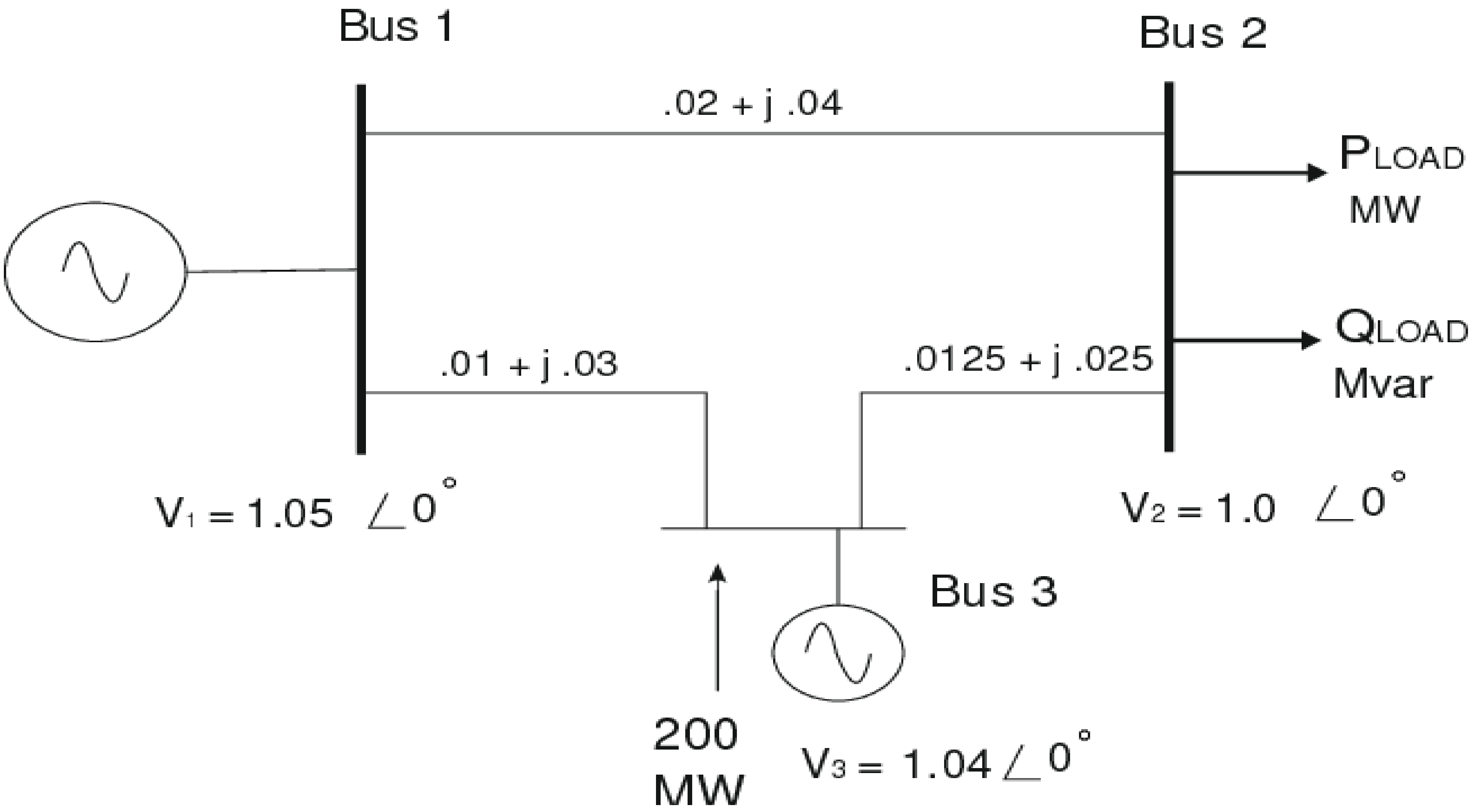


Classification of Buses

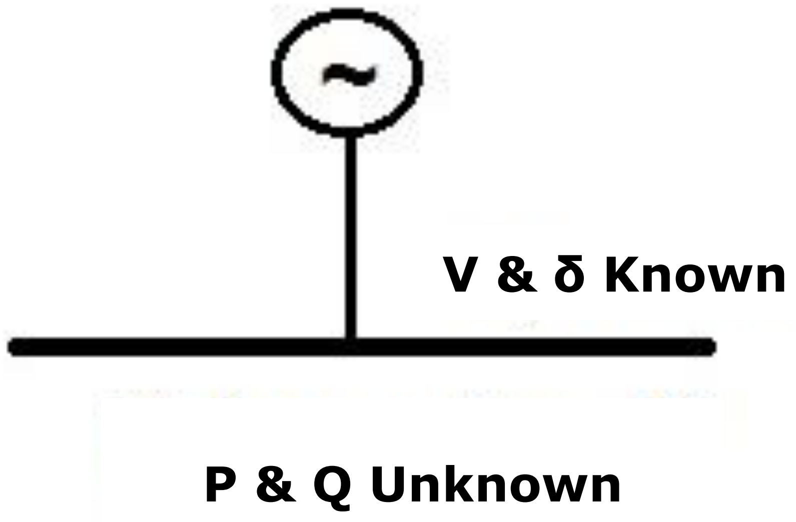


Classification of Buses

- **Slack Bus or Swing Bus or Reference Bus**
  - The swing bus is the first one to respond to a changing load condition.
  - Slack bus in a power system absorb or emit the active or reactive power from the power system.
  - The slack bus does not carry any load.
  - At this bus, the VOLTAGE MAGNITUDE (V) and PHASE ANGLE (δ) of the voltage are specified.
  - The phase angle (δ) of the voltage is usually set equal to zero.
  - The ACTIVE POWER (P) and REACTIVE POWER (Q) of this bus is usually determined through the solution of equations.

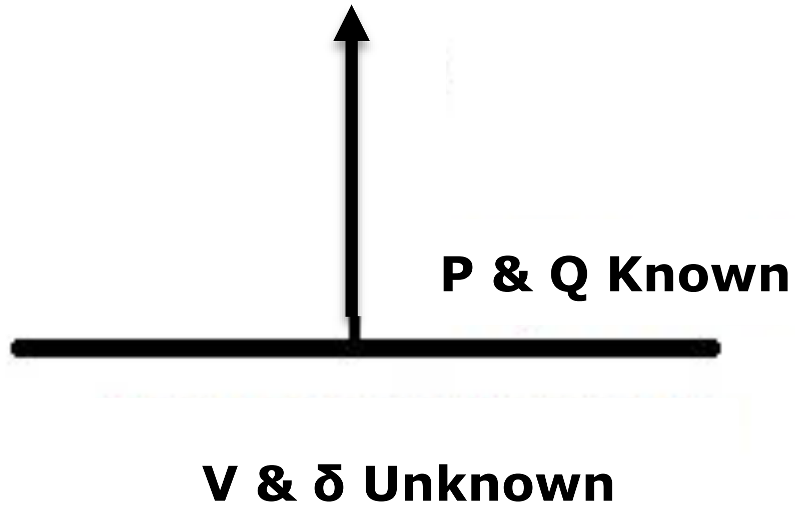
Classification of Buses

- **Slack Bus or Swing Bus or Reference Bus**
  - The slack bus is a fictional concept in load flow studies and arises because the 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.



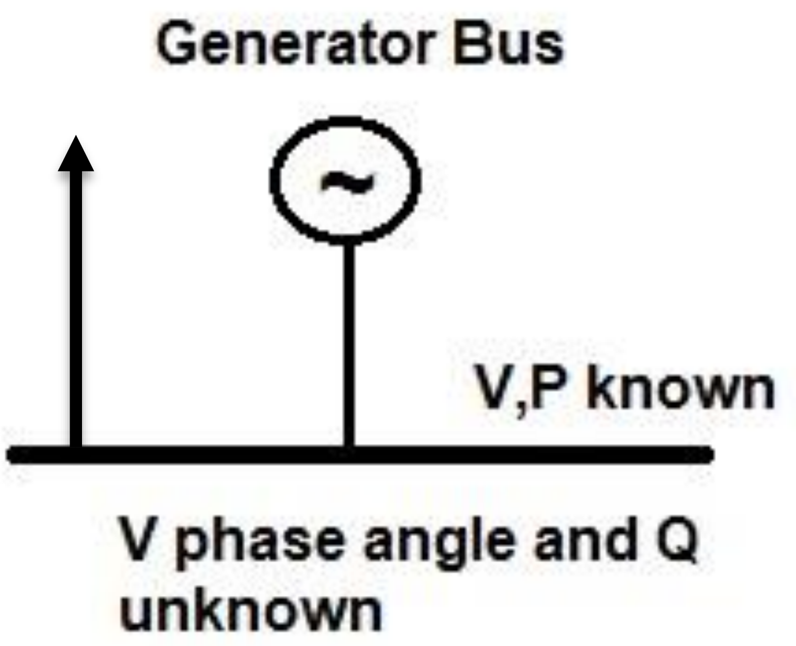
Classification of Buses

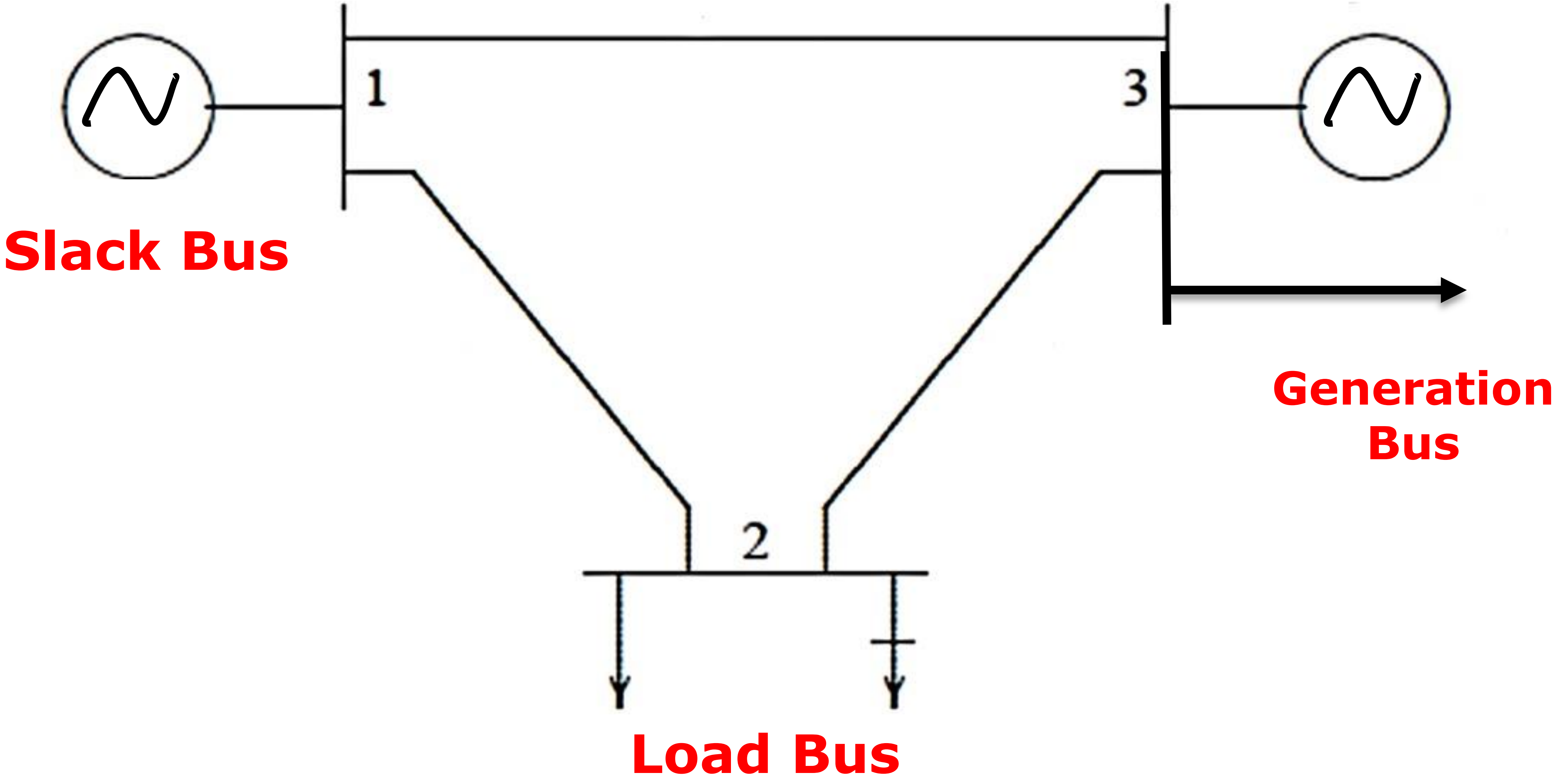
- **Load Bus**
  - This is also called the P-Q bus.
  - And at this bus, the ACTIVE POWER (P) and REACTIVE POWER (Q) is injected into the network.
  - The VOLTAGE MAGNITUDE (V) and PHASE ANGLE (δ) of the voltage are to be computed.
  - Here the active power and reactive power are specified, and the load 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.



Classification of Buses

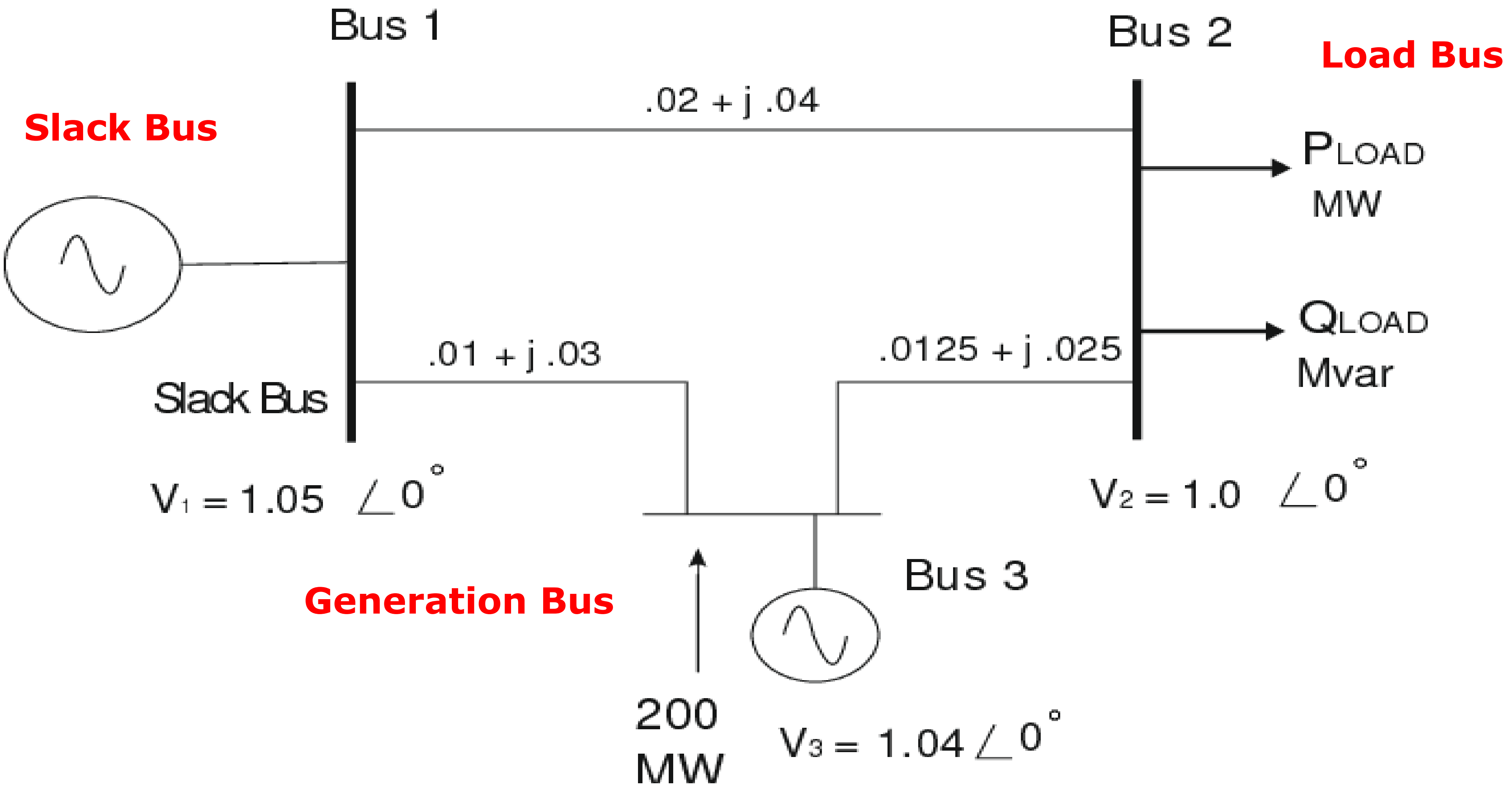
- **Generation Bus or Voltage Control Bus**
  - This bus is also called the P-V bus.
  - And on this bus, the VOLTAGE MAGNITUDE (V) corresponding to generate voltage and TRUE or ACTIVE POWER (P) corresponding to its rating are specified.
  - Voltage magnitude is maintained constant at a specified value by injection of reactive power.
  - The REACTIVE POWER GENERATION (Q) and PHASE ANGLE (δ) of the voltage are to be computed.





1
3
2
Slack Bus
Generation Bus
Load Bus

Classification of Buses



Classification of Buses

Sl. No.	Bus Types	Specified Variables	Unspecified variables	Remarks
1	Slack/ Swing Bus	$\|V\|$, δ	P_G, Q_G	$\|V\|$, δ: are assumed if not specified as 1.0 and 0^0
2	Generator/ Machine/ PV Bus	P_G, $\|V\|$	Q_G, δ	A generator is present at the machine bus
3	Load/ PQ Bus	P_G, Q_G	$\|V\|$, δ	About 80% buses are of PQ type
4	Voltage Controlled Bus	P_G,Q_G, $\|V\|$	δ, a	'a' is the % tap change in tap-changing transformer


Thank you