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Apêndice A – Metodologia Utilizada para a Construção da Ferramenta de Simulação Dinâmica

De acordo com o que foi exposto na seção 3.6. Sabe-se que o comportamento dinâmico dos sistemas elétricos de potência pode ser representado por um conjunto de equações diferenciais ordinárias (A.1) e algébricas (A.2) da seguinte forma:

$$\dot{Y} = f(y, x, t) \quad \text{(A.1)}$$

$$0 = g(y, x, t) \quad \text{(A.2)}$$

Onde (A.1) é o vetor de variáveis de estado que representam os modelos dinâmicos dos elementos de controle da rede (máquinas síncronas, reguladores de tensão e velocidade, compensadores estáticos, etc.).
E (A.2) é o vetor de variáveis de estado que representam os modelos dinâmicos da rede elétrica (linhas, transformadores, capacitores, etc.).

Equações Diferenciais Referentes ao Modelo de Gerador Adotado:

$$F1 = \frac{d\Delta w}{dt} = \frac{-1}{2 \cdot H}\left[E''_D \cdot I_D + E''_Q \cdot I_Q \right] \quad \text{(A.3)}$$

$$F2 = \frac{d\delta}{dt} = W_S \cdot \Delta_W \quad \text{(A.4)}$$

$$F3 = \frac{dE''_D}{dt} = \left[\frac{1}{T''_Q}\right] \cdot \left[I_Q \cdot (L_Q - L''_Q) - E''_D \right] \quad \text{(A.5)}$$

$$F4 = \frac{dE'_Q}{dt} = \left[\frac{w}{T'_D}\right] \cdot \left[E_{FD} - E_Q \right] \quad \text{(A.6)}$$

$$F5= \frac{dE''_Q}{dt} = \frac{dE'_Q}{dt}\cdot\left(\frac{L''_D - L_L}{L'_D - L_L}\right) + \left[\frac{w}{T''_D}\right]\cdot\left[\frac{E'_Q}{w} - I_D\cdot\left(L'_D - L''_D\right) - \frac{E''_Q}{w}\right] \quad \text{(A.7)}$$

Equações Diferenciais Referentes ao Regulador de Tensão Adotado:

$$F6 = \frac{d\,V_{A3}}{d\,t} = \frac{V_{TR} - V_{A3}}{T_M} \quad \text{(A.8)}$$

$$F7 = \frac{d\,V_{A2}}{d\,t} = \frac{V_{A3} - V_{A2}}{T_M} \quad \text{(A.9)}$$

$$F8 = \frac{d\,V_{A1}}{d\,t} = \left[\frac{K_A\cdot\left(V_{REF} - V_{A2} - \frac{T_1}{T_M}\cdot\left(V_{A3} - V_{A2}\right)\right) - V_{A1}}{T_2}\right] \quad \text{(A.10)}$$

$$F9 = \frac{d\,V_{A0}}{d\,t} = \frac{1}{T_M}\cdot\left\{V_{A1} + \frac{T_3}{T_2}\cdot\left[K_A\cdot\left(V_{REF} - V_{A2} - \frac{T_1}{T_M}\cdot\left(V_{A3} - V_{A2}\right)\right) - V_{A1}\right] - V_{A0}\right\}$$

(A.11)

Equações Algébricas Referentes ao Gerador Adotado:

$$F10 = E''_D - V_1\cdot\sin(\delta - \theta_1) + L''d\cdot I_Q \quad \text{(A.12)}$$

$$F11 = E''_Q - V_1\cdot\cos(\delta - \theta_1) - L''d\cdot I_D \quad \text{(A.13)}$$

Equações Algébricas Referentes ao Sistema de Duas Barras:

$$F12 = I_D\cdot\sin(\delta) + I_Q\cdot\cos(\delta) - V_1\cdot(G_{11}\cdot\cos(\theta_1) - B_{11}\cdot\sin(\theta_1)) - V_2\cdot(G_{12}\cdot\cos(\theta_2) - B_{12}\cdot\sin(\theta_2)) \quad \text{(A.14)}$$

$$F13 = I_D \cdot \cos(\delta) - I_Q \cdot \sin(\delta) + V_1 \cdot (G_{11} \cdot \sin(\theta_1) + B_{11} \cdot \cos(\theta_1)) + V_2 \cdot (G_{12} \cdot \cos(\theta_2) + B_{12} \cdot \sin(\theta_2)) \quad \text{(A.15)}$$

$$F14 = \frac{-P_{L2} \cdot \cos(\theta_2)}{V_2} - \frac{Q_{L2} \cdot \sin(\theta_2)}{V_2} - V_2 \cdot (G_{22} \cdot \cos(\theta_2) - B_{22} \cdot \sin(\theta_2)) - V_1 \cdot (G_{21} \cdot \cos(\theta_1) - B_{21} \cdot \sin(\theta_1)) \quad \text{(A.16)}$$

$$F15 = \frac{-P_{L2} \cdot \sin(\theta_2)}{V_2} + \frac{Q_{L2} \cdot \cos(\theta_2)}{V_2} - V_2 \cdot (G_{22} \cdot \sin(\theta_2) + B_{22} \cdot \cos(\theta_2)) - V_1 \cdot (G_{21} \cdot \sin(\theta_1) + B_{21} \cdot \cos(\theta_1)) \quad \text{(A.17)}$$

A estruturação da matriz jacobiana em (3.5), é formada através da representação da derivadas por função :

Função 1:

$$F1 = \frac{d\Delta w}{dt} = \frac{-1}{2 \cdot H}\left[E''_D \cdot I_D + E''_Q \cdot I_Q \right]$$

$$\frac{\partial F(\Delta w)}{\partial E''_D} = \frac{-I_D}{2 \cdot H} \quad \text{(A.18)} \qquad \frac{\partial F(\Delta w)}{\partial I_D} = \frac{-E''_D}{2 \cdot H} \quad \text{(A.19)} \qquad \frac{\partial F(\Delta w)}{\partial E'_Q} = \frac{-I_Q}{2 \cdot H} \quad \text{(A.20)}$$

$$\frac{\partial F(\Delta w)}{\partial I_Q} = \frac{-E''_Q}{2 \cdot H} \quad \text{(A.21)} \qquad \frac{\partial F(\Delta w)}{\partial \Delta w} = \frac{-D}{2 \cdot H} \quad \text{(A.22)}$$

Função 2:

$$F2 = \frac{d\delta}{dt} = W_S \cdot \Delta_W$$

$$\frac{\partial F(\delta)}{\partial \Delta w} = W_S \quad \text{(A.23)}$$

Função 3:

$$F3= \frac{dE''_D}{dt} = \left[\frac{1}{T''_Q}\right].\left[I_Q.(L_Q - L''_Q) - E''_D\right]$$

$$\frac{\partial F(E''_D)}{\partial I_Q} = \frac{(L_Q - L''_Q)}{T''_Q} \quad \text{(A.24)} \qquad \frac{\partial F(E''_D)}{\partial E''_D} = \frac{(-1)}{T''_Q} \quad \text{(A.25)}$$

Função 4:

$$F4= \frac{dE'_Q}{dt} = \left[\frac{w}{T'_D}\right].\left[E_{FD} - E_Q\right]$$

Sabe-se que $E_Q = S_{AT} + \left[\frac{L_D - L'_D}{L'_D - L_L}\right].\left[\frac{E'_Q}{w}.\left(\frac{L_D - L_L}{L_D - L'_D}\right) + I_D.\left(L''_D - L_L\right) - \frac{E''_Q}{w}\right]$,

então:

Dado que $S_{AT} = 0$ e que em (P.U) W=1, então:

$$\frac{dE'_Q}{dt} = \left[\frac{1}{T'_D}\right]\cdot\left[E_{FD} - \left[\frac{L_D - L'_D}{L'_D - L_L}\right]\cdot\left[\frac{E'_Q}{1}\cdot\left(\frac{L_D - L_L}{L_D - L'_D}\right) + I_D\cdot(L''_D - L_L) - \frac{E''_Q}{1}\right]\right]$$

$$\frac{\partial F(E'_Q)}{\partial E'_Q} = \left(\frac{-1}{T'_D}\right)\cdot\left(\frac{L_D - L'_D}{L'_D - L_L}\right)\cdot\left(\frac{L_D - L_L}{L_D - L'_D}\right) \quad \text{(A.26)}$$

$$\frac{\partial F(E'_Q)}{\partial I_D} = \left(\frac{-1}{T'_D}\right) \cdot \left(\frac{L_D - L'_D}{L'_D - L_L}\right) \cdot (L''_D - L_L) \tag{A.27}$$

$$\frac{\partial F(E'_Q)}{\partial E''_Q} = \left(\frac{1}{T'_D}\right) \cdot \left(\frac{L_D - L'_D}{L'_D - L_L}\right) \tag{A.28}$$

$$\frac{\partial F(E'_Q)}{\partial E_{EFD}} = \left(\frac{1}{T'_D}\right) \tag{A.29}$$

Função 5:

$$F5 = \frac{dE''_Q}{dt} = \frac{dE'_Q}{dt} \cdot \left(\frac{L''_D - L_L}{L'_D - L_L}\right) + \left[\frac{w}{T''_D}\right] \cdot \left[\frac{E'_Q}{w} - I_D \cdot (L'_D - L''_D) - \frac{E''_Q}{w}\right]$$

$$\frac{\partial F(E''_Q)}{\partial E'_Q} = \left[\left(\frac{-1}{T'_D}\right) \cdot \left(\frac{L_D - L'_D}{L'_D - L_L}\right) \cdot \left(\frac{L_D - L_L}{L_D - L'_D}\right) \cdot \left(\frac{L''_D - L_L}{L'_D - L_L}\right)\right] + \left[\frac{1}{T''_D}\right] \tag{A.30}$$

$$\frac{\partial F(E''_Q)}{\partial I_D} = \left[\left(\frac{-1}{T'_D}\right) \cdot \left(\frac{L_D - L'_D}{L'_D - L_L}\right) \cdot (L''_D - L_L) \cdot \left(\frac{L''_D - L_L}{L'_D - L_L}\right)\right] + \left[\left(\frac{-1}{T''_D}\right) \cdot (L'_D - L''_D)\right] \tag{A.31}$$

$$\frac{\partial F(E''_Q)}{\partial E''_Q} = \left[\left(\frac{1}{T'_D}\right) \cdot \left(\frac{L_D - L'_D}{L'_D - L_L}\right) \cdot \left(\frac{L''_D - L_L}{L'_D - L_L}\right)\right] + \left[\frac{-1}{T''_D}\right] \tag{A.32}$$

$$\frac{\partial F(E''_Q)}{\partial E_{EFD}} = \left[\left(\frac{1}{T'_D}\right)\cdot\left(\frac{L''_D - L_L}{L'_D - L_L}\right)\right] \quad \text{(A.33)}$$

Função 6:

$$\frac{dV_{A3}}{dt} = \frac{V_{TR} - V_{A3}}{T_M} \qquad \frac{\partial F(V_{A3})}{\partial t} = \frac{-1}{T_M} \quad \text{(A.34)}$$

Função 7:

$$\frac{dV_{A2}}{dt} = \frac{V_{A3} - V_{A2}}{T_M}$$

$$\frac{\partial F(V_{A2})}{\partial V_{A2}} = \frac{-1}{T_M} \quad \text{(A.35)} \qquad \frac{\partial F(V_{A2})}{\partial V_{A3}} = \frac{1}{T_M} \quad \text{(A.36)}$$

Função 8:

$$\frac{dV_{A1}}{dt} = \left[\frac{K_A\cdot\left(V_{REF} - V_{A2} - \frac{T_1}{T_M}\cdot\left(V_{A3} - V_{A2}\right)\right) - V_{A1}}{T_2}\right]$$

$$\frac{\partial F(V_{A1})}{\partial V_{A1}} = \frac{-1}{T_2} \quad \text{(A.37)} \qquad \frac{\partial F(V_{A1})}{\partial V_{A2}} = \frac{K_A}{T_2}\left(\frac{T_1}{T_M} - 1\right) \quad \text{(A.38)} \qquad \frac{\partial F(V_{A1})}{\partial V_{A3}} = \frac{K_A}{T_2}\cdot\frac{-T_1}{T_M}$$

(A.39)

Função 9:

$$\frac{dV_{A0}}{dt} = \frac{1}{T_M}\cdot\left\{V_{A1} + \frac{T_3}{T_2}\cdot\left[K_A\cdot\left(V_{REF} - V_{A2} - \frac{T_1}{T_M}\cdot\left(V_{A3} - V_{A2}\right)\right) - V_{A1}\right] - V_{A0}\right\}$$

$$\frac{\partial F(V_{A0})}{\partial V_{A0}} = \frac{-1}{T_M} \quad \text{(A.39)} \qquad \frac{\partial F(V_{A0})}{\partial V_{A1}} = \frac{1}{T_M}\cdot\left(1 - \frac{T_3}{T_2}\right) \quad \text{(A.40)}$$

$$\frac{\partial F(V_{A0})}{\partial V_{A2}} = \frac{1}{T_M}\cdot\left[\frac{T_3}{T_2}\cdot\left(-1 + \frac{T_1}{T_M}\right)\right] \quad \text{(A.41)}$$

$$\frac{\partial F(V_{A0})}{\partial V_{A3}} = \frac{1}{T_M}\cdot\left[\frac{T_3}{T_2}\cdot\left(-\frac{T_1}{T_M}\right)\right] \quad \text{(A.42)}$$

Função 10:

$$F10 = E''_D - V_1\cdot\sin(\delta - \theta_1) + L''d\cdot I_Q$$

$$\frac{\partial F(F10)}{\partial E''_D} = 1 \quad \text{(A.43)} \qquad \frac{\partial F(F10)}{\partial V_1} = -\sin(\delta - \theta_1) \quad \text{(A.44)} \qquad \frac{\partial F(F10)}{\partial I_Q} = L''d \quad \text{(A.45)}$$

$$\frac{\partial F(F10)}{\partial \delta} = -V_1\cdot\cos(\delta - \theta_1) \quad \text{(A.46)} \qquad \frac{\partial F(F10)}{\partial \theta_1} = V_1\cdot\cos(\delta - \theta_1) \quad \text{(A.47)}$$

Função 11:

$$F11 = E''_Q - V_1\cdot\cos(\delta - \theta_1) - L''d\cdot I_D$$

$$\frac{\partial F(F11)}{\partial E''_Q} = 1 \quad \text{(A.48)} \qquad \frac{\partial F(F11)}{\partial V_1} = -\cos(\delta - \theta_1) \quad \text{(A.49)} \qquad \frac{\partial F(F11)}{\partial I_D} = -L''d \quad \text{(A.50)}$$

$$\frac{\partial F(F11)}{\partial \delta} = V_1 \cdot \sin(\delta - \theta_1) \quad \text{(A.51)} \qquad \frac{\partial F(F11)}{\partial \theta_1} = -V_1 \cdot \sin(\delta - \theta_1) \quad \text{(A.52)}$$

Função 12:

$$F12 = I_D \cdot \sin(\delta) + I_Q \cdot \cos(\delta) - V_1 \cdot (G_{11} \cdot \cos(\theta_1) - B_{11} \cdot \sin(\theta_1)) - V_2 \cdot (G_{12} \cdot \cos(\theta_2) - B_{12} \cdot \sin(\theta_2))$$

$$\frac{\partial F(F12)}{\partial I_D} = \sin(\delta) \quad \text{(A.53)} \qquad \frac{\partial F(F12)}{\partial I_Q} = \cos(\delta) \quad \text{(A.54)}$$

$$\frac{\partial F(F12)}{\partial \delta} = I_D \cdot \cos(\delta) - I_Q \cdot \sin(\delta) \quad \text{(A.55)} \qquad \frac{\partial F(F12)}{\partial V_1} = -G_{11} \cdot \cos(\theta_1) + B_{11} \cdot \sin(\theta_1)$$

(A.56)

$$\frac{\partial F(F12)}{\partial \theta_1} = V_1 \cdot G_{11} \cdot \sin(\theta_1) + V_1 \cdot B_{11} \cdot \cos(\theta_1) \quad \text{(A.57)}$$

$$\frac{\partial F(F12)}{\partial V_2} = -G_{12} \cdot \cos(\theta_2) + \cdot B_{12} \cdot \sin(\theta_2) \quad \text{(A.58)}$$

$$\frac{\partial F(F12)}{\partial \theta_2} = V_2 \cdot G_{12} \cdot \sin(\theta_2) + V_2 \cdot B_{12} \cdot \cos(\theta_2)$$

Função 13:

$$F13 = I_D \cdot \cos(\delta) - I_Q \cdot \sin(\delta) + V_1 \cdot (G_{11} \cdot \sin(\theta_1) + B_{11} \cdot \cos(\theta_1)) + V_2 \cdot (G_{12} \cdot \cos(\theta_2) + B_{12} \cdot \sin(\theta_2))$$

$$\frac{\partial F(F13)}{\partial I_D} = \cos(\delta) \qquad \frac{\partial F(F13)}{\partial I_Q} = -\sin(\delta) \quad \text{(A.59) (A.60)}$$

$$\frac{\partial F(F13)}{\partial \delta} = -I_D \cdot \sin(\delta) - I_Q \cdot \cos(\delta) \quad \text{(A.61)}$$

$$\frac{\partial F(F13)}{\partial V_1} = G_{11} \cdot \sin(\theta_1) + B_{11} \cdot \cos(\theta_1) \quad \text{(A.62)}$$

$$\frac{\partial F(F13)}{\partial \theta_1} = V_1 \cdot G_{11} \cdot \cos(\theta_1) - V_1 \cdot B_{11} \cdot \sin(\theta_1) \quad \text{(A.63)}$$

$$\frac{\partial F(F13)}{\partial V_2} = G_{12} \cdot \sin(\theta_2) + \cdot B_{12} \cdot \cos(\theta_2) \quad \text{(A.64)}$$

$$\frac{\partial F(F13)}{\partial \theta_2} = V_2 \cdot G_{12} \cdot \cos(\theta_2) - V_2 \cdot B_{12} \cdot \sin(\theta_2) \quad \text{(A.65)}$$

Função 14:

$$F14 = \frac{-P_{L2} \cdot \cos(\theta_2)}{V_2} - \frac{Q_{L2} \cdot \sin(\theta_2)}{V_2} - V_2 \cdot (G_{22} \cdot \cos(\theta_2) - B_{22} \cdot \sin(\theta_2)) - V_1 \cdot (G_{21} \cdot \cos(\theta_1) - B_{21} \cdot \sin(\theta_1))$$

$$\frac{\partial F(F14)}{\partial V_1} = -G_{21} \cdot \cos(\theta_1) + B_{21} \cdot \sin(\theta_1) \quad \text{(A.66)}$$

$$\frac{\partial F(F14)}{\partial \theta_1} = V_1 \cdot G_{21} \cdot \sin(\theta_1) + V_1 \cdot B_{21} \cdot \cos(\theta_1) \quad \text{(A.67)}$$

$$\frac{\partial F(F14)}{\partial V_2} = \frac{1}{V_2^{\,2}}\left(P_{L2} \cdot \cos(\theta_2) + Q_{L2} \cdot \sin(\theta_2)\right) - G_{22} \cdot \cos(\theta_2) + \cdot B_{22} \cdot \sin(\theta_2)$$

(A.68)

$$\frac{\partial F(F14)}{\partial \theta_2} = \frac{1}{V_2^{\,2}}\left(P_{L2} \cdot \sin(\theta_2) - Q_{L2} \cdot \cos(\theta_2)\right) + V_2 \cdot (G_{22} \cdot \sin(\theta_2) + \cdot B_{22} \cdot \cos(\theta_2)$$

(A.69)

Função 15:

$$F15 = \frac{-P_{L2} \cdot \sin(\theta_2)}{V_2} + \frac{Q_{L2} \cdot \cos(\theta_2)}{V_2} - V_2 \cdot (G_{22} \cdot \sin(\theta_2) + B_{22} \cdot \cos(\theta_2)) - V_1 \cdot (G_{21} \cdot \sin(\theta_1) + B_{21} \cdot \cos(\theta_1))$$

$$\frac{\partial F(F15)}{\partial V_1} = -G_{21} \cdot \sin(\theta_1) - B_{21} \cdot \cos(\theta_1) \quad \text{(A.70)}$$

$$\frac{\partial F(F15)}{\partial \theta_1} = -V_1 \cdot G_{21} \cdot \cos(\theta_1) + V_1 \cdot B_{21} \cdot \sin(\theta_1) \quad \text{(A.71)}$$

$$\frac{\partial F(F15)}{\partial V_2} = \frac{1}{V_2^{\,2}}\left(P_{L2} \cdot \sin(\theta_2) - Q_{L2} \cdot \cos(\theta_2)\right) - G_{22} \cdot \sin(\theta_2) - B_{22} \cdot \cos(\theta_2)$$

(A.72)

$$\frac{\partial F(F15)}{\partial \theta_2} = \frac{1}{V_2^{\,2}}\left(-P_{L2}\cdot\cos(\theta_2) - Q_{L2}\cdot\sin(\theta_2)\right) - V_2\cdot\left(G_{22}\cdot\cos(\theta_2) - B_{22}\cdot\sin(\theta_2)\right)$$

(A.73)

E finalmente a estruturação da matriz jacobiana montada:

$$\begin{bmatrix} F1 \\ F2 \\ F3 \\ F4 \\ F5 \\ F6 \\ F7 \\ F8 \\ F9 \\ F10 \\ F11 \\ F12 \\ F13 \\ F14 \\ F15 \end{bmatrix} = \begin{bmatrix} \frac{\partial F_1}{\partial \Delta W} & \frac{\partial F_1}{\partial \delta} & \frac{\partial F_1}{\partial E''d} & \frac{\partial F_1}{\partial E'q} & \frac{\partial F_1}{\partial E''q} & \frac{\partial F_1}{\partial V_{A3}} & \frac{\partial F_1}{\partial V_{A2}} & \frac{\partial F_1}{\partial V_{A1}} & \frac{\partial F_1}{\partial E_{FD}} & \frac{\partial F_1}{\partial I_D} & \frac{\partial F_1}{\partial I_Q} & \frac{\partial F_1}{\partial V_1} & \frac{\partial F_1}{\partial \theta_1} & \frac{\partial F_1}{\partial V_2} & \frac{\partial F_1}{\partial \theta_2} \\ \frac{\partial F_2}{\partial \Delta W} & \frac{\partial F_2}{\partial \delta} & \frac{\partial F_2}{\partial E''d} & \frac{\partial F_2}{\partial E'q} & \frac{\partial F_2}{\partial E''q} & \frac{\partial F_2}{\partial V_{A3}} & \frac{\partial F_2}{\partial V_{A2}} & \frac{\partial F_2}{\partial V_{A1}} & \frac{\partial F_2}{\partial E_{FD}} & \frac{\partial F_2}{\partial I_D} & \frac{\partial F_2}{\partial I_Q} & \frac{\partial F_2}{\partial V_1} & \frac{\partial F_2}{\partial \theta_1} & \frac{\partial F_2}{\partial V_2} & \frac{\partial F_2}{\partial \theta_2} \\ \frac{\partial F_3}{\partial \Delta W} & \frac{\partial F_3}{\partial \delta} & \frac{\partial F_3}{\partial E''d} & \frac{\partial F_3}{\partial E'q} & \frac{\partial F_3}{\partial E''q} & \frac{\partial F_3}{\partial V_{A3}} & \frac{\partial F_3}{\partial V_{A2}} & \frac{\partial F_3}{\partial V_{A1}} & \frac{\partial F_3}{\partial E_{FD}} & \frac{\partial F_3}{\partial I_D} & \frac{\partial F_3}{\partial I_Q} & \frac{\partial F_3}{\partial V_1} & \frac{\partial F_3}{\partial \theta_1} & \frac{\partial F_3}{\partial V_2} & \frac{\partial F_3}{\partial \theta_2} \\ \frac{\partial F_4}{\partial \Delta W} & \frac{\partial F_4}{\partial \delta} & \frac{\partial F_4}{\partial E''d} & \frac{\partial F_4}{\partial E'q} & \frac{\partial F_4}{\partial E''q} & \frac{\partial F_4}{\partial V_{A3}} & \frac{\partial F_4}{\partial V_{A2}} & \frac{\partial F_4}{\partial V_{A1}} & \frac{\partial F_4}{\partial E_{FD}} & \frac{\partial F_4}{\partial I_D} & \frac{\partial F_4}{\partial I_Q} & \frac{\partial F_4}{\partial V_1} & \frac{\partial F_4}{\partial \theta_1} & \frac{\partial F_4}{\partial V_2} & \frac{\partial F_4}{\partial \theta_2} \\ \frac{\partial F_5}{\partial \Delta W} & \frac{\partial F_5}{\partial \delta} & \frac{\partial F_5}{\partial E''d} & \frac{\partial F_5}{\partial E'q} & \frac{\partial F_5}{\partial E''q} & \frac{\partial F_5}{\partial V_{A3}} & \frac{\partial F_5}{\partial V_{A2}} & \frac{\partial F_5}{\partial V_{A1}} & \frac{\partial F_5}{\partial E_{FD}} & \frac{\partial F_5}{\partial I_D} & \frac{\partial F_5}{\partial I_Q} & \frac{\partial F_5}{\partial V_1} & \frac{\partial F_5}{\partial \theta_1} & \frac{\partial F_5}{\partial V_2} & \frac{\partial F_5}{\partial \theta_2} \\ \frac{\partial F_6}{\partial \Delta W} & \frac{\partial F_6}{\partial \delta} & \frac{\partial F_6}{\partial E''d} & \frac{\partial F_6}{\partial E'q} & \frac{\partial F_6}{\partial E''q} & \frac{\partial F_6}{\partial V_{A3}} & \frac{\partial F_6}{\partial V_{A2}} & \frac{\partial F_6}{\partial V_{A1}} & \frac{\partial F_6}{\partial E_{FD}} & \frac{\partial F_6}{\partial I_D} & \frac{\partial F_6}{\partial I_Q} & \frac{\partial F_6}{\partial V_1} & \frac{\partial F_6}{\partial \theta_1} & \frac{\partial F_6}{\partial V_2} & \frac{\partial F_6}{\partial \theta_2} \\ \frac{\partial F_7}{\partial \Delta W} & \frac{\partial F_7}{\partial \delta} & \frac{\partial F_7}{\partial E''d} & \frac{\partial F_7}{\partial E'q} & \frac{\partial F_7}{\partial E''q} & \frac{\partial F_7}{\partial V_{A3}} & \frac{\partial F_7}{\partial V_{A2}} & \frac{\partial F_7}{\partial V_{A1}} & \frac{\partial F_7}{\partial E_{FD}} & \frac{\partial F_7}{\partial I_D} & \frac{\partial F_7}{\partial I_Q} & \frac{\partial F_7}{\partial V_1} & \frac{\partial F_7}{\partial \theta_1} & \frac{\partial F_7}{\partial V_2} & \frac{\partial F_7}{\partial \theta_2} \\ \frac{\partial F_8}{\partial \Delta W} & \frac{\partial F_8}{\partial \delta} & \frac{\partial F_8}{\partial E''d} & \frac{\partial F_8}{\partial E'q} & \frac{\partial F_8}{\partial E''q} & \frac{\partial F_8}{\partial V_{A3}} & \frac{\partial F_8}{\partial V_{A2}} & \frac{\partial F_8}{\partial V_{A1}} & \frac{\partial F_8}{\partial E_{FD}} & \frac{\partial F_8}{\partial I_D} & \frac{\partial F_8}{\partial I_Q} & \frac{\partial F_8}{\partial V_1} & \frac{\partial F_8}{\partial \theta_1} & \frac{\partial F_8}{\partial V_2} & \frac{\partial F_8}{\partial \theta_2} \\ \frac{\partial F_9}{\partial \Delta W} & \frac{\partial F_9}{\partial \delta} & \frac{\partial F_9}{\partial E''d} & \frac{\partial F_9}{\partial E'q} & \frac{\partial F_9}{\partial E''q} & \frac{\partial F_9}{\partial V_{A3}} & \frac{\partial F_9}{\partial V_{A2}} & \frac{\partial F_9}{\partial V_{A1}} & \frac{\partial F_9}{\partial E_{FD}} & \frac{\partial F_9}{\partial I_D} & \frac{\partial F_9}{\partial I_Q} & \frac{\partial F_9}{\partial V_1} & \frac{\partial F_9}{\partial \theta_1} & \frac{\partial F_9}{\partial V_2} & \frac{\partial F_9}{\partial \theta_2} \\ \frac{\partial F_{10}}{\partial \Delta W} & \frac{\partial F_{10}}{\partial \delta} & \frac{\partial F_{10}}{\partial E''d} & \frac{\partial F_{10}}{\partial E'q} & \frac{\partial F_{10}}{\partial E''q} & \frac{\partial F_{10}}{\partial V_{A3}} & \frac{\partial F_{10}}{\partial V_{A2}} & \frac{\partial F_{10}}{\partial V_{A1}} & \frac{\partial F_{10}}{\partial E_{FD}} & \frac{\partial F_{10}}{\partial I_D} & \frac{\partial F_{10}}{\partial I_Q} & \frac{\partial F_{10}}{\partial V_1} & \frac{\partial F_{10}}{\partial \theta_1} & \frac{\partial F_{10}}{\partial V_2} & \frac{\partial F_{10}}{\partial \theta_2} \\ \frac{\partial F_{11}}{\partial \Delta W} & \frac{\partial F_{11}}{\partial \delta} & \frac{\partial F_{11}}{\partial E''d} & \frac{\partial F_{11}}{\partial E'q} & \frac{\partial F_{11}}{\partial E''q} & \frac{\partial F_{11}}{\partial V_{A3}} & \frac{\partial F_{11}}{\partial V_{A2}} & \frac{\partial F_{11}}{\partial V_{A1}} & \frac{\partial F_{11}}{\partial E_{FD}} & \frac{\partial F_{11}}{\partial I_D} & \frac{\partial F_{11}}{\partial I_Q} & \frac{\partial F_{11}}{\partial V_1} & \frac{\partial F_{11}}{\partial \theta_1} & \frac{\partial F_{11}}{\partial V_2} & \frac{\partial F_{11}}{\partial \theta_2} \\ \frac{\partial F_{12}}{\partial \Delta W} & \frac{\partial F_{12}}{\partial \delta} & \frac{\partial F_{12}}{\partial E''d} & \frac{\partial F_{12}}{\partial E'q} & \frac{\partial F_{12}}{\partial E''q} & \frac{\partial F_{12}}{\partial V_{A3}} & \frac{\partial F_{12}}{\partial V_{A2}} & \frac{\partial F_{12}}{\partial V_{A1}} & \frac{\partial F_{12}}{\partial E_{FD}} & \frac{\partial F_{12}}{\partial I_D} & \frac{\partial F_{12}}{\partial I_Q} & \frac{\partial F_{12}}{\partial V_1} & \frac{\partial F_{12}}{\partial \theta_1} & \frac{\partial F_{12}}{\partial V_2} & \frac{\partial F_{12}}{\partial \theta_2} \\ \frac{\partial F_{13}}{\partial \Delta W} & \frac{\partial F_{13}}{\partial \delta} & \frac{\partial F_{13}}{\partial E''d} & \frac{\partial F_{13}}{\partial E'q} & \frac{\partial F_{13}}{\partial E''q} & \frac{\partial F_{13}}{\partial V_{A3}} & \frac{\partial F_{13}}{\partial V_{A2}} & \frac{\partial F_{13}}{\partial V_{A1}} & \frac{\partial F_{13}}{\partial E_{FD}} & \frac{\partial F_{13}}{\partial I_D} & \frac{\partial F_{13}}{\partial I_Q} & \frac{\partial F_{13}}{\partial V_1} & \frac{\partial F_{13}}{\partial \theta_1} & \frac{\partial F_{13}}{\partial V_2} & \frac{\partial F_{13}}{\partial \theta_2} \\ \frac{\partial F_{14}}{\partial \Delta W} & \frac{\partial F_{14}}{\partial \delta} & \frac{\partial F_{14}}{\partial E''d} & \frac{\partial F_{14}}{\partial E'q} & \frac{\partial F_{14}}{\partial E''q} & \frac{\partial F_{14}}{\partial V_{A3}} & \frac{\partial F_{14}}{\partial V_{A2}} & \frac{\partial F_{14}}{\partial V_{A1}} & \frac{\partial F_{14}}{\partial E_{FD}} & \frac{\partial F_{14}}{\partial I_D} & \frac{\partial F_{14}}{\partial I_Q} & \frac{\partial F_{14}}{\partial V_1} & \frac{\partial F_{14}}{\partial \theta_1} & \frac{\partial F_{14}}{\partial V_2} & \frac{\partial F_{14}}{\partial \theta_2} \\ \frac{\partial F_{15}}{\partial \Delta W} & \frac{\partial F_{15}}{\partial \delta} & \frac{\partial F_{15}}{\partial E''d} & \frac{\partial F_{15}}{\partial E'q} & \frac{\partial F_{15}}{\partial E''q} & \frac{\partial F_{15}}{\partial V_{A3}} & \frac{\partial F_{15}}{\partial V_{A2}} & \frac{\partial F_{15}}{\partial V_{A1}} & \frac{\partial F_{15}}{\partial E_{FD}} & \frac{\partial F_{15}}{\partial I_D} & \frac{\partial F_{15}}{\partial I_Q} & \frac{\partial F_{15}}{\partial V_1} & \frac{\partial F_{15}}{\partial \theta_1} & \frac{\partial F_{15}}{\partial V_2} & \frac{\partial F_{15}}{\partial \theta_2} \end{bmatrix} \cdot \begin{bmatrix} \Delta W \\ \Delta \delta \\ \Delta E''d \\ \Delta E'q \\ \Delta E''q \\ \Delta V_{A3} \\ \Delta V_{A2} \\ \Delta V_{A1} \\ \Delta E_{FD} \\ \Delta I_D \\ \Delta I_Q \\ \Delta V_1 \\ \Delta \theta_1 \\ \Delta V_2 \\ \Delta \theta_2 \end{bmatrix}$$