APPENDIX B

LIST OF PUBLICATIONS

INTERNATIONAL JOURNALS:

Accepted/Published:

1) R. K. Pandey, and Deepak K. Gupta, "Intelligent Multi-Area Power Control: Dynamic Knowledge Domain Inference Concept", ***IEEE Transactions on Power Systems***, Vol-32, 6, 2017, pp- 4310-4318.

   Web Link: http://ieeexplore.ieee.org/document/7837729/

2) Rajendra K. Pandey, and Deepak K. Gupta, "Knowledge Domain States Mapping Concept for Controller Tuning in an Interconnected Power Network", ***Electrical Power and Energy Systems,*** 80, 2016, 160–170 ***Elsevier***, January 2016, ISSN: 0142-0615, SCI Impact Factor: 2.587.

   Web Link:
   http://www.sciencedirect.com/science/article/pii/S0142061516000612/pdfft?md5=b2aa5b4848d7664d0191c0023b4049a0&pid=1-s2.0-S0142061516000612-main.pdf

3) R. K. Pandey, and Deepak K. Gupta, "Integrated Multi-Stage LQR-Power Oscillation Damping FACTS Controller", accepted in ***CSEE Journal of Power and Energy Systems***.

   Web Link:
   http://el.csee.org.cn/detail/5C7E5BD6EE965676E054D89D67F5A4E2

4) R. K. Pandey, and Deepak K. Gupta, "Performance Evaluation of Power Oscillation Damping Controller -Firefly Algorithm based Parameter Tuning" accepted in ***Electric Power Components and Systems. Taylor & Francis***.

INTERNATIONAL CONFERENCES:

Accepted/Published:

5) R. K. Pandey, and Deepak K. Gupta, "PSS Tuning with Firefly Driven Knowledge Domain- A Smart Control Concept", **IEEE TENCON**, 1-4 Nov, 2015, USB ISBN: 978-1-4799-8640-8.

   Web Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7373057

6) R. K. Pandey, and Deepak Kumar Gupta. "Intelligent Power Oscillation Damping Control with Dynamic Knowledge Inference", Proceedings of the **International Conference on Information and Knowledge Engineering (IKE)**. Las Vegas, P.p. 85-91. (WorldComp), 2016, ISBN-1-60132-441-3.

   Web Link: http://worldcomp-proceedings.com/proc/p2016/IKE3184.pdf

7) Rajendra K. Pandey, and Deepak K. Gupta, "ATC Enhancement with SSSC-Knowledge Inference based Intelligent Controller Tuning", **IEEE TENCON**, Singapore, 22-25 Nov 2016, ISBN: 978-1-5090-2596-1.

   Web Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7848536

8) R. K. Pandey, and Deepak K. Gupta, "Modified-Multi Stage LQR (M-MSLQR) UPFC Controller for Inter-area Oscillations Damping- Design and Analysis", **UPCON 2016**, IIT (BHU), Varanasi, pp. 156-161.

   Web Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7894644

Submitted:

NATIONAL CONFERENCES:

Accepted/Published:

9) Deepak Kumar Gupta, and R. K. Pandey, "Grid Stabilization with PMU Signals- A Survey", **IEEE, NPSC 2014**, Guwahati, ISBN: 978-1-4799-5141-3.

   Web Link: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7103812

APPENDIX A

COMPLETE DATA SET

Generator's rating of the 10 area 50 Machine system (Refer Figure 3.7):

Ratings of Generators in Area 1 are:

G11=100MW, G21=184MW, G31=140MW, G41=140MW, G51=184MW.

Ratings of Generators in Area 2 are:

G12=100MW, G22=184MW, G32=140MW, G42=140MW, G52=100MW.

Ratings of Generators in Area 3 are:

G13=100MW, G23=184MW, G33=184MW, G43=135MW, G53=140MW.

Ratings of Generators in Area 4 are:

G14=100MW, G24=135MW, G34=135MW, G44=184MW, G54=184MW.

Ratings of Generators in Area 5 are:

G15=184MW, G25=184MW, G35=135MW, G45=140MW, G55=135MW.

Ratings of Generators in Area 6 are:

G16=100MW, G26=100MW, G36=100MW, G46=184MW, G56=135MW.

Ratings of Generators in Area 7 are:

G17=184MW, G27=184MW, G37=184MW, G47=100MW, G57=100MW.

Ratings of Generators in Area 8 are:

G18=140MW, G28=140MW, G38=184MW, G48=135MW, G58=184MW.

Ratings of Generators in Area 9 are:

G19=184MW, G29=184MW, G39=184MW, G49=184MW, G59=184MW.

Ratings of Generators in Area 10 are:

G110=140MW, G210=135MW, G310=184MW, G410=184MW, G510=100MW.

UPFC between area 1 and area 2:

Transformer: X_{te}=0.03; X_b=0.30;

Transmission line: X_e=0.3; X_{bv}=0.03;

Operating conditions: V_b=1.0 p.u.; δ=40 degree;

DC Link Capacitor: C_{dc}=0.0005; V_{dc}=1.0 p.u.

Data Set of Sample Six Area Test System 1 (Refer Figure 5.2):

Generator 1 (100 MW): M_1=16.64 MJ/MVA; T_{1d0}=5.6 sec; X_{1d}=1.192; X_{1q}=1.192; X_{1d1}=0.1269; E'_{q1}=1.024 p.u.; Excitation System 1: K_{1A}=18.5; T_{1A}=0.2 sec;

Generator 2 (135MW): M_2=6.52 MJ/MVA; T_{2d0}=3.5sec; X_{2d}=0.8667; X_{2q}=0.5207; X_{2d1}=0.2467; E'_{q2}=1.024 p.u.; Excitation System 2: K_{2A}=40; T_{2A}=0.06 sec;

Generator 3 (140 MW): M_3=16.10 MJ/MVA; T_{3d0}=7.9 sec; X_{3d}=1.540; X_{3q}=1.490; X_{3d1}=0.1060; E'_{q3}=1.024 p.u.; Excitation System 3: K_{3A}=45; T_{3A}=0.06 sec;

Generator 4 (184MW): M_4=27.94 MJ/MVA; T_{4d0}=3.3 sec; X_{4d}=0.4993; X_{4q}=0.4819; X_{4d1}=0.0789; E'_{q4}=1.024 p.u.; Excitation System 4: K_{4A}=18.5; T_{4A}=0.2 sec;

Generator 5 (135MW): M_5=6.52 MJ/MVA; T_{5d0}=3.5 sec; X_{5d}=0.8667; X_{5q}=0.5207; X_{5d1}=0.2467; E'_{q5}=1.024 p.u.; Excitation System 5: K_{5A}=40; T_{5A}=0.06 sec;

Generator 6 (100MW): M_6=16.64 MJ/MVA; T_{6d0}=5.6 sec; X_{6d}=1.192; X_{6q}=1.192; X_{6d1}=0.1269; E'_{q6}=1.024 p.u.; Excitation System 6: K_{6A}=18.5; T_{6A}=0.2 sec;

UPFC between area 2 and area 3:

Transformer: X_{te}=0.03; X_b=0.30;

Transmission line: X_e=0.3; X_{bv}=0.03;

Operating conditions: V_b=1.0 p.u.; δ=40 degree;

DC Link Capacitor: C_{dc}=0.0005; V_{dc}=1.0 p.u.

Data Set of Sample Six Area Test System 2 (Refer Figure 5.6):

Area 1 with PSS1 (G1):

Generator 1 (184 MW): M_1=27.94 MJ/MVA; T_{1d0}=3.3 sec; X_{1d}=0.4993; X_{1q}=0.4849; X_{1d1}=0.0789; E'_{q1}=1.0 p.u., E_{fd1}=1.0

Excitation System 1: K_{1A}=18.5; T_{1A}=0.2 sec;

Area 2 with PSS2 (G2):

Generator 2 (184 MW): M_2=27.94 MJ/MVA; T_{2d0}=3.3 sec; X_{2d}=0.4993; X_{2q}=0.4849; X_{2d1}=0.0789; E'_{q2}=1.0 p.u., E_{fd2}=1.0

Excitation System 2: K_{2A}=18.5; T_{2A}=0.2 sec;

Area 3 with PSS3 (G3):

Generator 3 (140 MW): M_3=16.1 MJ/MVA; T_{3d0}=7.9 sec; X_{3d}=1.54; X_{3q}=1.49; X_{3d1}=0.1060; E'_{q3}=1.0p.u. E_{fd3}=1.0;

Excitation System 3: K_{3A}=45; T_{3A}=0.060 sec;

Area 4 with PSS4 (G4):

Generator 4 (184 MW): M_4=27.94 MJ/MVA; T_{4d0}=3.3 sec; X_{4d}=.4993; X_{4q}=.4819; X_{4d1}=0.0789; E'_{q4}=1.0p.u., E_{fd4}=1.0;

Excitation System 4: K_{4A}=18.5; T_{4A}=0.2 sec;

Parameters for UPFC installed between two areas:

Transformer: X_{te}=0.03; X_b=0.30;

Transmission line: X_e=0.3; X_{bv}=0.03;

Operating conditions: V_b=1.0 p.u.; δ=40 degree;

DC Link Capacitor: C_{dc}=0.0005; V_{dc}=1.0 p.u.

Generator 5 (140 MW): M_5=16.1; MJ/MVA; T_{5d0}=7.9 sec; X_{5d}=1.54; X_{5q}=1.49; X_{5d1}=0.1060; E'_{q5}=1.0 p.u., E_{fd5}=1.0;

Excitation System 5: K_{5A}=45; T_{5A}=0.060 sec;

Generator 6 (140 MW): M_6=16.1 MJ/MVA; T_{6d0}=7.9 sec; X_{6d}=1.54; X_{6q}=1.49; X_{6d1}=0.1060; E'_{q6}=1.0p.u., E_{fd6}=1.0;

Excitation System 6: K_{6A}=45; T_{6A}=0.060 sec;

Two Area Two Machine Test System (Refer Figure 3.4):

Transformer: X_{te} =0.03; X_b =0.30

Transmission line: X_e =0.3; X_{bv}=0.03;

Operating conditions: V_b =1.0 p.u.; δ =40 degree;

DC link capacitor: C_{dc}=0.0005 p.u.; V_{dc} =1.0 p.u.;

Generator 1:M_1=0.0255 MJ/MVA; D_1=0.0sec; T_{1d0}=5.044 sec, X_{1d}=0.190; X_{1q}=0.163; X_{1d1}=0.0765; E'_{q11}=1.024;

Excitation system 1: K_{1A}=10; T_{1A} =0.010 sec;

Generator 2: M_2=0.0255 MJ/MVA; D_2=0.0 sec; T_{2d0}=5.6 sec, X_{2d}=0.190; X_{2q}=0.163; X_{2d1}=0.0765; E'_{q21}=1.024;

Excitation system 2: K_{2A}=20; T_{2A}=0.010 sec;

Two Area Four Machine Test System (Refer Figure 3.10)

Generator 1 with PSS1 (Area 1):

Generator 1 (960 MW): M_1=65.46 MJ/MVA; T_{1d0}= 6.7 sec; X_{1d}= 0.1675; X_{1q}= 0.1675; X_{1d1}= 0.0208; E'_{q11}=1.024p.u., E_{fd11}=1.0 p.u.;

Excitation System 1: K_{1A}=100; T_{1A}=0.020 sec;

Generator 2 with PSS2 (Area 1):

Generator 2 (660 MW): M_2= 64.56 MJ/MVA; T_{2d0}= 6.1sec; X_{2d}= 0.1715; X_{2q}= 0.1023; X_{2d1}= 0.0440; E'_{q21}=1.024 p.u., E_{fd21}=1.0;

Excitation System 2: K_{2A}=100; T_{2A}=0.020 sec;

Generator 3 with PSS3 (Area 2):

Generator 3 (600 MW): M_3= 55.20MJ/MVA; T_{3d0}= 6.7sec; X_{3d}= 0.3030; X_{3q}= 0.2820; X_{3d1}= 0.0560; E'_{q32}=1.0p.u. E_{fd32}=1.0;

Excitation System 3: K_{3A}=100; T_{3A}=0.020 sec;

Generator 4 with PSS4 (Area 2):

Generator 4 (390 MW): M_4= 38.36MJ/MVA; T_{4d0}= 6.1sec; X_{4d}=0.3158; X_{4q}= 0.2624; X_{4d1}= 0.0386; E'_{q42}=1.0p.u. E_{fd42}=1.0;

Excitation System 4: K_{4A}=160; T_{4A}=0.030 sec;

Two Area Four Machine Test System (Refer Figure 5.34) (PSCAD Validation)

Generator 1 with PSS1 (Area 1):

Generator 1 (120 MW): M_1= 3.117MJ/MVA; T_{1d0}= 6.55sec; X_{1d}= 1.014; X_{1q}= .770; X_{1d1}= .314; E'_{q11}=1.0p.u., E_{fd11}=1.0 p.u.;

Excitation System 1: K_{1A}=200; T_{1A}=0.020 sec;

Generator 2 with PSS2 (Area 1):

Generator 2 (120 MW): M_2= 3.117 MJ/MVA; T_{2d0}= 6.55sec; X_{2d}= 1.014; X_{2q}= 0.770; X_{2d1}= 0.314; E'_{q21}=1.0 p.u., E_{fd21}=1.0;

Excitation System 2: K_{2A}=200; T_{2A}=0.020 sec;

Generator 3 with PSS3 (Area 2):

Generator 3 (120 MW): M_3= 3.1170MJ/MVA; T_{3d0}= 6.55sec; X_{3d}= 1.014; X_{3q}= 0.770; X_{3d1}= 0.314; E'_{q32}=1.0p.u. E_{fd32}=1.0;

Excitation System 3: K_{3A}=200; T_{3A}=0.020 sec;

Generator 4 with PSS4 (Area 2):

Generator 4 (120 MW): M_4= 3.117MJ/MVA; T_{4d0}= 6.55 sec; X_{4d}=1.014; X_{4q}= 0.770; X_{4d1}= 0.314; E'_{q42}=1.0p.u. E_{fd42}=1.0;

Excitation System 4: K_{4A}=200; T_{4A}=0.020 sec;

STATCOM Parameters:

C_{dc}=0.005; V_{dc}=1.0; δ_0=0.6981; d_{11}=0.45; d_{21}=.45; d_{12}=.45; d_{22}=.45; X_{te}=0.03; X_{e11}=0.3; X_{e21}=.3; X_e=.3; X_b=0.3; X_{bv}=0.03;

Parameters of Heuristic Optimization Techniques:

PSO Parameters:

No. of Particles: 70; No. of Iteration: 15; Damping Coefficient: 0.9; acceleration coefficient c1=1.5 and c2=4-c1;

GSA Parameters:

No. of Populations: 70; No. of Iteration: 15; G_0 (Gravitational constant)=100; α=20

Firefly Algorithm Parameters:

No. of fireflies: 70; No. of Iteration: 15; α (randomness)=0.5; β_0=0.2; γ (absorption)=1

Linearized constant used in the derivation of close loop matrix of UPFC with two machine system model: (section 3.2.3)

$a_{31} = L_1 D_4 \cos\delta$; $a_{32} = L_1 D_4 E'_{q2}\, sin\delta$; $a_{33} = L_1 D_4 E'_{q2}\, sin\delta_b$; $a_{34} = L_1 D_4 m_b \cos\delta_b (V_{dc}/2)$;

$a_{35} = (L_1/2) D_4 m_b \sin\delta_b$; $a_{36} = L_1 D_5 \sin\delta_e (V_{dc}/2)$; $a_{37} = L_1 D_5 m_e \cos\delta_e (V_{dc}/2)$;

$a_{38} = (L_1/2) D_5 m_e \sin\delta_e$; $a_{39} = L_1 D_6$; $a_{41} = L_2 Q_3 \cos\delta_e V_{dc}$; $a_{42} = L_2 Q_3 m_e \sin\delta_e V_{dc}$;

$a_{43} = L_2 Q_3 m_e \cos\delta_e$; $a_{44} = L_2 Q_4 \cos\delta_b (V_{dc}/2)$; $a_{45} = -L_2 Q_4 \sin\delta_b (V_{dc}/2)$;

$a_{46} = (L_2/2) Q_4 m_b \cos\delta_b$; $a_{47} = L_2 Q_4 \sin\delta$; $a_{48} = L_2 Q_4 E'_{q2} \cos\delta$; $a_{351} = a_{35} + a_{38}$;

$a_{431} = a_{43} + a_{46}$; $a_{11} = D_1 - D_3 X'_{2d}\, a_{39}$; $a_{12} = D_2 \sin\delta_e V_{dc} - D_3 X'_{2d}\, a_{36}$;

$a_{13} = D_2 m_e \cos\delta_e V_{dc} - D_3 X'_{2d}\, a_{37}$; $a_{14} = D_2 m_e \sin\delta_e - D_3 X'_{2d}\, a_{351} + (D_3/2) m_b \sin\delta_b$;

$a_{15} = D_3 \cos\delta - D_3 X'_{2d}\, a_{31};\; a_{16} = -D_3 E'_{q2} \sin\delta - D_3 X'_{2d}\, a_{32}$

$a_{17} = -D_3 X'_{2d}\, a_{33} + D_3 \sin\delta_b (V_{dc}/2);\; a_{18} = -D_3 X'_{2d}\, a_{34} + D_3 m_b \cos\delta_b (V_{dc}/2);$

$a_{21} = Q_1 \cos\delta_e V_{dc} + Q_2 X_{2q} a_{41};\; a_{22} = Q_2 X_{2q} a_{42} - Q_1 m_e \sin\delta_e V_{dc};$

$a_{23} = Q_1 m_e \cos\delta_e + (Q_2/2) m_b \cos\delta_b + Q_2 X_{2q} a_{431};\; a_{24} = Q_2 \cos\delta_b (V_{dc}/2) + Q_2 X_{2q} a_{44};$

$a_{25} = Q_2 X_{2q} a_{45} - Q_2 m_b \sin\delta_b (V_{dc}/2);\; a_{26} = Q_2 \sin\delta + Q_2 X_{2q} a_{47};$

$a_{27} = Q_2 E'_{q2} \cos\delta + Q_2 X_{2q} a_{48};$

$a_{51} = a_{11} - a_{39};\; a_{52} = a_{12} - a_{36};\; a_{53} = a_{13} - a_{37};\; a_{54} = a_{14} - a_{351};\; a_{55} = a_{15} - a_{31};$

$a_{56} = a_{16} - a_{32};\; a_{57} = a_{17} - a_{33};\; a_{58} = a_{18} - a_{34};\; a_{61} = a_{21} - a_{11};\; a_{62} = a_{22} - a_{42};$

$a_{63} = a_{23} - a_{431};\; a_{64} = a_{24} - a_{44};\; a_{65} = a_{25} - a_{45};\; a_{66} = a_{26} - a_{47};\; a_{67} = a_{27} - a_{48};$

$$a_e = a_b = \frac{3}{4C_{dc}}$$

$a_{e1} = -a_e m_e \sin\delta_e I_{1d} + a_e m_e \cos\delta_e I_{1q};\; a_{e2} = a_e m_e \cos\delta_e;\; a_{e3} = a_e m_e \sin\delta_e;$

$a_{e4} = a_e \cos\delta_e I_{1d} + a_e \sin\delta_e I_{1q};\; a_{b1} = a_b m_b I_{2d} - a_b m_b \cos\delta_b I_{2q};\; a_{b2} = -a_b m_b \cos\delta_b;$

$a_{b3} = -a_b m_b \sin\delta_b;\; a_{b4} = -a_b \cos\delta_b I_{2d} - a_b \sin\delta_b I_{2q}$

$a_{v1} = a_{e1} + a_{e2} a_{13} + a_{e3} a_{22} + a_{b2} a_{37} + a_{b3} a_{42};\; a_{v2} = a_{e2} a_{11} + a_{b2} a_{39};$

$a_{v3} = a_{e2} a_{12} + a_{e3} a_{21} + a_{b2} a_{36} + a_{b3} a_{41};\; a_{v4} = a_{e2} a_{14} + a_{e3} a_{23} + a_{b2} a_{351} + a_{b3} a_{431};$

$a_{v5} = a_{e2} a_{15} + a_{e3} a_{26} + a_{b2} a_{31} + a_{b3} a_{47};\; a_{v6} = a_{e2} a_{16} + a_{e3} a_{27} + a_{b2} a_{32} + a_{b3} a_{48};$

$a_{v7} = a_{e2} a_{17} + a_{e3} a_{24} + a_{b2} a_{33} + a_{b3} a_{44};\; a_{v8} = a_{e2} a_{18} + a_{e3} a_{25} + a_{b1} + a_{b2} a_{34} + a_{b3} a_{45};$

$n_{11} = -I_{tq};\; n_{12} = -[E'_{q1} + (X_{1q} - X'_{1d}) I_{td}];\; n_{13} = -(X_{1q} - X'_{1d}) I_{tq};\; n_{14} = n_{11} + n_{13} a_{51};$

$n_{15} = n_{12} a_{61} + n_{13} a_{52};\; n_{16} = n_{12} a_{62} + n_{13} a_{53};\; n_{17} = n_{12} a_{63} + n_{13} a_{54};\; n_{18} = n_{12} a_{64} + n_{13} a_{57};$

$n_{19} = n_{12} a_{65} + n_{13} a_{58};\; n_{110} = n_{12} a_{66} + n_{13} a_{55};\; n_{111} = n_{12} a_{67} + n_{13} a_{56};\; n_{21} = -(X_{1d} - X'_{1d});$

$v_1 = (-1 + n_{22})$; $n_{22} = n_{21}a_{21}$; $n_{23} = n_{21}a_{52}$; $n_{24} = n_{21}a_{53}$; $n_{25} = n_{21}a_{54}$; $n_{26} = n_{21}a_{55}$;

$n_{27} = n_{21}a_{56}$; $n_{28} = n_{21}a_{57}$; $n_{29} = n_{21}a_{58}$;

$F_{11} = E'_{q1} - I_{td}X'_{1d}$; $F_{12} = -F_{11}X'_{1d}$; $F_{13} = I_{tq}X^2_{1q}$; $F_{14} = F_{11} + F_{12}a_{51}$; $F_{15} = F_{12}a_{52} + F_{13}a_{61}$;

$F_{16} = F_{12}a_{53} + F_{13}a_{62}$; $F_{17} = F_{12}a_{54} + F_{13}a_{63}$; $F_{18} = F_{12}a_{55} + F_{13}a_{66}$; $F_{19} = F_{12}a_{56} + F_{13}a_{67}$;

$F_{110} = F_{12}a_{57} + F_{13}a_{64}$; $F_{111} = F_{12}a_{58} + F_{13}a_{65}$; $v_3 = -\dfrac{K_{1A}}{v_{1t}T_{1A}}$;

$m_{11} = -[E'_{q2} + (X_{2q} - X'_{2d})I_{2d}]$; $m_{12} = -I_{2q}$; $m_{13} = -(X_{2q} - X'_{2d})I_{2q}$;

$m_{14} = m_{11}a_{41} + m_{13}a_{36}$; $m_{15} = m_{11}a_{42} + m_{13}a_{37}$; $m_{16} = m_{11}a_{431} + m_{13}a_{351}$; $m_{17} = m_{11}a_{44} + m_{13}a_{33}$;

$m_{18} = m_{11}a_{54} + m_{13}a_{34}$; $m_{19} = m_{11}a_{47} + m_{12} + m_{13}a_{31}$; $m_{110} = m_{11}a_{48} + m_{13}a_{32}$; $m_{111} = m_{11}a_{39}$;

$m_{21} = -(X_{2d} - X'_{2d})$; $m_{22} = m_{21}a_{31}$; $m_{23} = m_{21}a_{32}$; $m_{24} = m_{21}a_{33}$; $m_{25} = m_{21}a_{34}$;

$m_{26} = m_{21}a_{351}$; $m_{27} = m_{21}a_{36}$; $m_{28} = m_{21}a_{37}$; $m_{29} = m_{21}a_{39}$; $v_2 = (-1 + m_{22})$;

$G_{11} = E'_{q2} - I_{2d}X'_{2d}$; $G_{12} = -G_{11}X'_{2d}$; $G_{13} = I_{2q}X^2_{2q}$; $G_{14} = G_{11} + G_{12}a_{31} + G_{13}a_{47}$;

$G_{15} = G_{12}a_{32} + G_{13}a_{48}$; $G_{16} = G_{12}a_{33} + G_{13}a_{44}$; $G_{17} = G_{12}a_{34} + G_{13}a_{45}$; $G_{18} = G_{12}a_{351} + G_{13}a_{431}$;

$G_{19} = G_{12}a_{36} + G_{13}a_{41}$; $G_{110} = G_{12}a_{37} + G_{13}a_{42}$; $G_{111} = G_{12}a_{39}$; $v_4 = \dfrac{K_{2A}}{v_{2t}T_{2A}}$;

$X_{Be} = X_B + X_{Bv}$; $X_{qe} = X_{1q} + X_{te}$; $X_{BB} = -X_{be} - X_{2q}$; $X_{dd} = X_{1d} + X_{te}$;

$X_{BE} = X_{be} + X'_{2d}$;

$N_1 = 2k^2m^2_{eo}V_{dco}$; $N_2 = 2k^2m_{eo}V^2_{dco}$; $N_3 = 2E'_{q1} - 2I_{td}X_{de} - 2I_{1d}X_e$;

$N_4 = 2I_{td}X^2_{de} + 2I_{1d}X_dX_{de} - 2E'_{q1}X_{de}$; $N_5 = 2I_{tq}X^2_{qe} + 2I_{1q}X_{qe}X_e$;

$N_6 = 2I_{1d}X^2_e + 2I_{td}X_{1d}X_{de} - 2E'_{q1}X_e$; $N_7 = 2I_{1q}X^2_e + 2I_{1q}X_{qe}X_e$;

$N_8 = N_1 - N_4a_{52} - N_5a_{61} - N_6a_{12} - N_7a_{21}$; $N_9 = -N_4a_{53} - N_5a_{62} - N_6a_{13} - N_7a_{22}$;

$N_{10} = -N_4 a_{57} - N_5 a_{64} - N_6 a_{17} - N_7 a_{24}$; $N_{11} = -N_4 a_{58} - N_5 a_{65} - N_6 a_{18} - N_7 a_{25}$;

$N_{12} = N_4 a_{56} + N_5 a_{67} + N_6 a_{16} + N_7 a_{27}$; $N_{13} = N_3 + N_4 a_{51} + N_6 a_{11}$;

$N_{14} = N_4 a_{55} + N_5 a_{66} + N_6 a_{15} + N_7 a_{26}$; $N_{15} = -N_2 + N_4 a_{54} + N_5 a_{63} + N_6 a_{14} + N_7 a_{23}$;

$P_1 = X_{qe} I_{1q} \sec^2 \delta_e + X_e I_{eq} \sec^2 \delta_e$; $P_2 = -X_{de}$; $P_3 = -X_{qe} \tan \delta_e$; $P_4 = -X_e$;

$P_5 = -X_e \tan \delta_e$; $P_6 = -P_2 a_{52} - P_3 a_{61} - P_4 a_{12} - P_5 a_{21}$; $P_7 = P_1 - P_2 a_{53} - P_3 a_{62} - P_4 a_{13} - P_5 a_{22}$;

$P_8 = -P_2 a_{57} - P_3 a_{64} - P_4 a_{17} - P_5 a_{25}$; $P_9 = -P_2 a_{58} - P_3 a_{65} - P_4 a_{18} - P_5 a_{25}$;

$P_{10} = P_2 a_{56} + P_3 a_{67} + P_4 a_{16} + P_5 a_{27}$; $P_{11} = P_2 a_{51} + P_4 a_{11} + 1$; $P_{12} = P_3 a_{66} + P_4 a_{15} + P_5 a_{26} + P_2 a_{55}$;

$P_{13} = P_2 a_{54} + P_3 a_{63} + P_4 a_{14} + P_5 a_{23}$; $N_{16} = 2k^2 V^2{}_{dc} m_b$; $N_{17} = 2k^2 m^2{}_b V_{dc}$;

$N_{18} = 2E'_{q1} - 2E'_{q2} \sin \delta - 2X_{de} I_{1d} + 2I_{2d} X_{BE}$;

$N_{19} = 2E'_{q2} - 2I_{1q} \cos \delta X_{qe} - 2I_{2q} \cos \delta X_{BB} - 2E'_{q1} \sin \delta + 2I_{1d} \sin \delta X_{de} - 2I_{2d} \sin \delta X_{BE}$;

$N_{20} = 2X^2{}_{de} I_{1d} - 2E'_{q1} X_{de} + 2E'_{q2} \sin \delta X_{de} - 2I_{2d} X_{de} X_{BE}$;

$N_{21} = 2X^2{}_{qe} I_{1q} + 2I_{2q} X_{BB} X_{qe} - 2E'_{q2} \cos \delta X_{qe}$;

$N_{22} = 2X^2{}_{BE} I_{2d} + 2E'_{q1} X_{BE} - 2E'_{q2} \sin \delta X_{BE} - 2I_{1d} X_{de} X_{BE}$;

$N_{23} = 2X^2{}_{BB} I_{2q} + 2I_{1q} X_{BB} X_{qe} - 2E'_{q2} \cos \delta X_{BB}$;

$N_{24} = 2I_{1q} E'_{q2} \sin \delta X_{qe} + 2I_{2q} E'_{q2} \sin \delta X_{BB} - 2E'_{q1} E'_{q2} \cos \delta + 2I_{1d} E'_{q2} \cos \delta X_{de} - 2I_{2d} E'_{q2} \cos \delta X_{BE}$

$N_{25} = -N_{20} a_{52} - N_{21} a_{61} - N_{22} a_{36} - N_{23} a_{41}$; $N_{26} = -N_{20} a_{53} - N_{21} a_{62} - N_{22} a_{37} - N_{23} a_{42}$

$N_{27} = N_{16} - N_{20} a_{57} - N_{22} a_{33} - N_{23} a_{44} - N_{21} a_{64}$; $N_{28} = -N_{20} a_{58} - N_{21} a_{65} - N_{22} a_{34} - N_{23} a_{45}$;

$N_{29} = N_{20} a_{56} + N_{21} a_{67} + N_{22} a_{32} + N_{23} a_{48} + N_{24}$; $N_{30} = N_{18} + N_{20} a_{51} + N_{22} a_{39}$;

$N_{31} = N_{19} + N_{20} a_{55} + N_{21} a_{66} + N_{22} a_{31} + N_{23} a_{47}$;

$N_{32} = -N_{17} + N_{20} a_{54} + N_{21} a_{63} + N_{22} a_{351} + N_{23} a_{431}$;

$P_{14} = I_{1q} X_{qe} \sec^2 \delta_b + I_{2q} X_{bb} \sec^2 \delta_b - E'_{q2} \sec^2 \delta_b \cos \delta$;

$P_{15} = -E'_{q2} \cos \delta - E'_{q2} \tan \delta_b \sin \delta$; $P_{16} = 1$; $P_{17} = \cos \delta \tan \delta_b - \sin \delta$; $P_{18} = -X_{de}$;

$P_{19} = -X_{qe} \tan\delta_b$; $P_{20} = X_{BE}$; $P_{21} = -\tan\delta_b X_{bb}$; $P_{22} = -P_{18}a_{52} - P_{19}a_{61} - P_{20}a_{36} - P_{21}a_{41}$;

$P_{23} = -P_{18}a_{53} - P_{19}a_{62} - P_{20}a_{37} - P_{21}a_{42}$; $P_{24} = -P_{18}a_{57} - P_{19}a_{64} - P_{20}a_{33} - P_{21}a_{44}$;

$P_{25} = P_{14} - P_{18}a_{58} - P_{19}a_{65} - P_{20}a_{34} - P_{21}a_{45}$; $P_{26} = P_{15} + P_{18}a_{56} + P_{19}a_{67} + P_{20}a_{32} + P_{21}a_{48}$;

$P_{27} = P_{16} + P_{18}a_{51} + P_{20}a_{39}$; $P_{28} = P_{17} + P_{18}a_{55} + P_{19}a_{66} + P_{20}a_{31} + P_{21}a_{47}$;

$P_{29} = P_{18}a_{54} + P_{19}a_{63} + P_{20}a_{351} + P_{21}a_{431}$;

Linearized constant used in the derivation of close loop matrix of UPFC with two machine system model: (section 3.2.4)

$X_{qee11} = (X_{11q} + X_{te} + X_e)*(X_b + X_{bv}) + X_e*(X_{11q} + X_{te})$;

$X_{qee21} = (X_{21q} + X_{te} + X_e)*(X_b + X_{bv}) + X_e*(X_{21q} + X_{te})$; $X_{qe11} = X_{11q} + X_{te}$;

$X_{qe21} = X_{21q} + X_{te}$; $X_{bq11} = X_b + X_{bv} + X_{11q} + X_{te}$; $X_{bq21} = X_b + X_{bv} + X_{21q} + X_{te}$;

$X_{qt11} = X_{11q} + X_{te} + X_e$; $X_{qt21} = X_{21q} + X_{te} + X_e$;

$X_{dee11} = (X'_{11d} + X_{te} + X_e)*(X_b + X_{bv}) + X_e*(X'_{11d} + X_{te})$;

$X_{dee21} = (X'_{21d} + X_{te} + X_e)*(X_b + X_{bv}) + X_e*(X'_{21d} + X_{te})$; $X_{dt11} = X'_{11d} + X_{te} + X_e$;

$X_{dt12} = X'_{12d} + X_{te} + X_e$; $X_{dt21} = X'_{21d} + X_{te} + X_e$; $X_{dt22} = X'_{22d} + X_{te} + X_e$;

$X_{bd11} = X_b + X_{bv} + X_{te} + X'_{11d}$; $X_{bd21} = X_b + X_{bv} + X_{te} + X'_{21d}$;

$X_{bd12} = X_b + X_{bv} + X_{te} + X'_{12d}$; $X_{bd22} = X_b + X_{bv} + X_{te} + X'_{22d}$;

$M_1 = X_{bb11} / X_{dee11}$; $M_2 = X_{bd11} / X_{dee11}$; $M_3 = X_{de11} / X_{dee11}$; $M_4 = X_{bb21} / X_{dee21}$;

$M_5 = X_{bd21} / X_{dee21}$; $M_6 = X_{de21} / X_{dee21}$; $M_7 = X_{dt11} / X_{dee11}$; $M_8 = X_{e11} / X_{dee11}$;

$M_9 = X_{dt21} / X_{dee21}$; $M_{10} = X_{e21} / X_{de21}$; $N_1 = X_{bq11} / X_{qee11}$; $N_2 = X_{qe11} / X_{qee11}$;

$N_3 = X_{bq21} / X_{qee21}$; $N_4 = X_{qe21} / X_{qee21}$; $N_5 = X_{qt11} / X_{qee11}$; $N_6 = X_{qt21} / X_{qee21}$;

$S_1 = 1/(1 + M_7 * X'_{12d} + M_9 * X'_{22d})$; $S_2 = 1/(1 + N_5 * X_{12q} + N_6 * X_{22q})$;

$A_{31} = S_1 * M_8$; $A_{32} = S_1 * M_{10}$; $A_{33} = S_1 * M_7 * \cos\delta_0$; $A_{34} = S_1 * M_9 * \cos\delta_0$;

$A_{35} = -S_1 * M_7 * E'_{q12} \sin\delta_0 - S_1 * M_9 * E'_{q22} * \sin\delta_0$;

$A_{37} = S_1 * (M_3 + M_6) * \sin\delta_0 * V_{dc0} / 2$; $A_{38} = S_1 * (M_3 + M_6) * m_e * \cos\delta_0 * V_{dc0} / 2$;

$A_{39} = S_1 * (M_7 + M_9) * \sin\delta_b * V_{dc0} / 2$; $A_{311} = S_1 * (M_7 + M_9) * m_b * \cos\delta_b * V_{dc0} / 2$;

$A_{312} = S_1 * (M_3 + M_6) * m_e * (\sin\delta_e / 2) + S_1 * (M_7 + M_9) * m_b * (\sin\delta_b / 2)$;

$A_{41} = -S_2 * N_5 * \sin\delta_0$; $A_{42} = -S_2 * N_6 * \sin\delta_0$;

$A_{43} = -(S_2 * N_5 * E'_{q12} * \cos\delta_0 + S_2 * N_6 * E'_{q22} * \cos\delta_0$;

$A_{45} = S_2 * (N_2 + N_4) * \cos\delta_e * V_{dc0} / 2$; $A_{46} = -S_2 * (N_2 + N_4) * m_e * \sin\delta_e * V_{dc0} / 2$;

$A_{47} = -S_2 * (N_5 + N_6) * \cos\delta_b * V_{dc0} / 2$; $A_{48} = S_2 * (N_5 + N_6) * m_b * \sin\delta_b * V_{dc0} / 2$;

$A_{49} = S_2 * (N_2 + N_4) * m_e * \cos\delta_e / 2 - S_2 * (N_5 + N_6) * m_b * (\cos\delta_b) / 2$;

$M_{111} = M_3 * X'_{12d} + M_6 X'_{22d}$; $A_{11} = M_1 - M_{111} * A_{31}$; $A_{12} = M_4 - M_{111} * A_{32}$;

$A_{13} = M_3 * \cos\delta_0 - M_{111} * A_{33}$; $A_{14} = M_6 * \cos\delta_0 - M_{111} * A_{34}$;

$A_{15} = -M_3 * E'_{q12} * \sin\delta_0 - M_6 * E'_{q22} * \sin\delta_0 - M_{111} * A_{35}$;

$A_{17} = -(M_2 + M_5) * V_{dc0} * (\sin\delta_e) / 2 - M_{111} * A_{37}$;

$A_{18} = -(M_2 + M_5) * m_e * V_{dc0} * (\cos\delta_e) / 2 - M_{111} * A_{38}$;

$A_{19} = (M_3 + M_6) * V_{dc0} * (\sin\delta_b) / 2 - M_{111} * A_{39}$;

$A_{110} = (M_3 + M_6) * m_b * V_{dc0} * (\cos\delta_b) / 2 - M_{111} * A_{311}$;

$A_{111} = (M_3 + M_6) * m_b * (\sin\delta_b) / 2 - (M_2 + M_5) * m_e * (\sin\delta_e) / 2 - M_{111} * A_{312}$;

$M_{112} = N_2 * X_{12q} + N_4 * X_{22q}$; $A_{21} = -N_2 * \sin\delta_0 - M_{112} * A_{41}$;

$A_{22} = -N_4 * \sin\delta_0 - M_{112} * A_{42}$; $A_{23} = -N_2 * E'_{q12} * \cos\delta_0 - N_4 * E'_{q22} * \cos\delta_0 - M_{112} * A_{43}$;

$A_{25} = (N_1 + N_3) * \cos\delta_e * (V_{dc0} / 2) - M_{112} * A_{45}$;

$A_{26} = -(N_1 + N_3) * m_e * \sin\delta_e * V_{dc0} / 2 - M_{112} * A_{46}$;

$A_{27} = -(N_2 + N_4) * \cos\delta_b * V_{dc0} / 2 - M_{112} * A_{47}$;

$A_{28} = (N_2 + N_4) * m_b * \sin\delta_b * V_{dc0} / 2 - M_{112} * A_{48}$;

$A_{29} = (N_1 + N_3) * m_e * \cos\delta_e / 2 - (N_2 + N_4) * m_b * (\cos\delta_b) / 2 - M_{112} * A_{49}$;

$A_{51} = A_{11} - A_{31}$; $A_{52} = A_{12} - A_{32}$; $A_{53} = A_{13} - A_{33}$; $A_{54} = A_{14} - A_{34}$; $A_{55} = A_{15} - A_{35}$;

$A_{57} = A_{17} - A_{37}$; $A_{58} = A_{18} - A_{38}$; $A_{59} = A_{19} - A_{39}$; $A_{510} = A_{110} - A_{311}$; $A_{511} = A_{111} - A_{312}$;

$A_{61} = A_{21} - A_{41}$; $A_{62} = A_{22} - A_{42}$; $A_{63} = A_{23} - A_{43}$; $A_{65} = A_{25} - A_{45}$; $A_{66} = A_{26} - A_{46}$;

$A_{67} = A_{27} - A_{47}$; $A_{68} = A_{28} - A_{48}$; $A_{69} = A_{29} - A_{49}$; $a_e = 3/(4 * C_{dc})$; $a_b = 3/(4 * C_{dc})$;

$a_{e1} = -a_e * m_e * \sin\delta_e * i_{1d} + a_e * m_e * \cos\delta_e * i_{1q}$; $a_{e2} = a_e * m_e * \cos\delta_e$; $a_{e3} = a_e * m_e * \sin\delta_e$;

$a_{e4} = a_e * \cos\delta_e * i_{1d} + a_e * \sin\delta_e * i_{1q}$; $a_{b1} = a_b * m_b * \sin\delta_b * i_{2d} - a_b * m_b * \cos\delta_b * i_{2q}$;

$a_{b2} = -a_b * m_b * \cos\delta_b$; $a_{b3} = -a_b * m_b * \sin\delta_b$; $a_{b4} = -a_b * \cos\delta_b * i_{2d} + a_b * \sin\delta_b * i_{2q}$;

$A_{71} = a_{e2} * A_{11} + a_{b2} * A_{31}$; $A_{72} = a_{e2} * A_{12} + a_{b2} * A_{32}$;

$A_{73} = a_{e2} * A_{13} + a_{e3} * A_{21} + a_{b2} * A_{33} + a_{b3} * A_{41}$;

$A_{74} = a_{e2} * A_{14} + a_{e3} * A_{22} + a_{b2} * A_{34} + a_{b3} * A_{42}$;

$A_{75} = a_{e2} * A_{15} + a_{e3} * A_{23} + a_{b2} * A_{35} + a_{b3} * A_{43}$;

$A_{77} = a_{e4} + a_{e2} * A_{17} + a_{e3} * A_{25} + a_{b2} * A_{37} + a_{b3} * A_{45}$;

$A_{78} = a_{e1} + a_{e2} * A_{18} + a_{e3} * A_{26} + a_{b2} * A_{38} + a_{b3} * A_{46}$;

$A_{79} = a_{b4} + a_{e2} * A_{19} + a_{e3} * A_{27} + a_{b2} * A_{39} + a_{b3} * A_{47}$;

$A_{710} = a_{b1} + a_{e2} * A_{110} + a_{e3} * A_{28} + a_{b2} * A_{311} + a_{b3} * A_{48}$;

$A_{711} = a_{e2} * A_{111} + a_{e3} * A_{29} + a_{b2} * A_{312} + a_{b3} * A_{49}$;

$n11 = -i_{tq}$; $n21 = -i_{tq}$; $n12 = -[E'_{q11} + (X_{11q} - X'_{11d}) * i_{td}]$;

$n22 = -[E'_{q21} + (X_{21q} - X'_{21d}) * i_{td}]$; $n13 = -(X_{11q} - X'_{11d}) * i_{tq}$; $n23 = -(X_{21q} - X'_{21d}) * i_{tq}$;

$$n14 = n11 + n13 * A_{51};\ n24 = n23 * A_{51};\ n15 = n13 * A_{52};\ n25 = n21 + n23 * A_{52};$$

$$n16 = n21 * A_{61} + n13 * A_{53};\ n26 = n22 * A_{61} + n23 * A_{53};\ n17 = n12 * A_{62} + n13 * A_{54};$$

$$n27 = n22 * A_{62} + n23 * A_{54};\ n18 = n12 * A_{63} + n13 * A_{55};\ n28 = n22 * A_{63} + n23 * A_{55};$$

$$n110 = n12 * A_{65} + n13 * A_{57};\ n210 = n22 * A_{65} + n23 * A_{57};\ n111 = n12 * A_{66} + n13 * A_{58};$$

$$n211 = n22 * A_{66} + n23 * A_{58};\ n112 = n12 * A_{67} + n13 * A_{59};\ n212 = n22 * A_{67} + n23 * A_{59};$$

$$n113 = n12 * A_{68} + n13 * A_{510};\ n213 = n22 * A_{68} + n23 * A_{510};\ n114 = n12 * A_{69} + n13 * A_{511};$$

$$n214 = n22 * A_{69} + n23 * A_{511};\ \ n31 = -(X_{11d} - X'_{11d});\ n32 = n31 * A_{51};\ n33 = n31 * A_{52};$$

$$n34 = n31 * A_{53};\ n35 = n31 * A_{54};\ n36 = n31 * A_{55};\ n38 = n31 * A_{57};\ n39 = n31 * A_{58};$$

$$n310 = n31 * A_{59};\ n311 = n31 * A_{510};\ n312 = n31 * A_{511};\ v1 = n32 - 1;$$

$$n41 = -(X_{21d} - X'_{21d});\ n42 = n41 * A_{51};\ n43 = n41 * A_{52};\ n44 = n41 * A_{53};\ n45 = n41 * A_{54}$$

$$n46 = n41 * A_{55};\ n48 = n41 * A_{57};\ n49 = n41 * A_{58};\ n410 = n41 * A_{59};\ n411 = n41 * A_{510};$$

$$n412 = n41 * A_{511};\ v2 = n43 - 1;$$

$$F11 = E'_{q11} - i_{td} * X'_{11d};\ F12 = -F11 * X'_{11d};\ F13 = i_{tq} * (X_{11q}{}^{2});\ F14 = F11 + F12 * A_{51};$$

$$F15 = F12 * A_{52};\ F16 = F12 * A_{53} + F13 * A_{61};\ F17 = F12 * A_{54} + F13 * A_{62};$$

$$F18 = F12 * A_{55} + F13 * A_{63};\ F110 = F12 * A_{57} + F13 * A_{65};\ F111 = F12 * A_{58} + F13 * A_{66};$$

$$F112 = F12 * A_{59} + F13 * A_{67};\ F113 = F12 * A_{510} + F13 * A_{68};$$

$$F114 = F12 * A_{511} + F13 * A_{69};\ v3 = -K_{11A} / (V_{11t} * T_{11A});$$

$$F21 = E'_{q21} - i_{td} * X'_{21d};\ F22 = -F21 * X'_{21d};F23 = i_{tq} * (X_{21q}{}^{2});\ F24 = F22 * A_{51};$$

$$F25 = F22 * A_{52} + F21;\ F26 = F22 * A_{53} + F23 * A_{61};\ F27 = F22 * A_{54} + F23 * A_{62};$$

$$F28 = F22 * A_{55} + F23 * A_{63};\ F210 = F22 * A_{57} + F23 * A_{65};$$

$$F211 = F22 * A_{58} + F23 * A_{66};\ F212 = F22 * A_{59} + F23 * A_{67};$$

$F213 = F22 * A_{510} + F23 * A_{68}$; $F214 = F22 * A_{511} + F23 * A_{69}$; $v4 = -K_{21A} / (V_{21t} * T_{21A})$;

$m11 = -[E'_{q12} + (X_{12q} - X'_{12d}) * i_{2d}]$; $m12 = -i_{2q}$; $m13 = -(X_{12q} - X'_{12d}) * i_{2q}$;

$m14 = m13 * A_{31}$; $m15 = m13 * A_{32}$; $m16 = m11 * A_{41} + m13 * A_{33} + m12$;

$m17 = m11 * A_{42} + m13 * A_{34}$; $m18 = m11 * A_{43} + m13 * A_{35}$; $m110 = m11 * A_{45} + m13 * A_{37}$;

$m111 = m11 * A_{46} + m13 * A_{38}$; $m112 = m11 * A_{47} + m13 * A_{39}$; $m113 = m11 * A_{48} + m13 * A_{311}$

$m114 = m11 * A_{49} + m13 * A_{312}$; $m21 = -[E'_{q22} + (X_{22q} - X'_{22d}) * i_{2d}]$; $m22 = -i_{2q}$;

$m23 = -(X_{22q} - X'_{22d}) * i_{2q}$; $m24 = m23 * A_{31}$; $m25 = m23 * A_{32}$;

$m26 = m21 * A_{41} + m23 * A_{33}$; $m27 = m21 * A_{42} + m22 + m23 * A_{34}$;

$m28 = m21 * A_{43} + m23 * A_{35}$; $m210 = m21 * A_{45} + m23 * A_{37}$;

$m211 = m21 * A_{46} + m23 * A_{38}$; $m212 = m21 * A_{47} + m23 * A_{39}$;

$m213 = m21 * A_{48} + m23 * A_{311}$; $m214 = m21 * A_{49} + m23 * A_{312}$;

$m31 = -(X_{12d} - X'_{12d})$; $m32 = m31 * A_{31}$; $m33 = m31 * A_{32}$; $m34 = m31 * A_{33}$;

$m35 = m31 * A_{34}$; $m36 = m31 * A_{35}$; $m38 = m31 * A_{37}$; $m39 = m31 * A_{38}$; $m310 = m31 * A_{39}$;

$m311 = m31 * A_{311}$; $m312 = m31 * A_{312}$; $v5 = m34 - 1$; $m41 = -(X_{22d} - X'_{22d})$;

$m42 = m41 * A_{31}$; $m43 = m41 * A_{32}$; $m44 = m41 * A_{33}$; $m45 = m41 * A_{34}$; $m46 = m41 * A_{35}$;

$m48 = m41 * A_{37}$; $m49 = m41 * A_{38}$; $m410 = m41 * A_{39}$; $m411 = m41 * A_{311}$;

$m412 = m41 * A_{312}$; $v6 = m45 - 1$;

$G11 = E'_{q12} - i_{2d} * X'_{12d}$; $G12 = -G11 * X'_{12d}$; $G13 = i_{2q} * (X_{12q}{}^{2})$; $G14 = G12 * A_{31}$;

$G15 = G12 * A_{32}$; $G16 = G11 + G12 * A_{33} + G13 * A_{41}$; $G17 = G12 * A_{34} + G13 * A_{42}$;

$G18 = G12 * A_{35} + G13 * A_{43}$; $G110 = G12 * A_{37} + G13 * A_{45}$; $G111 = G12 * A_{38} + G13 * A_{46}$;

$G112 = G12 * A_{39} + G13 * A_{47}$; $G113 = G12 * A_{311} + G13 * A_{48}$;

$G114 = G12 * A_{312} + G13 * A_{49}$; $v7 = K_{12A} / (V_{12t} * T_{12A})$; $G21 = E'_{q22} - i_{2d} * X'_{22d}$;

$G22 = -G21 * X'_{22d}$; $G23 = i_{2q} * (X_{22q}{}^{2})$; $G24 = G22 * A_{31}$; $G25 = G22 * A_{32}$;

$G26 = G22 * A_{33} + G23 * A_{41}$; $G27 = G22 * A_{34} + G23 * A_{42} + G21$;

$G28 = G22 * A_{35} + G23 * A_{43}$; $G210 = G22 * A_{37} + G23 * A_{45}$;

$G211 = G22 * A_{38} + G23 * A_{46}$; $G212 = G22 * A_{39} + G23 * A_{47}$;

$G213 = G22 * A_{311} + G23 * A_{48}$; $G214 = G22 * A_{312} + G23 * A_{49}$; $v8 = K_{22A} / (V_{22t} * T_{22A})$;

$X_{be} = X_b + X_{bv}$; $X_{21qe} = X_{21q} + X_{te}$; $X_{11qe} = X_{11q} + X_{te}$; $X_{22bb} = -X_{be} - X_{22q}$;

$X_{12bb} = -X_{be} - X_{12q}$; $X_{21de} = X_{21d} + X_{te}$; $X_{11de} = X_{11d} + X_{te}$; $X_{12be} = X_{be} + X'_{12d}$;

$X_{22be} = X_{be} + X'_{22d}$;

$J1 = \sin(\delta_{11})$; $J2 = \sin(\delta_{21})$; $J3 = -X_{11de} * J1 - J2 * X_{21de}$;

$J4 = X_{11qe} * \cos(\delta_{11}) - X_{21qe} * \cos(\delta_{21})$; $J5 = X_e * (\cos(\delta_{11}) + \cos(\delta_{21}))$;

$J6 = -(J1 + J2) * X_e$; $L1 = \cos(\delta_{11})$; $L2 = \cos(\delta_{21})$; $L3 = -X_{11de} * L1 - L2 * X_{21de}$;

$L4 = -X_{11qe} * \sin(\delta_{11}) - X_{21qe} * \sin(\delta_{21})$; $L5 = -X_e * (\sin(\delta_{11}) + \sin(\delta_{21}))$;

$L6 = -(L1 + L2) * X_e$;

$a1 = J1^2 + L1^2$; $a2 = J2^2 + L2^2$; $a3 = J3^2 + L3^2$; $a4 = J4^2 + L4^2$; $a5 = J5^2 + L5^2$;

$a6 = J6^2 + L6^2$; $a7 = 2 * (J1 * J2 + L1 * L2)$; $a8 = 2 * (J1 * J3 + L1 * L3)$;

$a9 = 2 * (J1 * J4 + L1 * L4)$; $a10 = 2 * (J1 * J5 + L1 * L5)$; $a11 = 2 * (J1 * J6 + L1 * L6)$;

$a12 = 2 * (J2 * J3 + L2 * L3)$; $a13 = 2 * (J2 * J4 + L2 * L4)$; $a14 = 2 * (J2 * J5 + L2 * L5)$;

$a15 = 2 * (J2 * J6 + L2 * L6)$; $a16 = 2 * (J3 * J4 + L3 * L4)$; $a17 = 2 * (J3 * J5 + L3 * L5)$;

$a18 = 2 * (J3 * J6 + L3 * L6)$; $a19 = 2 * (J4 * J5 + L4 * L5)$; $a20 = 2 * (J4 * J6 + L4 * L6)$;

$a21 = 2 * (J5 * J6 + L5 * L6)$;

$B1 = 2*K^2*m_e*V_{dc0}{}^2$; $B2 = 2*K^2*m_e{}^2*V_{dc0}$;

$B3 = 2*a1*E'_{q11} + a7*E'_{q21} + a8*i_{td} + a9*i_{tq} + a10*i_{1q} + a11*i_{1d}$;

$B4 = 2*a2*E'_{q21} + a7*E'_{q11} + a12*i_{td} + a13*i_{tq} + a14*i_{1q} + a14*i_{1d}$;

$B5 = 2*a3*i_{td} + a8*E'_{q11} + a12*E'_{q21} + a16*i_{tq} + a17*i_{1q} + a18*i_{1d}$;

$B6 = 2*a4*i_{tq} + a9*E'_{q11} + a13*E'_{q21} + a16*i_{tq} + a19*i_{1q} + a20*i_{1d}$;

$B7 = 2*a6*i_{1d} + a11*E'_{q11} + a15*E'_{q21} + a18*i_{td} + a20*i_{tq} + a21*i_{1q}$;

$B8 = 2*a5*i_{1q} + a10*E'_{q11} + a14*E'_{q21} + a17*i_{td} + a19*i_{tq} + a21*i_{1d}$;

$B9 = B1 - B5*A_{57} - B6*A_{65} - B7*A_{17} - B8*A_{25}$;

$B10 = -B5*A_{58} - B6*A_{66} - B7*A_{18} - B8*A_{26}$;

$B11 = -B5*A_{59} - B6*A_{67} - B7*A_{19} - B8*A_{27}$;

$B12 = -B5*A_{510} - B6*A_{68} - B7*A_{110} - B8*A_{28}$;

$B13 = B5*A_{55} + B6*A_{63} + B7*A_{15} + B8*A_{23}$; $B14 = B3 + B5*A_{51} + B7*A_{11}$;

$B15 = B4 + B5*A_{52} + B7*A_{12}$; $B16 = B5*A_{53} + B6*A_{61} + B7*A_{13} + B8*A_{21}$;

$B17 = B5*A_{54} + B6*A_{62} + B7*A_{14} + B8*A_{22}$;

$B18 = -B2 + B5*A_{511} + B6*A_{69} + B7*A_{111} + B8*A_{29}$;

$C1 = (J1*E'_{q11} + J2*E'_{q21} + J3*i_{td} + J4*i_{tq} + J5*i_{1q} + J6*i_{1d})*\sec(\delta_e)\wedge 2$;

$C2 = L1 - J1*\tan(\delta_e)$; $C3 = L2 - J2*\tan(\delta_e)$; $C4 = L3 - J3*\tan(\delta_e)$;

$C5 = L4 - J4*\tan(\delta_e)$; $C6 = L5 - J5*\tan(\delta_e)$; $C7 = L6 - J6*\tan(\delta_e)$;

$C8 = -C4*A_{57} - C5*A_{65} - C6*A_{25} - C7*A_{17}$;

$C9 = C1 - C4*A_{58} - C5*A_{66} - C6*A_{26} - C7*A_{18}$;

$C10 = -C4*A_{59} - C5*A_{67} - C6*A_{27} - C7*A_{19}$;

$C11 = -C4*A_{510} - C5*A_{68} - C6*A_{28} - C7*A_{110}$;

$C12 = C4*A_{55} + C5*A_{63} + C6*A_{23} + C7*A_{15}$; $C13 = C2 + C4*A_{51} + C7*A_{11}$;

$C14 = C3 + C4*A_{52} + C7*A_{12}$; $C15 = C4*A_{53} + C5*A_{61} + C6*A_{21} + C7*A_{13}$;

$C16 = C4*A_{54} + C5*A_{62} + C6*A_{22} + C7*A_{14}$;

$C17 = C4*A_{511} + C5*A_{69} + C6*A_{29} + C7*A_{111}$; $R1 = \sin(\delta_{12})$; $R2 = \sin(\delta_{22})$;

$R3 = \cos(\delta_{12})$; $R4 = \cos(\delta_{22})$; $R5 = -R1*X_{11de} - R2*X_{21de}$ $R6 = R3*X_{11qe} + R4*X_{21qe}$;

$R7 = R1*X_{12be} + R2*X_{22be}$; $R8 = R3*X_{12bb} + R4*X_{22bb}$; $R9 = -R3*X_{11de} - R4*X_{21de}$;

$R10 = -R1*X_{11qe} - R2*X_{21qe}$; $R11 = R3*X_{12be} + R4*X_{22be}$;

$R12 = -R1*X_{12bb} - R2*X_{22bb}$; $P1 = R1 \wedge 2 + R3 \wedge 2$; $P2 = R2 \wedge 2 + R4 \wedge 2$;

$P3 = R5 \wedge 2 + R9 \wedge 2$; $P4 = R6 \wedge 2 + R10 \wedge 2$; $P5 = R7 \wedge 2 + R11 \wedge 2$;

$P6 = R8 \wedge 2 + R12 \wedge 2$; $P7 = 2*(R1*R2 + R3*R4)$; $P8 = 2*(R1*R5 + R3*R9)$;

$P9 = 2*(R1*R6 + R3*R10)$; $P10 = 2*(R1*R7 + R3*R11)$;

$P11 = 2*(R1*R8 + R3*R12)$; $P12 = 2*(R2*R5 + R4*R9)$;

$P13 = 2*(R6*R2 + R10*R4)$; $P14 = 2*(R7*R2 + R11*R4)$;

$P15 = 2*(R8*R2 + R12*R4)$; $P16 = 2*(R5*R6 + R9*R10)$;

$P17 = 2*(R5*R7 + R9*R11)$; $P18 = 2*(R5*R8 + R9*R12)$;

$P19 = 2*(R6*R7 + R10*R11)$; $P20 = 2*(R6*R8 + R10*R12)$;

$P21 = 2*(R7*R8 + R11*R12)$; $P22 = 2*(R1*R4 - R2*R3)$;

$P23 = 2*(R1*R9 - R3*R5)$; $P24 = 2*(R1*R10 - R3*R6)$;

$P25 = 2*(R1*R11 - R3*R7)$; $P26 = 2*(R1*R12 - R3*R8)$; $P27 = -2*P1$;

$P28 = 2*(R2*R9 - R4*R5)$; $P29 = 2*(R2*R10 - R4*R6)$;

$P30 = 2*(R2*R11 - R4*R7)$; $P31 = 2*(R2*R12 - R4*R8)$; $P32 = -2*P2$;

$B19 = 2*K^2*V_{dc0}{}^2*m_b$; $B20 = 2*K^2*V_{dc0}*m_b{}^2$;

$$B21 = 2*P1*E'_{q11} + P1*E'_{q21} + P8*i_{1d} + P9*i_{1q} + P10*i_{2d} + P11*i_{2q} + P27*E'_{q12}*\sin(\delta_0) - P22*E'_{q22}*\cos(\delta_0) - P7*E'_{q22}*\sin(\delta_0)$$

$$B22 = 2*P2*E'_{q21} + P1*E'_{q11} + P12*i_{1d} + P13*i_{1q} + P14*i_{2d} + P15*i_{2q} - P7*E'_{q12}*\sin(\delta_0) + P22*E'_{q12}*\cos(\delta_0) + P32*E'_{q22}*\sin(\delta_0)$$

$$B23 = 2*P1*E'_{q12} + P7*E'_{q22} + E'_{q21}*(P22*\cos(\delta_0) - P7*\sin(\delta_0)) + P27*E'_{q11}*\sin(\delta_0) + i_{1d}*(-P8*\sin(\delta_0) + P23*\cos(\delta_0)) + i_{1q}*(-P9*\sin(\delta_0) + P24*\cos(\delta_0)) + i_{2d}*(-P10*\sin(\delta_0) + P25*\cos(\delta_0)) + i_{2q}*(-P11*\sin(\delta_0) + P26*\cos(\delta_0))$$

$$B24 = 2*P2*E'_{q22} + P7*E'_{q12} + E'_{q11}*(-P22*\cos(\delta_0) - P7*\sin(\delta_0)) + P32*E'_{q21}*\sin(\delta_0) + i_{1d}*(-P12*\sin(\delta_0) + P28*\cos(\delta_0)) + i_{1q}*(-P13*\sin(\delta_0) + P29*\cos(\delta_0)) + i_{2d}*(-P14*\sin(\delta_0) + P30*\cos(\delta_0)) + i_{2q}*(-P15*\sin(\delta_0) + P31*\cos(\delta_0))$$

$$B25 = P8*E'_{q11} + P12*E'_{q21} + E'_{q12}*(P23*\cos(\delta_0) - P8*\sin(\delta_0)) + E'_{q22}*(P28*\cos(\delta_0) - P12*\sin(\delta_0)) + 2*P3*i_{1d} + P16*i_{1q} + P17*i_{2d} + P18*i_{2q}$$

$$B26 = P9*E'_{q11} + P13*E'_{q21} + E'_{q12}*(P24*\cos(\delta_0) - P9*\sin(\delta_0)) + E'_{q22}*(P29*\cos(\delta_0) - P13*\sin(\delta_0)) + P16*i_{1d} + 2*P4*i_{1q} + P19*i_{2d} + P20*i_{2q}$$

$$B27 = P10*E'_{q11} + P14*E'_{q21} + E'_{q12}*(P25*\cos(\delta_0) - P10*\sin(\delta_0)) + E'_{q22}*(P30*\cos(\delta_0) - P14*\sin(\delta_0)) + P17*i_{1d} + P19*i_{1q} + 2*P5*i_{2d} + P21*i_{2q}$$

$$B28 = P11*E'_{q11} + P15*E'_{q21} + E'_{q12}*(P26*\cos(\delta_0) - P11*\sin(\delta_0)) + E'_{q22}*(P31*\cos(\delta_0) - P15*\sin(\delta_0)) + P18*i_{1d} + P20*i_{1q} + P21*i_{2d} + 2*P6*i_{2q}$$

$$B29 = \sin(\delta_0)*(-P22*E'_{q21}*E'_{q12} - P23*E'_{q12}*i_{1d} - P24*E'_{q12}*i_{1q} - P25*E'_{q12}*i_{2d} - P26*E'_{q12}*i_{2q} + P22*E'_{q22}*E'_{q11} - P28*E'_{q22}*i_{1d} - P29*E'_{q22}*i_{1q} - P30*E'_{q22}*i_{2d} - P31*E'_{q22}*i_{2q}) + \cos(\delta_0)*(P27*E'_{q11}*E'_{q12} - P7*E'_{q12}*E'_{q21} - P8*E'_{q12}*i_{1d} - P9*E'_{q12}*i_{1q} - P10*E'_{q12}*i_{2d} - P11*E'_{q12}*i_{2q} - P7*E'_{q22}*E'_{q11} + P32*E'_{q22}*E'_{q21} - P12*E'_{q22}*i_{1d} - P13*E'_{q22}*i_{1q} - P14*E'_{q22}*i_{2d} - P15*E'_{q22}*i_{2q})$$

$$B30 = B19 + B25*A_{57} - B26*A_{65} - B27*A_{37} - B28*A_{45}$$

$$B31 = -B25*A_{58} - B26*A_{66} - B27*A_{38} - B28*A_{46}$$

$$B32 = -B25*A_{59} - B26*A_{67} - B27*A_{39} - B28*A_{47}$$
$$B33 = -B25*A_{510} - B26*A_{68} - B27*A_{311} - B28*A_{48}$$
$$B34 = B29 + B25*A_{55} + B26*A_{63} + B27*A_{35} + B28*A_{43}$$

$B35 = B21 + B25*A_{51} + B27*A_{31}$; $B36 = B22 + B25*A_{52} + B27*A_{32}$

$$B37 = B23 + B25*A_{53} + B26*A_{61} + B27*A_{33} + B28*A_{41}$$

$$B38 = B24 + B25*A_{54} + B26*A_{62} + B27*A_{34} + B28*A_{42}$$

$$B39 = -B20 + B25*A_{511} + B26*A_{69} + B27*A_{312} + B28*A_{49}$$

$$C18 = (R1*E'_{q11} + R2*E'_{q21} - E'_{q12}*(R3*\cos(\delta_0) + R1*\sin(\delta_0)) - E'_{q22}*(R4*\cos(\delta_0) + R2*\sin(\delta_0)) + (R5*i_{1d} + R6*i_{1q} + R7*i_{2d} + R8*i_{2q})*\sec(\delta_b)\wedge 2$$

$$C19 = E'_{q12}*(R3*\cos(\delta_0) + R4*\sin(\delta_0)) - E'_{q22}*(R4*\cos(\delta_0) + R2*\sin(\delta_0)) + E'_{q12}*(R1*\cos(\delta_0) - R3*\sin(\delta_0))*\tan(\delta_b) + E'_{q22}*(R2*\cos(\delta_0) - R4*\sin(\delta_0))*\tan(\delta_b)$$

$C20 = R3 - R1*\tan(\delta_b)$; $C21 = R4 - R2*\tan(\delta_b)$;

$$C22 = (R4*\cos(\delta_0) - R3*\sin(\delta_0)) + (R3*\cos(\delta_0) + R1*\sin(\delta_0))*\tan(\delta_b);$$

$$C23 = (R2*\cos(\delta_0) - R4*\sin(\delta_0)) + (R4*\cos(\delta_0) + R2*\sin(\delta_0))*\tan(\delta_b);$$

$C24 = R9 - R5*\tan(\delta_b)$; $C25 = R10 - R6*\tan(\delta_b)$; $C26 = R11 - R7*\tan(\delta_b)$;

$C27 = R12 - R8*\tan(\delta_b)$; $C28 = -C24*A_{57} - C25*A_{65} - C26*A_{37} - C27*A_{45}$;

$$C29 = -C24*A_{58} - C25*A_{66} - C26*A_{38} - C27*A_{46};$$

$$C30 = -C24*A_{59} - C25*A_{67} - C26*A_{39} - C27*A_{47};$$

$$C31 = C18 - C24*A_{510} - C25*A_{68} - C26*A_{311} - C27*A_{48};$$

$$C32 = C19 + C24*A_{55} + C25*A_{63} + C26*A_{35} + C27*A_{43};$$

$C33 = C20 + C24*A_{51} + C26*A_{31}$; $C34 = C21 + C24*A_{52} + C26*A_{32}$;

$$C35 = C22 + C24*A_{53} + C25*A_{61} + C26*A_{33} + C27*A_{41};$$

$$C36 = C23 + C24 * A_{54} + C25 * A_{62} + C26 * A_{34} + C27 * A_{42};$$

$$C37 = C24 * A_{511} + C25 * A_{69} + C26 * A_{312} + C27 * A_{49};$$

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