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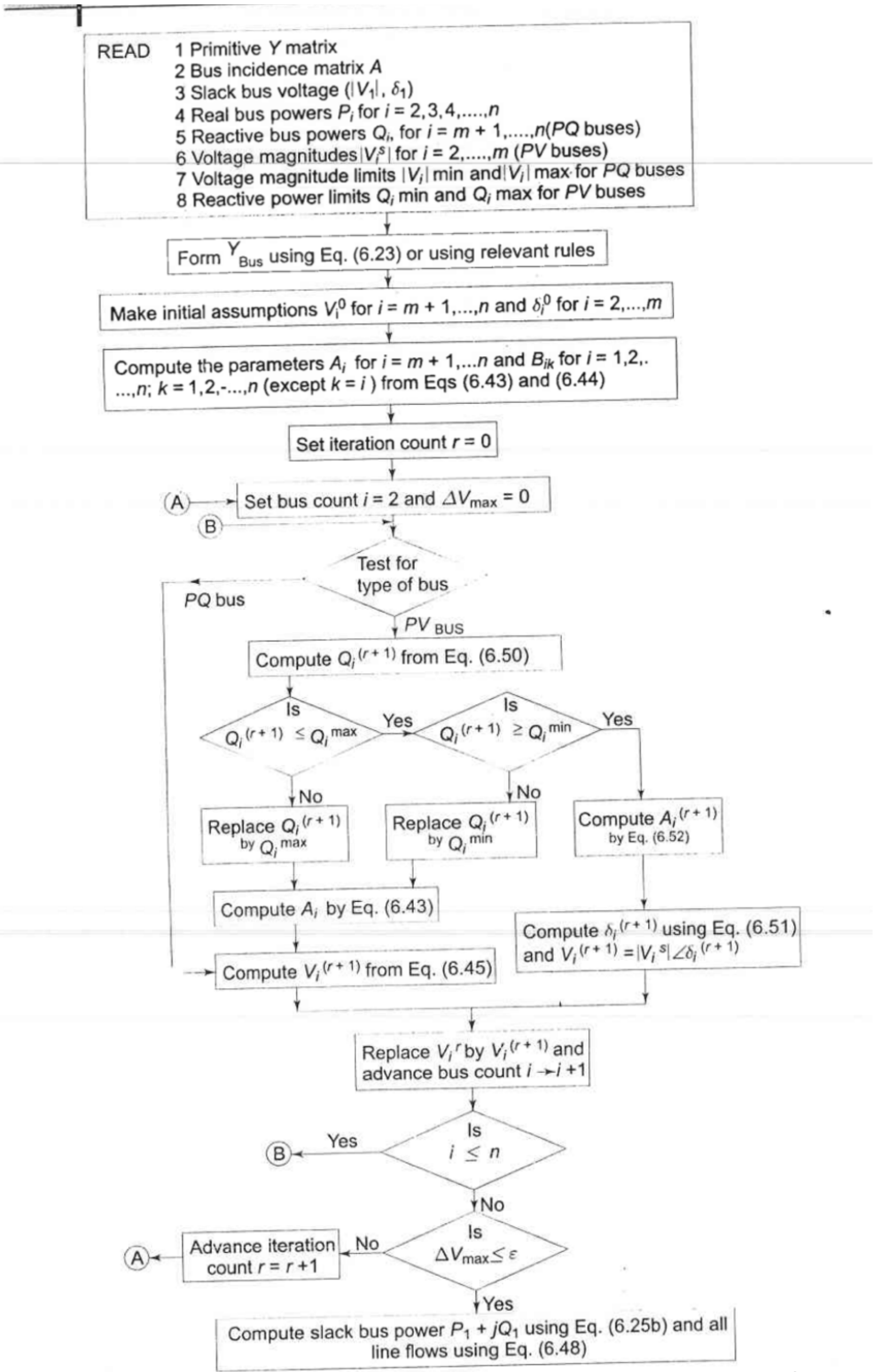
Internal Assesment Test I – July - 2024

Sub:	Power System Analysis - II						Code:	21EE62
Date:	11/07/2024	Duration:	90 Min	Max Marks:	50	Sem: 6	Section:	A & B

Note: Answer any **FIVE FULL** Questions & Sketch Neat Figures Wherever Necessary.

		Marks	OBE CO	OBE RBT
1	For a three bus system shown in figure the elements of diagonal are 5.868 – j23.514 pu and off diagonal elements are – 2.9 + j 11.767 pu. Reactive power limits at bus 3 are $0 \leq Q3 \leq 1.5$ pu. Determine whether bus 3 continues as PV Bus and thereafter determine the estimate of the voltage and phase angles at bus 3 using GS Method.  **Fig. 6.9** Flow chart for load flow solution by the Gauss-Seidel iterative method using Y_{BUS}	[10]	CO2	L3

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Starting from the assumptions made deduce the fast decoupled load flow model.

[6] CO2 L1

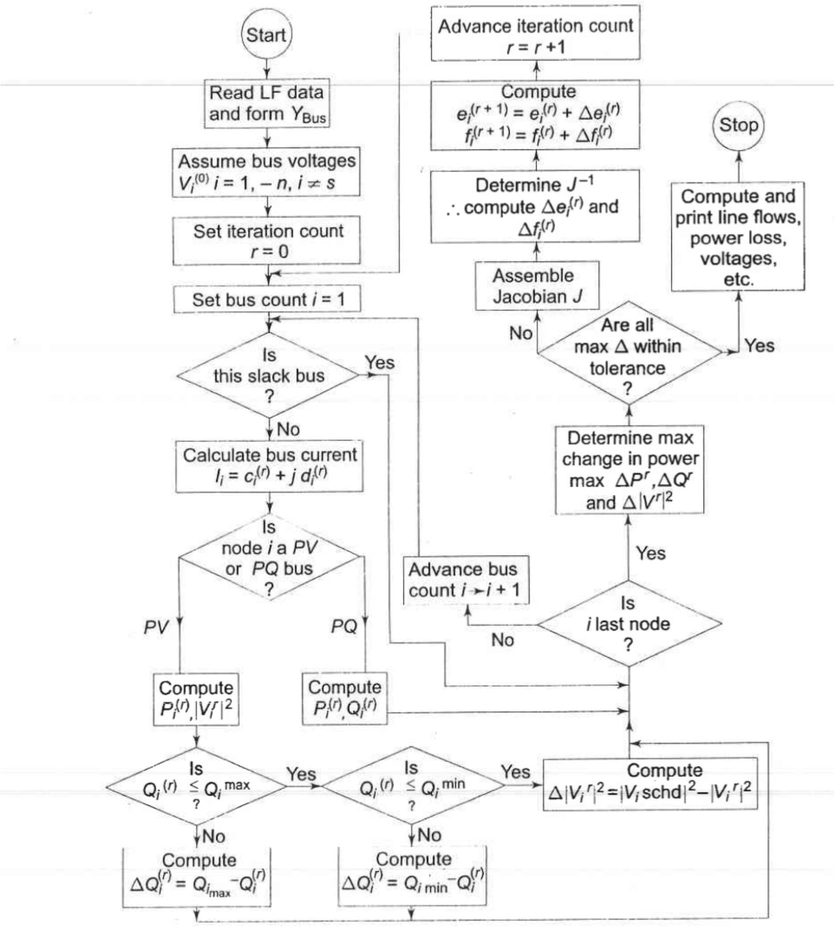


Fig. 6.12

$$\cos\,\delta_{ij} \approx 1;$$

$$\sin\,\delta_{ij} \approx 0$$

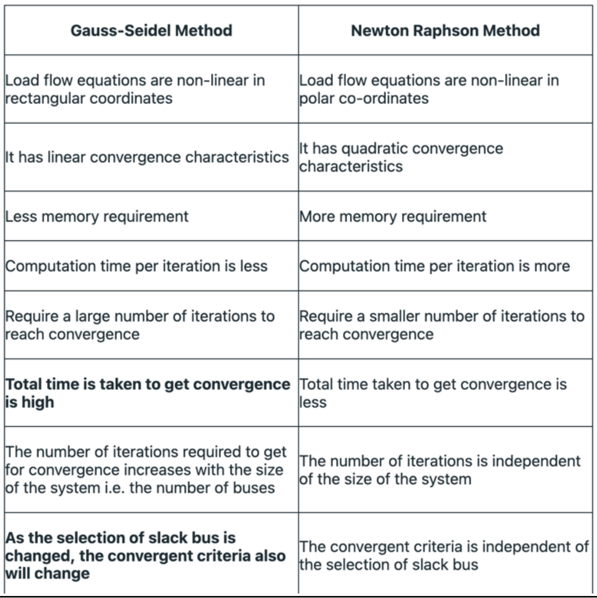
$$G_{ij}\,\sin\,\delta_{ij} \ll B_{ij}; \qquad (6.81$$

and

$$Q_i \ll B_{ii}\,|V_i|^2$$

Compare GSM, NR LFMs with respect to time, iteration, number of iterations, solution time, convergence characteristics.

[4] CO2 L1



Gauss-Seidel Method	Newton Raphson Method
Load flow equations are non-linear in rectangular coordinates	Load flow equations are non-linear in polar co-ordinates
It has linear convergence characteristics	It has quadratic convergence characteristics
Less memory requirement	More memory requirement
Computation time per iteration is less	Computation time per iteration is more
Require a large number of iterations to reach convergence	Require a smaller number of iterations to reach convergence
Total time is taken to get convergence is high	Total time taken to get convergence is less
The number of iterations required to get for convergence increases with the size of the system i.e. the number of buses	The number of iterations is independent of the size of the system
As the selection of slack bus is changed, the convergent criteria also will change	The convergent criteria is independent of the selection of slack bus

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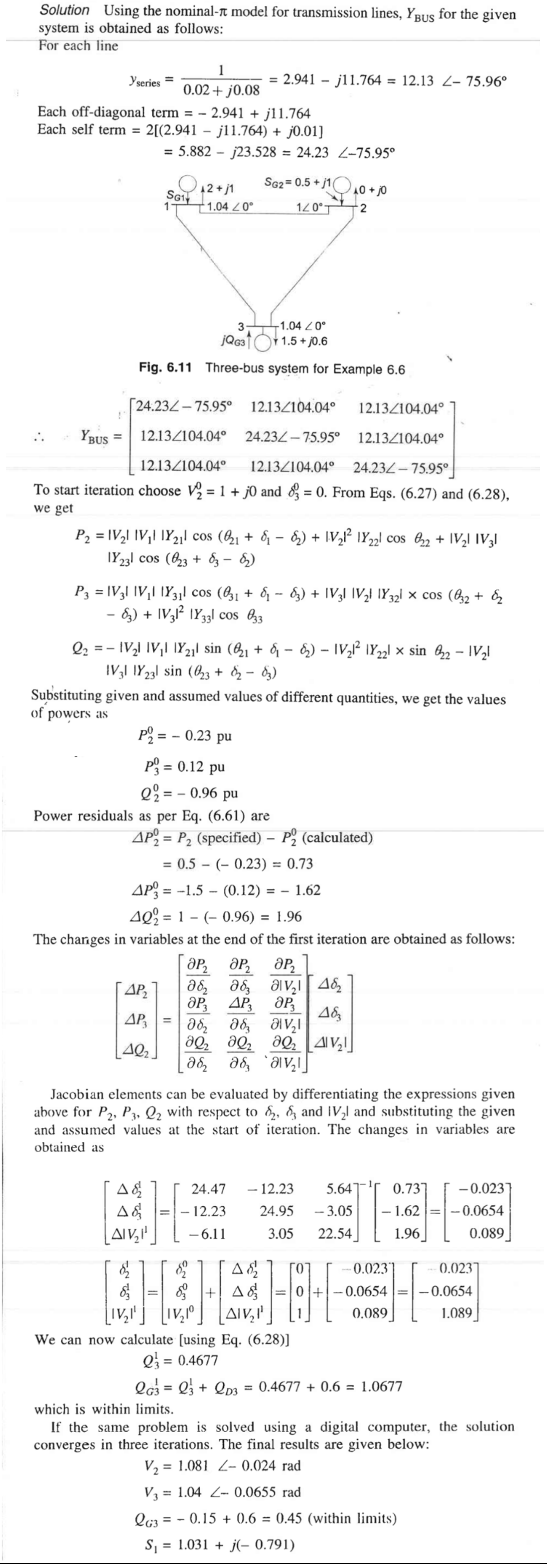
For a three bus system shown in figure the elements of diagonal are 5.868 – j23.514 pu and off diagonal elements are – 2.9 + j 11.767 pu. Reactive power limits at bus 3 are 0 ≤ Q3 ≤ 1.5 pu. Determine whether bus 3 continues as PV Bus and thereafter determine the estimate of the voltage and phase angles at bus 3 using NR Method.



Solution Using the nominal-π model for transmission lines, Y_{BUS} for the given system is obtained as follows:
For each line

$$y_{\text{series}} = \frac{1}{0.02 + j0.08} = 2.941 - j11.764 = 12.13\ \angle -75.96^\circ$$

Each off-diagonal term = – 2.941 + j11.764
Each self term = 2[(2.941 – j11.764) + j0.01]
= 5.882 – j23.528 = 24.23 ∠–75.95°

Fig. 6.11 Three-bus system for Example 6.6

$$\therefore \quad Y_{BUS} = \begin{bmatrix} 24.23\angle -75.95^\circ & 12.13\angle 104.04^\circ & 12.13\angle 104.04^\circ \\ 12.13\angle 104.04^\circ & 24.23\angle -75.95^\circ & 12.13\angle 104.04^\circ \\ 12.13\angle 104.04^\circ & 12.13\angle 104.04^\circ & 24.23\angle -75.95^\circ \end{bmatrix}$$

To start iteration choose $V_2^0 = 1 + j0$ and $\delta_3^0 = 0$. From Eqs. (6.27) and (6.28), we get

$$P_2 = |V_2|\,|V_1|\,|Y_{21}| \cos(\theta_{21} + \delta_1 - \delta_2) + |V_2|^2 |Y_{22}| \cos \theta_{22} + |V_2|\,|V_3|\,|Y_{23}| \cos(\theta_{23} + \delta_3 - \delta_2)$$

$$P_3 = |V_3|\,|V_1|\,|Y_{31}| \cos(\theta_{31} + \delta_1 - \delta_3) + |V_3|\,|V_2|\,|Y_{32}| \times \cos(\theta_{32} + \delta_2 - \delta_3) + |V_3|^2 |Y_{33}| \cos \theta_{33}$$

$$Q_2 = -|V_2|\,|V_1|\,|Y_{21}| \sin(\theta_{21} + \delta_1 - \delta_2) - |V_2|^2 |Y_{22}| \times \sin \theta_{22} - |V_2|\,|V_3|\,|Y_{23}| \sin(\theta_{23} + \delta_2 - \delta_3)$$

Substituting given and assumed values of different quantities, we get the values of powers as

$$P_2^0 = -0.23 \text{ pu}$$

$$P_3^0 = 0.12 \text{ pu}$$

$$Q_2^0 = -0.96 \text{ pu}$$

Power residuals as per Eq. (6.61) are

$$\Delta P_2^0 = P_2 \text{ (specified)} - P_2^0 \text{ (calculated)}$$

$$= 0.5 - (-0.23) = 0.73$$

$$\Delta P_3^0 = -1.5 - (0.12) = -1.62$$

$$\Delta Q_2^0 = 1 - (-0.96) = 1.96$$

The changes in variables at the end of the first iteration are obtained as follows:

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \Delta Q_2 \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} & \frac{\partial P_2}{\partial |V_2|} \\ \frac{\partial P_3}{\partial \delta_2} & \frac{\Delta P_3}{\partial \delta_3} & \frac{\partial P_3}{\partial |V_2|} \\ \frac{\partial Q_2}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_3} & \frac{\partial Q_2}{\partial |V_2|} \end{bmatrix} \begin{bmatrix} \Delta \delta_2 \\ \Delta \delta_3 \\ \Delta |V_2| \end{bmatrix}$$

Jacobian elements can be evaluated by differentiating the expressions given above for P_2, P_3, Q_2 with respect to δ_2, δ_3 and $|V_2|$ and substituting the given and assumed values at the start of iteration. The changes in variables are obtained as

$$\begin{bmatrix} \Delta \delta_2^1 \\ \Delta \delta_3^1 \\ \Delta |V_2|^1 \end{bmatrix} = \begin{bmatrix} 24.47 & -12.23 & 5.64 \\ -12.23 & 24.95 & -3.05 \\ -6.11 & 3.05 & 22.54 \end{bmatrix}^{-1} \begin{bmatrix} 0.73 \\ -1.62 \\ 1.96 \end{bmatrix} = \begin{bmatrix} -0.023 \\ -0.0654 \\ 0.089 \end{bmatrix}$$

$$\begin{bmatrix} \delta_2^1 \\ \delta_3^1 \\ |V_2|^1 \end{bmatrix} = \begin{bmatrix} \delta_2^0 \\ \delta_3^0 \\ |V_2|^0 \end{bmatrix} + \begin{bmatrix} \Delta \delta_2^1 \\ \Delta \delta_3^1 \\ \Delta |V_2|^1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} + \begin{bmatrix} -0.023 \\ -0.0654 \\ 0.089 \end{bmatrix} = \begin{bmatrix} -0.023 \\ -0.0654 \\ 1.089 \end{bmatrix}$$

We can now calculate [using Eq. (6.28)]

$$Q_3^1 = 0.4677$$

$$Q_{G3}^1 = Q_3^1 + Q_{D3} = 0.4677 + 0.6 = 1.0677$$

which is within limits.

If the same problem is solved using a digital computer, the solution converges in three iterations. The final results are given below:

$$V_2 = 1.081\ \angle -0.024 \text{ rad}$$

$$V_3 = 1.04\ \angle -0.0655 \text{ rad}$$

$$Q_{G3} = -0.15 + 0.6 = 0.45 \text{ (within limits)}$$

$$S_1 = 1.031 + j(-0.791)$$

[10] CO3 L3

4

What is the data required to conduct load flow analysis? Discuss the operating constraints considered during the load flow analysis

2.3.1 Data at the Buses

In general, a bus in an electrical power system is fed from generating units which inject active and reactive powers into it and loads receive active and reactive powers from it. In the load flow studies, the generator and load (complex) powers are lumped into a net (complex) power. This net (complex) power is called the bus injected power.

The net power injected in the bus is given by

$$S_i = P_i + jQ_i = (P_G + jQ_G) - (P_D + jQ_D)$$

$$\therefore \quad S_i = (P_G - P_D) + j\,(Q_G - Q_D).$$

where P_G, Q_G = Generation real and reactive powers

P_D, Q_D = Load real and reactive powers

P_i, Q_i = Injected real and reactive powers

In addition to the above quantities, magnitude and phase angle of the voltage are also associated with each bus of the four quantities at a bus, *viz.*, active bus power, reactive bus power, bus voltage magnitude and bus voltage phase angle, two quantities are specified, the remaining two quantities to be obtained through the load flow solution. When all the four quantities at every bus in the power system are known, active and reactive power flows in all the transmission lines can be calculated.

2.3.2 Representation of Transmission Lines

Since the load flow study is an aspect of the symmetrical steady state operation, the three phase system is solved on per phase basis. Also, only positive sequence equivalent circuits of the system elements are considered.

The network model of a power system, it is sufficiently accurate to represent a short line by a series impedance and a long line by a nominal π model.

2.3.3 Representation of Transformers

A power transformer without tap-changing facility is represented by a lumped series positive impedance. The transformers with tap changing facility and the phase shifting transformers are discussed below:

2.3.3.1 Fixed tap setting transformers: A transformer with a fixed tap setting and connected between buses '*p*' and '*q*' is represented by its positive sequence series impedance /admittance in series with an ideal auto transformer having a turns ratio of *a* : 1 as shown in Fig. 2.1.

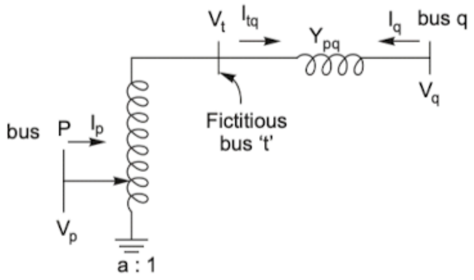


Fig. 2.1 *Transformer with a fixed tap setting*

[10] CO1 L2

From the Fig. 2.1,

$$\frac{V_p}{V_t} = \frac{I_{tq}}{I_p} = a \qquad \ldots(2.1)$$

and

$$I_{tq} = (V_t - V_q)\, Y_{pq} \qquad \ldots(2.2)$$

From equations (2.1) and (2.2)

$$I_p = \frac{I_{tq}}{a} = \frac{(V_t - V_q)}{a}\, Y_{pq} \qquad \ldots(2.3)$$

and

$$V_t = \frac{V_p}{a} \qquad \ldots(2.4)$$

Substituting V_t from equation (2.4) in equation (2.3)

$$\therefore \quad I_p = \left(\frac{V_p}{a} - V_q\right) \frac{Y_{pq}}{a} \qquad \ldots(2.5)$$

Similarly

$$I_q = (V_q - V_t)\, Y_{pq}$$

$$= (aV_q - V_p)\, \frac{Y_{pq}}{a} \qquad \ldots(2.6)$$

The above transformer connected between the buses '*p*' and '*q*' is represented by an equivalent π model as shown in Fig. 2.2.

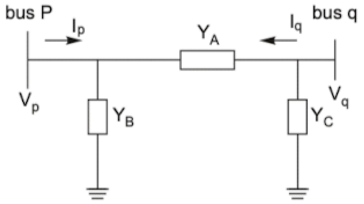


Fig. 2.2 *π-equivalent model*

From Fig. 2.2,

$$I_p = (V_p - V_q)\, Y_A + V_p\, Y_B \qquad \ldots(2.7)$$

and

$$I_q = (V_q - V_p)\, Y_A + V_q\, Y_C \qquad \ldots(2.8)$$

Solving equations (2.5) to (2.8), we get

$$Y_A = \frac{Y_{pq}}{a},\ Y_B = \frac{1}{a}\left(\frac{1}{a} - 1\right) Y_{pq}$$

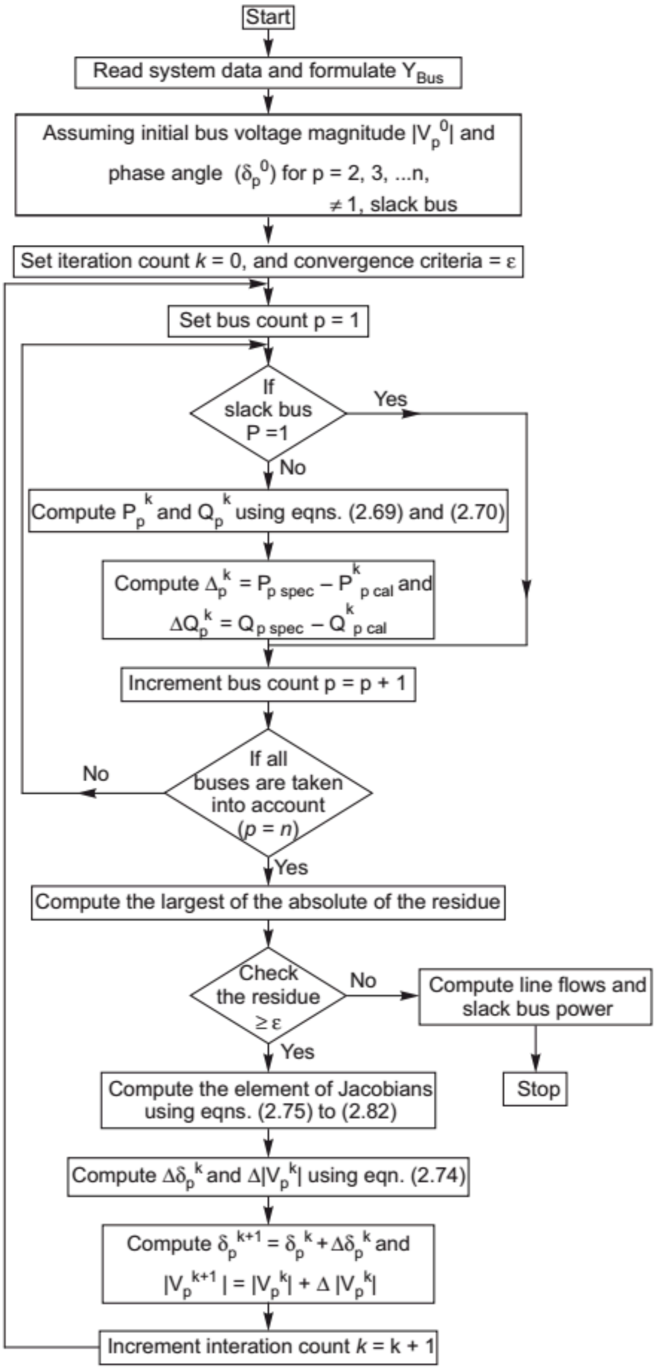
and

$$Y_C = \left(1 - \frac{1}{a}\right) Y_{pq} \qquad \ldots(2.9)$$

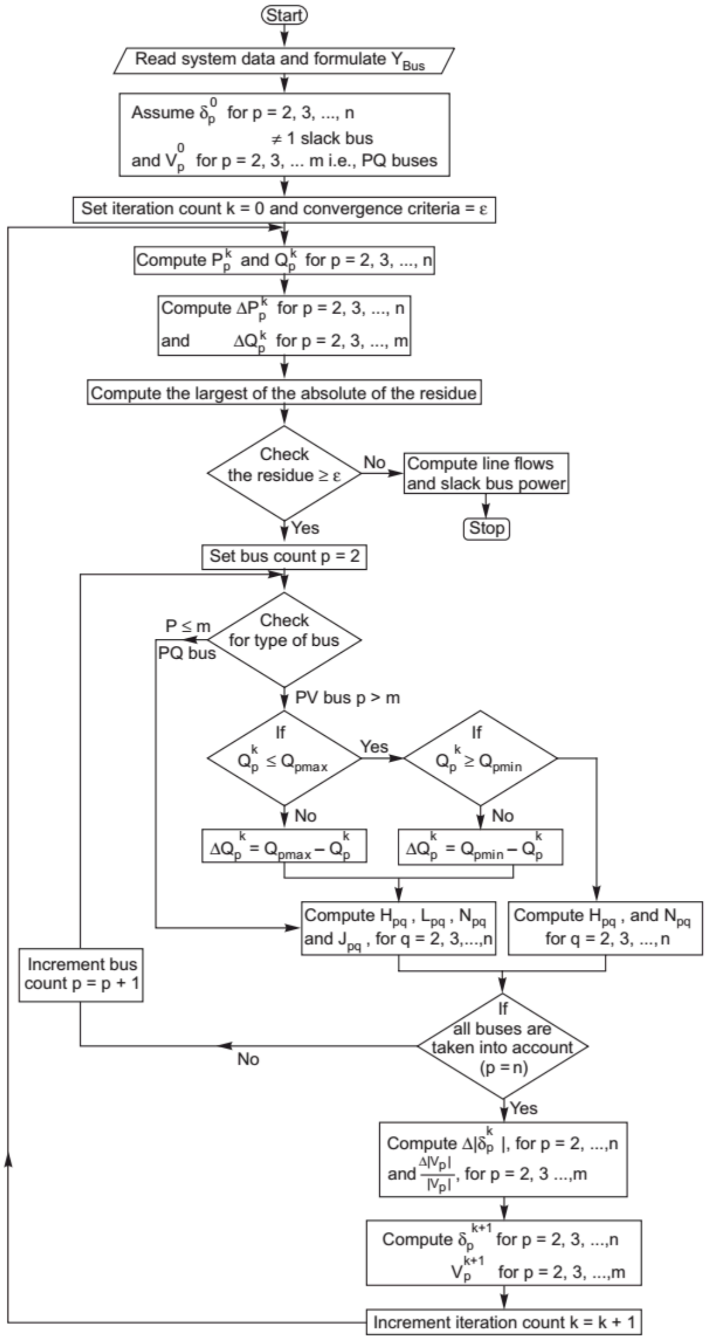
The mathematical model given in equation (2.9) is used to represent a transformer with fixed tap setting in load flow studies.

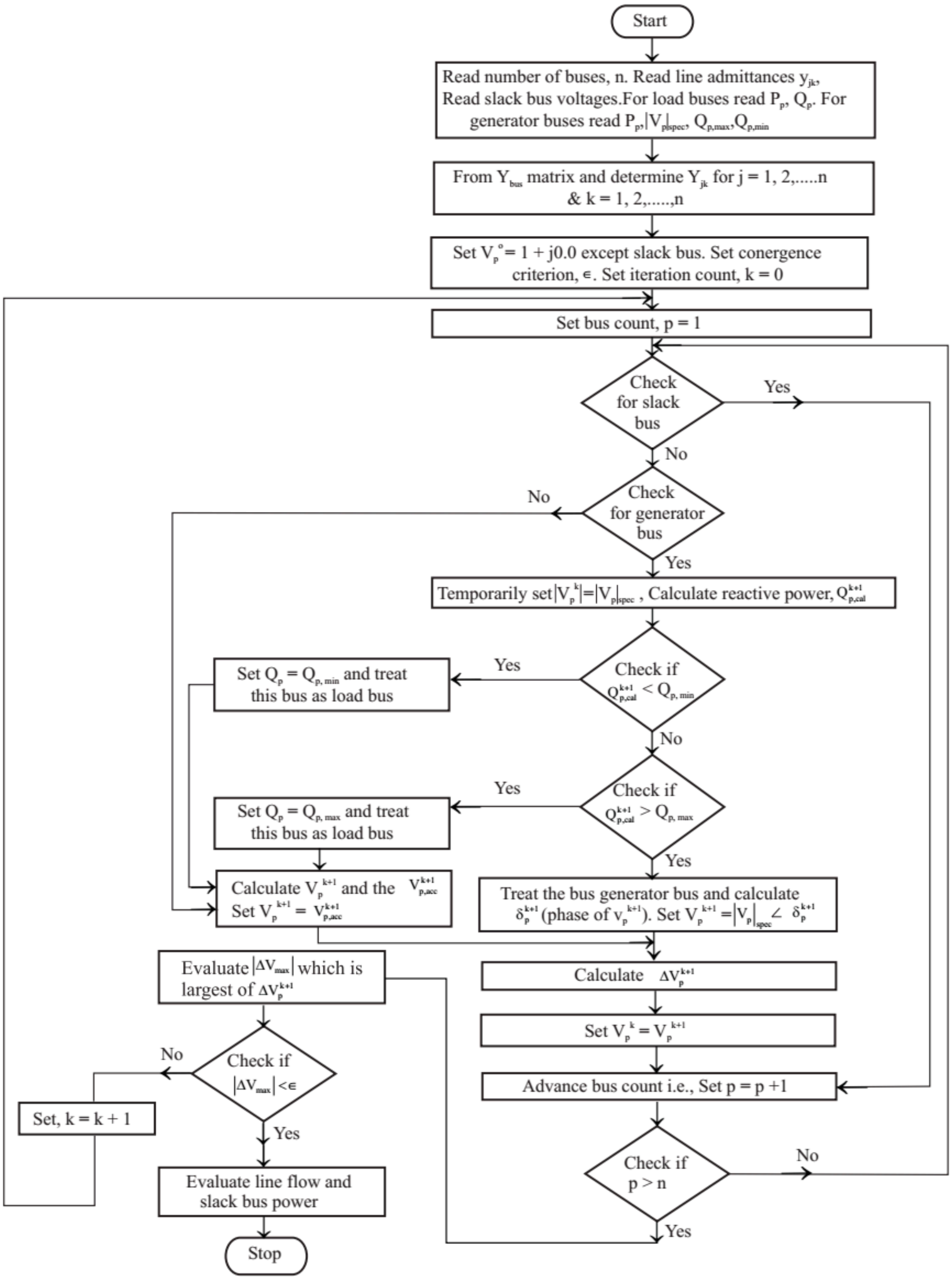
2.3.3.2 Tap changing under load transformer: In the case of a tap changing under load (TCUL) transformer, the tapping is changed *i.e.*, the value of '*a*'is varied to maintain the voltage magnitude within the specified tolerances. The load flow equations are solved by numerical methods involving a certain number of iterations. The value of '*a*' is changed normally once in two iterations, in this type of transformer also represented by an equivalent π model.

5	Explain the algorithm with equations how the load flow analysis is carried out using NR Method	[10]	CO1	L2

Start
Read system data and formulate Y_{Bus}
Assuming initial bus voltage magnitude $|V_p^0|$ and phase angle (δ_p^0) for p = 2, 3, ...n, $\neq 1$, slack bus
Set iteration count $k = 0$, and convergence criteria = ε
Set bus count p = 1
If slack bus P =1
Yes
No
Compute P_p^k and Q_p^k using eqns. (2.69) and (2.70)
Compute $\Delta_p^k = P_{p\,spec} - P^k_{p\,cal}$ and $\Delta Q_p^k = Q_{p\,spec} - Q^k_{p\,cal}$
Increment bus count p = p + 1
If all buses are taken into account ($p = n$)
No
Yes
Compute the largest of the absolute of the residue
Check the residue $\geq \varepsilon$
No
Compute line flows and slack bus power
Stop
Yes
Compute the element of Jacobians using eqns. (2.75) to (2.82)
Compute $\Delta\delta_p^k$ and $\Delta|V_p^k|$ using eqn. (2.74)
Compute $\delta_p^{k+1} = \delta_p^k + \Delta\delta_p^k$ and $|V_p^{k+1}| = |V_p^k| + \Delta |V_p^k|$
Increment interation count k = k + 1

				
6	Explain the flowchart with equations how the load flow analysis is carried out using GS Method	[10]	CO1	L3



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