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CERTIFICATION COURSE

Computer aided power system analysis

FDLF (Contd.)

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$$\Rightarrow v_i \frac{\partial Q_i}{\partial v_i} \approx -v_i^2 B_{ii}$$

$$\Rightarrow \frac{\partial Q_i}{\partial v_i} \approx -v_i B_{ii}$$

 $\Rightarrow$

$$\frac{\partial Q_i}{\partial v_i} \approx -B_{ii}$$

$$\frac{\partial Q_i}{\partial v_j} \approx -B_{ij}$$

 J_4

$$J_1 \left\{ \begin{array}{l} \frac{1}{v_i} \frac{\partial P_i}{\partial \theta_j} = -B_{ij} \quad j \neq i \\ \frac{1}{v_i} \frac{\partial P_i}{\partial \theta_i} \approx -B_{ii} \end{array} \right.$$

$$J_2 = 0$$

$$J_3 = 0$$



$$J_1 \cdot \Delta \bar{\theta} = \Delta \bar{P}$$

$$\begin{bmatrix} \frac{\partial P_2}{\partial \theta_2} & \frac{\partial P_2}{\partial \theta_3} & \cdots & \frac{\partial P_2}{\partial \theta_N} \\ \frac{\partial P_3}{\partial \theta_2} & \frac{\partial P_3}{\partial \theta_3} & \cdots & \frac{\partial P_3}{\partial \theta_N} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_N}{\partial \theta_2} & \frac{\partial P_N}{\partial \theta_3} & \cdots & \frac{\partial P_N}{\partial \theta_N} \end{bmatrix} \begin{bmatrix} \Delta \theta_2 \\ \Delta \theta_3 \\ \vdots \\ \Delta \theta_N \end{bmatrix} = \begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \vdots \\ \Delta P_N \end{bmatrix}$$

$N \rightarrow$ number of buses in the system



$$\Delta P_i = \frac{\partial P_i}{\partial \theta_2} \Delta \theta_2 + \frac{\partial P_i}{\partial \theta_3} \Delta \theta_3 + \dots + \frac{\partial P_i}{\partial \theta_i} \Delta \theta_i + \dots + \frac{\partial P_i}{\partial \theta_N} \Delta \theta_N$$

$$\Rightarrow \frac{1}{V_i} \Delta P_i = \frac{1}{V_i} \frac{\partial P_i}{\partial \theta_2} \Delta \theta_2 + \frac{1}{V_i} \frac{\partial P_i}{\partial \theta_3} \Delta \theta_3 + \dots + \frac{1}{V_i} \frac{\partial P_i}{\partial \theta_i} \Delta \theta_i + \dots +$$

Applying the modified expressions of the elements of J_1 ,

$$\frac{1}{V_i} \Delta P_i = -B_{i2} \Delta \theta_2 - B_{i3} \Delta \theta_3 - \dots - B_{ii} \Delta \theta_i - \dots - B_{iN} \Delta \theta_N$$

$$\forall i = 2, 3, \dots, N$$

Collecting all equations together in matrix form, we get



$$\begin{bmatrix} -B_{22} & -B_{23} & \dots & -B_{2N} \\ -B_{32} & -B_{33} & \dots & -B_{3N} \\ \vdots & \vdots & & \vdots \\ -B_{N2} & -B_{N3} & \dots & -B_{NN} \end{bmatrix} \begin{bmatrix} \Delta\theta_2 \\ \Delta\theta_3 \\ \vdots \\ \Delta\theta_N \end{bmatrix} = \begin{bmatrix} \Delta P_2/V_2 \\ \Delta P_3/V_3 \\ \vdots \\ \Delta P_N/V_N \end{bmatrix}$$

$\downarrow$ B' $\downarrow$ $\Delta\bar{\theta}$ $\downarrow$ $\left[\frac{\Delta\bar{P}}{\bar{V}} \right]$

$$\Rightarrow [B'] \Delta\bar{\theta} = \left[\frac{\Delta\bar{P}}{\bar{V}} \right]$$

$$\Rightarrow \Delta\bar{\theta} = [B']^{-1} \left[\frac{\Delta\bar{P}}{\bar{V}} \right]$$

$$\begin{aligned} J_1 \Delta\bar{\theta} &= \Delta\bar{P} \\ \Rightarrow \Delta\bar{\theta} &= J_1^{-1} \Delta\bar{P} \end{aligned}$$

$$J_y \cdot \Delta \bar{V} = \Delta \bar{Q}$$

$$\begin{bmatrix} \frac{\partial Q_{m+1}}{\partial V_{m+1}} & \cdots & \frac{\partial Q_{m+1}}{\partial V_N} \\ \vdots & & \vdots \\ \frac{\partial Q_N}{\partial V_{m+1}} & \cdots & \frac{\partial Q_N}{\partial V_N} \end{bmatrix} \begin{bmatrix} \Delta V_{m+1} \\ \vdots \\ \Delta V_N \end{bmatrix} = \begin{bmatrix} \Delta Q_{m+1} \\ \vdots \\ \Delta Q_N \end{bmatrix}$$

$M \rightarrow$ number of generators in the system.

$$\Rightarrow \frac{\partial Q_i}{\partial V_{m+1}} \cdot \Delta V_{m+1} + \frac{\partial Q_i}{\partial V_{m+2}} \Delta V_{m+2} \cdots + \frac{\partial Q_i}{\partial V_N} \cdot \Delta V_N = \Delta Q_i$$



$$-B_{i,m+1} \cdot \Delta V_{m+1} - B_{i,m+2} \cdot \Delta V_{m+2} \dots \dots \dots - B_{i,N} \Delta V_N = \Delta Q_i$$

$\forall i = m+1, m+2, \dots N$

Collecting all equations, we get

$$\begin{bmatrix} -B_{m+1,m+1} & -B_{m+1,m+2} & \dots & -B_{m+1,N} \\ -B_{m+2,m+1} & -B_{m+2,m+2} & \dots & -B_{m+2,N} \\ \vdots & & & \\ -B_{N,m+1} & -B_{N,m+2} & \dots & -B_{N,N} \end{bmatrix} \begin{bmatrix} \Delta V_{m+1} \\ \Delta V_{m+2} \\ \vdots \\ \Delta V_N \end{bmatrix} = \begin{bmatrix} \Delta Q_{m+1} \\ \Delta Q_{m+2} \\ \vdots \\ \Delta Q_N \end{bmatrix}$$

$\Rightarrow B'' \cdot \Delta \bar{V} = \Delta \bar{Q}$
 $\downarrow B''$
 $\downarrow \Delta \bar{V}$
 $\downarrow \Delta \bar{Q}$

$$\Rightarrow \Delta \bar{V} = [\bar{B}']^{-1} \Delta \bar{Q} ;$$

$$\begin{aligned} \bar{J}_4 \cdot \Delta \bar{V} &= \Delta \bar{Q} \\ \Rightarrow \Delta \bar{V} &= [\bar{J}_4]^{-1} \Delta \bar{Q} \end{aligned}$$

$$\bar{B}' \cdot \Delta \bar{\theta} = \Delta \bar{P} / \bar{V}$$

$$\begin{aligned} \bar{B}'' \cdot \Delta \bar{V} &= \Delta \bar{Q} \\ &\rightarrow (N-m) \times (N-m) \\ &\rightarrow (N-1) \times (N-1) \end{aligned}$$

Fast Decoupled Load flow

↓
Constant
 $\bar{B}'$ and $\bar{B}''$
matrices are
used at each
iteration

↓
 $\left. \begin{array}{l} \theta - P \\ Q - V \end{array} \right\} \underline{\underline{\text{Decoupling}}}$

FDLF results in 5 bus

$$\bar{\mathbf{Y}}_{\text{BUS}}(:, 1 : 3) = \begin{bmatrix} 3.2417 - 13.0138i & -1.4006 + 5.6022i & 0 \\ -1.4006 + 5.6022i & 3.2417 - 13.0138i & -1.8412 + 7.4835i \\ 0 & -1.8412 + 7.4835i & 4.2294 - 18.9271i \\ 0 & 0 & -1.2584 + 7.1309i \\ -1.8412 + 7.4835i & 0 & -1.1298 + 4.4768i \end{bmatrix};$$

$$\bar{\mathbf{Y}}_{\text{BUS}}(:, 4 : 5) = \begin{bmatrix} 0 & -1.8412 + 7.4835i \\ 0 & 0 \\ -1.2584 + 7.1309i & -1.1298 + 4.4768i \\ 2.1921 - 10.7227i & -0.9337 + 3.7348i \\ -0.9337 + 3.7348i & 3.9047 - 15.5521i \end{bmatrix};$$

FDLF results in 5 bus (contd..)

$$[B'] = \begin{bmatrix} 13.0138 & -7.4835 & 0 & 0 \\ -7.4835 & 18.9271 & -7.1309 & -4.4768 \\ 0 & -7.1309 & 10.7227 & -3.7348 \\ 0 & -4.4768 & -3.7348 & 15.5521 \end{bmatrix};$$

$$[B''] = \begin{bmatrix} 10.7227 & -3.7348 \\ -3.7348 & 15.5521 \end{bmatrix};$$

Final Results of the 5 bus system with FDLF

Bus no.	Without generator Q limit				With generator Q limit			
	$ V $ (p.u)	θ (deg)	P_{inj} (p.u)	Q_{inj} (p.u)	$ V $ (p.u)	θ (deg)	P_{inj} (p.u)	Q_{inj} (p.u)
1	1.0	0	0.56743	0.26505	1.0	0	0.56985	0.34069
2	1.0	1.65757	0.5	-0.18519	1.0	1.69742	0.5	-0.04522
3	1.0	-0.91206	1.0	0.68875	0.98219	-0.63507	1.0	0.49668
4	0.90594	-8.35088	-1.15	-0.6	0.88888	-8.35938	-1.15	-0.6
5	0.94397	-5.02735	-0.85	-0.4	0.93428	-4.9861	-0.85	-0.4
	Total iteration = 19				Total iteration = 20			