PER UNIT SYSTEM

Per unit system

- It is basically normalization of various voltage levels and various capacity equipments.
- Per unit value of any quantity is defined as :

  Actual value in any unit /the base or reference value in the same unit.
- Percent value
- Basic quantities in electrical engg. are

(i) Voltage
(ii) Current
(iii) Impedance
(iv) and power

PU System

$$PU\,Value = \frac{Actual\ \ Quantity}{Base\ \ Quantity}$$

$$I_{base} = \frac{[VA]_{base}}{[V]_{base}}$$

$$P_{base} = Q_{base} = |S_{base}| = [VA]_{base} = [V]_{base}[I]_{base}$$

$$R_{base} = X_{base} = |Z_{base}| = \frac{[V]_{base}}{[I]_{base}} = \frac{[V]_{base}^{2}}{S_{base}} = \frac{[V]_{base}^{2}}{[VA]_{base}}$$

$$Y_{base} = \frac{[I]_{base}}{[V]_{base}}$$

$$|Z|_{PU} = \frac{|Z|_{ohm}}{|Z_{base}|}$$

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$$|Z|_{PU} = \frac{|Z|_{ohm}}{|Z_{base}|}$$

Advantages of per unit value system

- By proper specifying base values , the transformer equivalent circuit can be simplified.

  Such that voltage currents , external impedances and admittances expressed in per unit do not change when they are referred from one side of a transformer to the others.
- P U quantity is dimensionless.
- Base value is always a real number. There for angle of the per unit value is the same as the angle of actual value.
- Quantities fall in narrow range by using p.u. system

Types of buses

SLACK BUS

- Slack Bus /swing Bus/ reference bus:Voltage magnitude and voltage phase angleare specified.Normally voltage magnitude is set to 1 pu and voltage angle is set to zero.
- The real and reactive powers are not specified.
- In load flow study, real nd reactive power cannot be fixed at all the buses. As the net complex power flow into the network is not known in advance. So, the system power losses are unknown till the load flow study is complete.

PQ BUS/PV BUS

- A pure load bus is PQ bus.The known variables on bus are real power P_i and reactive power Q_i.
- The unknown variables are V_i and voltage angle δ_i.The PQ buses are the most common comprising almost 85% of all the buses in a given power system.
- A generator is always connected to a PV bus. Hence the net power P_i,and the voltage magnitude V_i are known.PV buses comprise about 15% of all the buses in a power system.

Voltage controlled buses

- Voltage controlled bus has voltage controlled capabilities and uses a tap adjustable transformer. And /or a static VAR compensator instead of generator.

Limits:

- All the state and control variables must be within the specified limits.are called operating constraints.
- Voltage magnitude Vi ust satisfy the enquality..
- Certain value of teh volatge angles δi must satisfy the inequality.this constraint limits the maximum permissible power angle of transmission line connecting buses i and k and is imposed by consideration of stability.

LOAD FLOW ANALYSIS

Importance/Significance of Load flow Analysis

- Load flow analysis is the backbone of PSA.
- It is required for Planning, Operation, Economic Scheduling & Exchange of power b/w utilities . Expansion of system & also in design stage.

- Steady-state analysis, of an interconnected PS during normal operating conditions.
- Compute steady-state voltage & voltage angle b/w all buses in n/w.

- Real & Reactive power flow in every Tr. line and transformers under the assumption of known values of generation & load

Methods used for LFA

- Gauss- Seidel Load Flow Method
- Newton- Raphson Load Flow Method
- Fast-Decouple Load Flow Method

Gauss-Seidel Algorithm

1. Form Y bus matrix
2. Assume, $V_k = V_{k(spec)} \angle 0^o$ at all generator buses.
3. Assume , $V_k = 1 \angle 0^o = 1+j0$ at all load buses.
4. Iteration count setting (iter=1)
5. Let bus number i=1
6. If 'i' refer to generator bus go to step no.7,or else go to step 8
7. a. if 'i' refers to the slack bus go to step 9, or else go to step 7(b).

7. b. Compute Q_i using,

$$Q_i^{cal} = -\mathrm{Im}\left[\sum_{j=1}^{N} V_i^* Y_{ij} V_j\right]$$

$$Q_{Gi} = Q_i^{cal} + Q_{Li}$$

Contd…

Check for Q limit violation.

If $Q_{i(min)} < Q_{Gi} < Q_{i(max)}$, then $Q_{i(spec)} = Q_i^{cal}$

If $Q_{i(min)} < Q_{Gi}$, then $Q_{i(spec)} = Q_{i(min)} - Q_{Li}$

If $Q_{i(max)} < Q_{Gi}$, then $Q_{i(spec)} = Q_{i(max)} - Q_{Li}$

If Q_{limit} is violated , then treat this bus as P-Q bus till convergence is obtained

8. Compute Vi using the equation,

$$V_i^{new} = \frac{1}{Y_{ij}} \left[\frac{P_{i(spec)} - Q_{i(spec)}}{V_i^{old\,*}} - \sum_{i=1}^{j-1} Y_{ij} V_j^{new} - \sum_{i=j+1}^{n} Y_{ij} V_i^{old} \right]$$

9. If ‘i’ is less than number of buses, increment i by 1 and go to step 6.

Contd…

10. Compare two successive iteration values for Vi

   If $V_i^{new} - V_i^{old} <$ tolerance , go to step 12

11. Update new voltages as

$$V_i^{new} = V_i^{old} + \alpha (V_i^{new} - V_i^{old})$$

$$V_i^{old} = V_i^{new}$$

12. Compute relevant quantities

Slack bus power, $S_1 = P_i - j\,Q_i = V^* I = V_i^* \left[\sum_{j=1}^{N} Y_{ij} V_j \right]$

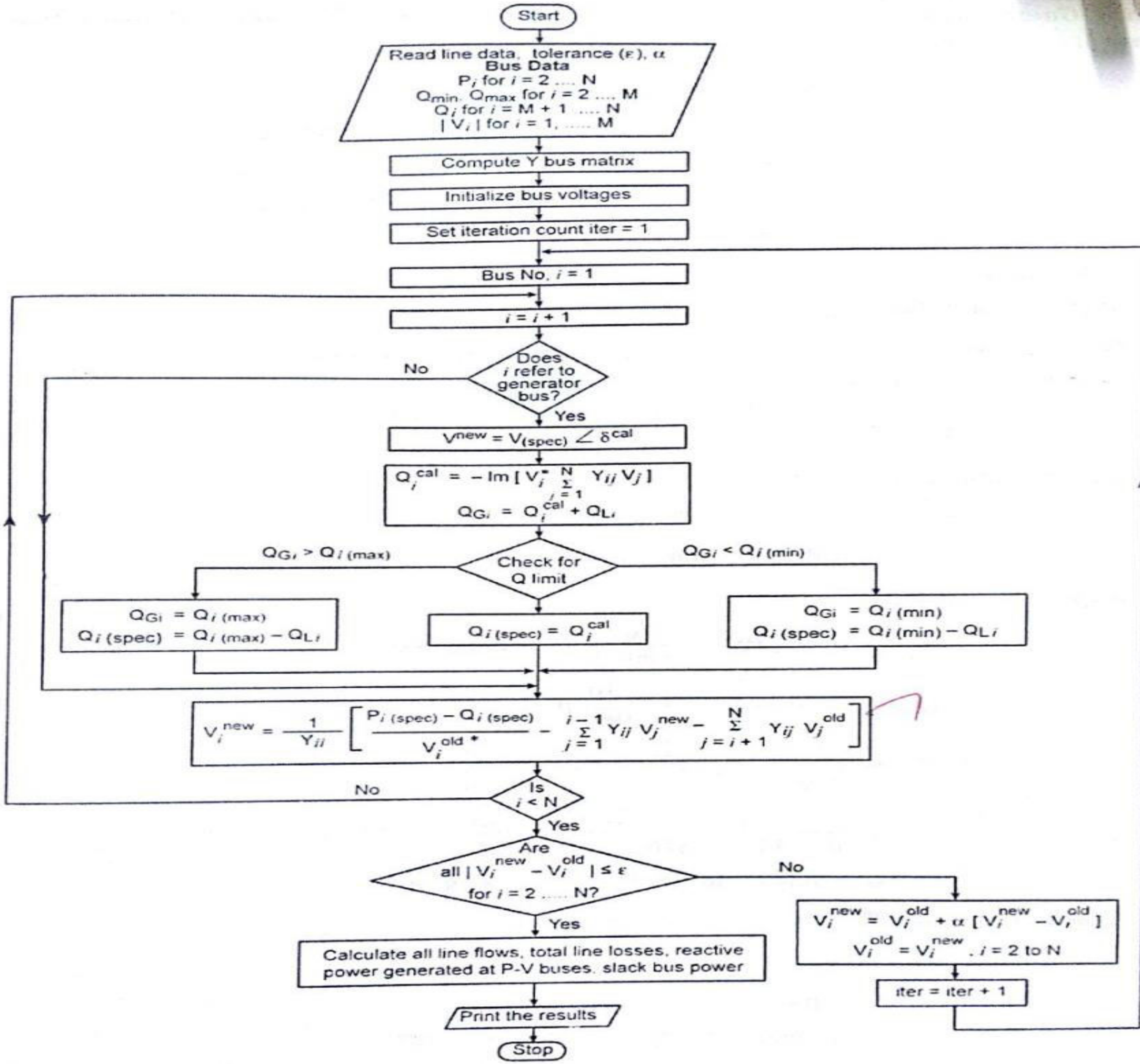
Line flow, $S_{ij} = P_{ij} + Q_{ij}$

$$= V_i [V_i^* - V_j^*] Y_{ij\,series}^* + |V_i|^2 \; Y_{ij}^*$$

$$P_{Loss} = P_{ij} + P_{ji}$$

$$Q_{Loss} = Q_{ij} + Q_{ji}$$

13. Stop the execution.


Start
Read line data, tolerance (ε), α
Bus Data
P_i for i = 2 .... N
Q_min, Q_max for i = 2 .... M
Q_i for i = M + 1 .... N
| V_i | for i = 1, ... M
Compute Y bus matrix
Initialize bus voltages
Set iteration count iter = 1
Bus No, i = 1
i = i + 1
Does i refer to generator bus?
No
Yes
V^new = V(spec) ∠ δ^cal
Q_i^cal = − Im [V_i* Σ_{j=1}^{N} Y_ij V_j]
Q_Gi = Q_i^cal + Q_Li
Check for Q limit
Q_Gi > Q_i (max)
Q_Gi < Q_i (min)
Q_Gi = Q_i (max)
Q_i (spec) = Q_i (max) − Q_Li
Q_i (spec) = Q_i^cal
Q_Gi = Q_i (min)
Q_i (spec) = Q_i (min) − Q_Li
V_i^new = 1/Y_ii [(P_i (spec) − Q_i (spec)) / V_i^old* − Σ_{j=1}^{i−1} Y_ij V_j^new − Σ_{j=i+1}^{N} Y_ij V_j^old]
Is i < N
No
Yes
Are all | V_i^new − V_i^old | ≤ ε for i = 2 ..... N?
No
Yes
V_i^new = V_i^old + α [V_i^new − V_i^old]
V_i^old = V_i^new , i = 2 to N
iter = iter + 1
Calculate all line flows, total line losses, reactive power generated at P-V buses, slack bus power
Print the results
Stop

Advantage of Gauss Seidel Method

- Calculation are simple.
- Programming task is lesser.
- Used for small size system.

Disadvantage of Gauss Seidel Method

- Not suitable for larger systems
- Required more no.of. iterations to reach convergence.
- Convergence time increases with size of the system.

Newton-Raphson Algorithm

1. Form Y-bus matrix
2. Assume flat start for starting voltage solution

$\delta i^{o} = 0$, for i=1,2,…N for all buses except slack bus

$|V i^{o}| = 1.0$, for i=M+1,M+2,….N (for all PQ bus.

$|V i| = |V i|$ (Spec) , for all PV buses and Slack bus.

3. For load bus, calculate $P i^{cal}$ and $Q i^{cal}$
4. For PV buses, check Q-limit violation .

If $Q_{i(min)} < Q i^{cal} < Q_{i(max)}$, the bus acts as P-V bus.

If $Q i^{cal} > Q i(max)$, $Q i(spec)=Q i(min)$

If $Q i^{cal} < Q_{i(min)}$, $Q_{i(spec)} = Q_{i(min)}$, the P-V bus will act as P-Q bus.

5. Compute mismatch vector using,

$$\Delta P i = P_{i(spec)} - P_i^{cal}$$

$$\Delta Q_i = Q_{i(spec)} - Q_i^{cal}$$

Contd….

6. Compute $\Delta P_i(\max) = \max |\Delta P_i|, \quad i=1,2,\ldots N(\text{except Slack bus})$

$\Delta Q_i(\max) = \max |\Delta Q_i|, \quad i=M+1\ldots.N$

7. Compute Jacobian matrix using,

$$J = \begin{pmatrix} \dfrac{\partial P_i}{\partial \delta} & |V| \cdot \dfrac{\partial P_i}{\partial |V|} \\ \dfrac{\partial Q_i}{\partial \delta} & |V| \cdot \dfrac{\partial Q_i}{\partial |V|} \end{pmatrix}$$

8. Obtain static correction vector using

$$\begin{pmatrix} \Delta \delta \\ \dfrac{\Delta V}{|V|} \end{pmatrix} = [J]^{-1} \begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix}$$

Contnd….

9. Update state vector using,

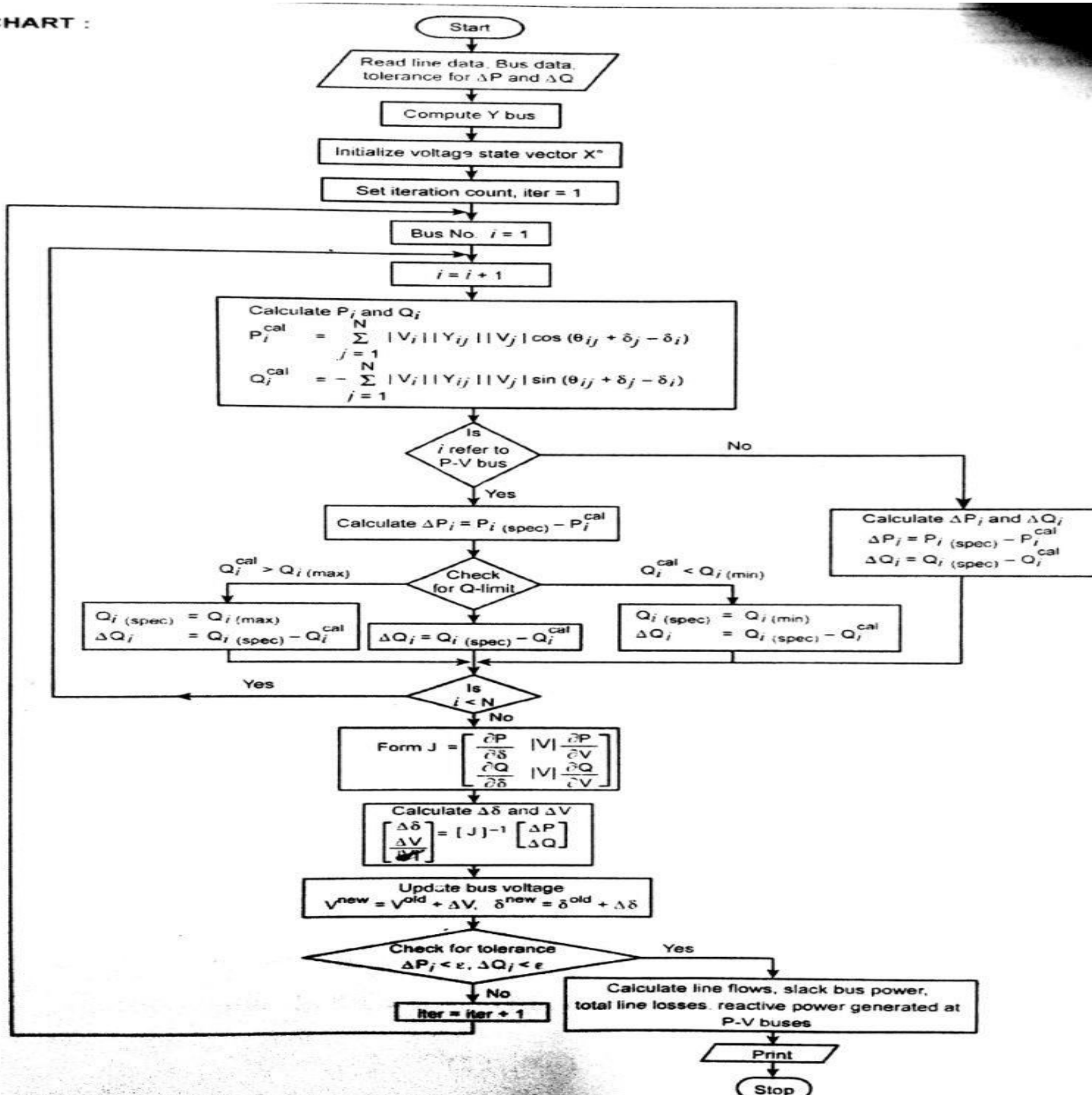
$$V^{new} = V^{old} + \Delta V$$
$$= V^{old} + [\,\Delta V / |V^{old}|\,]$$
$$= V^{old} + [1 + \{\Delta V / |V^{old}|\,\}]$$

$$\delta = \boldsymbol{\delta}^{old} + \Delta\boldsymbol{\delta}$$

10. This procedure is continued until,

$|\Delta Pi| < \varepsilon$ and $|\Delta Q_i| < \varepsilon$, otherwise go to step 3.

OW CHART :


Start
Read line data, Bus data, tolerance for ΔP and ΔQ
Compute Y bus
Initialize voltage state vector X°
Set iteration count, iter = 1
Bus No. i = 1
i = i + 1
Calculate P_i and Q_i
P_i^cal = Σ_{j=1}^{N} |V_i||Y_ij||V_j| cos (θ_ij + δ_j − δ_i)
Q_i^cal = − Σ_{j=1}^{N} |V_i||Y_ij||V_j| sin (θ_ij + δ_j − δ_i)
Is i refer to P-V bus
No
Yes
Calculate ΔP_i = P_i (spec) − P_i^cal
Calculate ΔP_i and ΔQ_i
ΔP_i = P_i (spec) − P_i^cal
ΔQ_i = Q_i (spec) − Q_i^cal
Q_i^cal > Q_i (max)
Check for Q-limit
Q_i^cal < Q_i (min)
Q_i (spec) = Q_i (max)
ΔQ_i = Q_i (spec) − Q_i^cal
ΔQ_i = Q_i (spec) − Q_i^cal
Q_i (spec) = Q_i (min)
ΔQ_i = Q_i (spec) − Q_i^cal
Yes
Is i < N
No
Form J = [∂P/∂δ |V| ∂P/∂V ; ∂Q/∂δ |V| ∂Q/∂V]
Calculate Δδ and ΔV
[Δδ ; ΔV/V] = [J]^−1 [ΔP ; ΔQ]
Update bus voltage
V^new = V^old + ΔV, δ^new = δ^old + Δδ
Check for tolerance ΔP_i < ε, ΔQ_i < ε
Yes
No
iter = iter + 1
Calculate line flows, slack bus power, total line losses, reactive power generated at P-V buses
Print
Stop

References

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