REFERENCES


[34] S. Peres, Dispatcher/Control Engineer, Electricité de France, Personal Communication, November 1996.


APPENDIX A

A-matrix Coefficient Expansions

The state-space system in (5.35) is given in expanded form in this appendix.

Placeholding Variables

\[ L_{\text{ppMD}} = \frac{1}{\text{Md}} + \frac{1}{\text{lf}} + \frac{1}{\text{lD}} \]
\[ L_{\text{pMQ}} = \frac{1}{\text{Mq}} + \frac{1}{\text{lQ1}} + \frac{1}{\text{lQ2}} \]
\[ r_{2\text{denom}} = (\text{ra}^2) + (\text{lq} + L_{\text{pMQ}})(\text{ld} + L_{\text{ppMD}}) \]
\[ L_{\text{numer}} = L_{\text{pMQ}} - L_{\text{ppMD}} + \text{lq} - \text{ld} \]
\[ w_0 = 2 \cdot \text{freqo} \cdot \pi \]
\[ p_{\text{ref}} = (\text{wo} \cdot \text{rf} \cdot L_{\text{ppMD}}) / \text{lf} \]
\[ p_{\text{relD}} = (\text{wo} \cdot \text{rD} \cdot L_{\text{ppMD}}) / \text{lD} \]
\[ p_{\text{relQ1}} = (\text{wo} \cdot \text{rQ1} \cdot L_{\text{pMQ}}) / \text{lQ1} \]
\[ p_{\text{relQ2}} = (\text{wo} \cdot \text{rQ2} \cdot L_{\text{pMQ}}) / \text{lQ2} \]

\[ dI_{\text{Qtheta}} = \left( (\text{ra} \cdot \text{UoR} \cdot \text{sin(thetao)}) - (\text{ra} \cdot \text{UoI} \cdot \text{cos(thetao)}) + \right. \]
\[ \left. (\text{ld} + L_{\text{ppMD}}) \cdot \text{UoR} \cdot \text{cos(thetao)} + \right. \]
\[ \left. (\text{ld} + L_{\text{ppMD}}) \cdot \text{UoI} \cdot \text{sin(thetao)} \right) / (r_{2\text{denom}}) \]

\[ dI_{\text{Dtheta}} = \left( - (\text{ra} \cdot \text{UoI} \cdot \text{sin(thetao)}) - (\text{ra} \cdot \text{UoR} \cdot \text{cos(thetao)}) + \right. \]
\[ \left. (\text{lq} + L_{\text{pMQ}}) \cdot \text{UoR} \cdot \text{sin(thetao)} - \right. \]
\[ \left. (\text{lq} + L_{\text{pMQ}}) \cdot \text{UoI} \cdot \text{cos(thetao)} \right) / (r_{2\text{denom}}) \]

\[ dI_{\text{Qf}} = \left( - \text{ra} \cdot (L_{\text{ppMD}} / \text{lf}) \right) / (r_{2\text{denom}}) \]
\[ dI_{\text{Df}} = \left( \text{(lq} + L_{\text{pMQ}}) \cdot (L_{\text{ppMD}} / \text{lf}) \right) / (r_{2\text{denom}}) \]
\[ dI_{\text{Qd}} = \left( - \text{ra} \cdot (L_{\text{ppMD}} / \text{ID}) \right) / (r_{2\text{denom}}) \]
\[ dI_{\text{Dd}} = \left( \text{(lq} + L_{\text{pMQ}}) \cdot (L_{\text{ppMD}} / \text{ID}) \right) / (r_{2\text{denom}}) \]
\[ dI_{\text{QQ1}} = \left( - (\text{ld} + L_{\text{ppMD}}) \cdot (L_{\text{pMQ}} / \text{lQ1}) \right) / (r_{2\text{denom}}) \]
\[ dI_{\text{DQ1}} = \left( \text{ra} \cdot (L_{\text{pMQ}} / \text{lQ1}) \right) / (r_{2\text{denom}}) \]
\[ dI_{\text{QQ2}} = \left( - (\text{ld} + L_{\text{ppMD}}) \cdot (L_{\text{pMQ}} / \text{lQ2}) \right) / (r_{2\text{denom}}) \]
\[ dI_{\text{DQ2}} = \left( \text{ra} \cdot (L_{\text{pMQ}} / \text{lQ2}) \right) / (r_{2\text{denom}}) \]

Row 1: the partial of d/dt(λₜ) with respect to each of the state variables

\[ a_{11} = 0.0 \]
\[ a_{12} = p_{\text{ref}} \cdot dI_{\text{Dtheta}} \]
\[ a_{13} = (\text{wo} \cdot \text{rf}) / \text{lf} + (\text{wo} \cdot \text{rf} \cdot L_{\text{ppMD}}) / (\text{lf} \cdot \text{lf}) - p_{\text{ref}} \cdot dI_{\text{Df}} \]
\[ a_{14} = (\text{wo} \cdot \text{rf} \cdot L_{\text{ppMD}}) / (\text{lf} \cdot \text{ID}) - p_{\text{ref}} \cdot dI_{\text{Dd}} \]
\[ a_{15} = p_{\text{ref}} \cdot dI_{\text{QQ1}} \]
\[ a_{16} = p_{\text{ref}} \cdot dI_{\text{DQ2}} ; \]
Row 2: the partial of \( \frac{d}{dt}(\lambda_d) \) with respect to each of the state variables

\[
\begin{align*}
a_{21} &= 0.0; \\
a_{22} &= \text{prelD} \times \text{dID}\text{theta}; \\
a_{23} &= ((\omega \times rD \times \text{LppMD}) / (\text{lD} \times \text{iD})) - \text{prelD} \times \text{dID}\text{f}; \\
a_{24} &= ((\omega \times rD \times \text{LppMD}) / (\text{lD} \times \text{iD})) - ((\omega \times rD) / \text{iD}) - \text{prelD} \times \text{dID}\text{d}; \\
a_{25} &= \text{prelD} \times \text{dID}\text{Q1}; \\
a_{26} &= \text{prelD} \times \text{dID}\text{Q2};
\end{align*}
\]

Row 3: the partial of \( \frac{d}{dt}(\lambda_{Q1}) \) with respect to each of the state variables

\[
\begin{align*}
a_{31} &= 0.0; \\
a_{32} &= \text{prelQ1} \times \text{dIQ}\text{theta}; \\
a_{33} &= \text{prelQ1} \times \text{dIQ}\text{f}; \\
a_{34} &= \text{prelQ1} \times \text{dIQ}\text{d}; \\
a_{35} &= ((\omega \times rQ1 \times \text{LpMQ}) / (\text{lQ1} \times \text{iQ1})) - ((\omega \times rQ1) / \text{iQ1}) - \text{prelQ1} \times (-\text{dIQQ1}); \\
a_{36} &= ((\omega \times rQ1 \times \text{LpMQ}) / (\text{lQ1} \times \text{iQ2})) - \text{prelQ1} \times (-\text{dIQQ2});
\end{align*}
\]

Row 4: the partial of \( \frac{d}{dt}(\lambda_{Q2}) \) with respect to each of the state variables

\[
\begin{align*}
a_{41} &= 0.0; \\
a_{42} &= \text{prelQ2} \times \text{dIQ}\text{theta}; \\
a_{43} &= \text{prelQ2} \times \text{dIQ}\text{f}; \\
a_{44} &= \text{prelQ2} \times \text{dIQ}\text{d}; \\
a_{45} &= ((\omega \times rQ2 \times \text{LpMQ}) / (\text{lQ2} \times \text{iQ2})) - \text{prelQ2} \times (-\text{dIQQ1}); \\
a_{46} &= ((\omega \times rQ2 \times \text{LpMQ}) / (\text{lQ2} \times \text{iQ2})) - ((\omega \times rQ2) / \text{iQ2}) - \text{prelQ2} \times (-\text{dIQQ2});
\end{align*}
\]

Row 5: the partial of \( \frac{d}{dt}(\omega) \) with respect to each of the state variables

\[
\begin{align*}
a_{51} &= 0 \\
a_{52} &= ((\text{LppMD}) / (2 \times \text{H} \times \text{lf})) \times \text{lambdafo} \times \text{dIQ}\text{theta} + \\
&((\text{LppMD}) / (2 \times \text{H} \times \text{iD})) \times \text{lambdafo} \times \text{dIQ}\text{f} - \\
&((\text{LpMQ}) / (2 \times \text{H} \times \text{iQ1})) \times \text{lambdaQ1o} \times \text{dID}\text{theta} - \\
&((\text{LpMQ}) / (2 \times \text{H} \times \text{iQ2})) \times \text{lambdaQ2o} \times \text{dID}\text{d} - \\
&((\text{Lnumer}) / (2 \times \text{H})) \times \text{ido} \times \text{dIQ}\text{theta} - ((\text{Lnumer}) / (2 \times \text{H})) \times \text{iqo} \times \text{dID}\text{theta};
\end{align*}
\]

\[
\begin{align*}
a_{53} &= ((\text{LppMD}) / (2 \times \text{H} \times \text{lf})) \times \text{iqo} + ((\text{LppMD}) / (2 \times \text{H} \times \text{iD})) \times \text{lambdafo} \times \text{dIQ}\text{f} + \\
&((\text{LppMD}) / (2 \times \text{H} \times \text{iD})) \times \text{lambdafo} \times \text{dIQ}\text{f} + \\
&((\text{LpMQ}) / (2 \times \text{H} \times \text{iQ1})) \times \text{lambdaQ1o} \times \text{dID}\text{f} + \\
&((\text{LpMQ}) / (2 \times \text{H} \times \text{iQ2})) \times \text{lambdaQ2o} \times \text{dID}\text{f} - ((\text{Lnumer}) / (2 \times \text{H})) \times \text{ido} \times \text{dIQ}\text{f} - \\
&((\text{Lnumer}) / (2 \times \text{H})) \times \text{iqo} \times \text{dID}\text{f};
\end{align*}
\]
\[ a_{54} = \frac{(L_{pMD})}{(2*H*lf)}*\lambda_{f0}*dIQd + \frac{(L_{pMD})}{(2*H*ID)}*\lambda_{d0}*dIQd + \]
\[ \frac{(L_{pMQ})}{(2*H*IQ1)}*\lambda_{Q1o}*dIDd + \frac{(L_{pMQ})}{(2*H*IQ2)}*\lambda_{Q2o}*dIDd - \frac{(L_{numer})}{(2*H)}*ido*dIQd - \]
\[ \frac{(L_{numer})}{(2*H)}*iqo*dIDd \]
\[ a_{55} = \frac{(L_{pMD})}{(2*H*lf)}*\lambda_{f0}*dIQQ1 + \frac{(L_{pMD})}{(2*H*ID)}*\lambda_{d0}*dIQQ1 - \frac{(L_{pMQ})}{(2*H*IQ1)}*ido - \]
\[ \frac{(L_{pMQ})}{(2*H*IQ1)}*\lambda_{Q1o}*dIDQ1 - \frac{(L_{pMQ})}{(2*H*IQ2)}*\lambda_{Q2o}*dIDQ1 - \frac{(L_{numer})}{(2*H)}*ido*dIQQ1 - \]
\[ \frac{(L_{numer})}{(2*H)}*iqo*dIDQ1 \]
\[ a_{56} = \frac{(L_{pMD})}{(2*H*lf)}*\lambda_{f0}*dIQQ2 + \frac{(L_{pMD})}{(2*H*ID)}*\lambda_{d0}*dIQQ2 - \]
\[ \frac{(L_{pMQ})}{(2*H*IQ1)}*\lambda_{Q1o}*dIDQ2 - \frac{(L_{pMQ})}{(2*H*IQ2)}*\lambda_{Q2o}*dIDQ2 - \frac{(L_{numer})}{(2*H)}*ido*dIQQ2 - \]
\[ \frac{(L_{numer})}{(2*H)}*iqo*dIDQ2 \]

Row 6: the partial of \(d/dt(\Theta)\) with respect to each of the variables

\[ a_{61} = \omega_{o} \]
\[ a_{62} = 0.0 \]
\[ a_{63} = 0.0 \]
\[ a_{64} = 0.0 \]
\[ a_{65} = 0.0 \]
\[ a_{66} = 0.0 \]

**B-matrix Coefficient Expansions**

\[ b_{11} = (PN/200*H)*\text{tmo} \]
\[ b_{12} = b_{13} = b_{14} = b_{15} = b_{16} = 0.0 \]
\[ b_{32} = -(\omega_{o}*\text{rf})/\text{Md} \]
\[ b_{12} = b_{22} = b_{42} = b_{52} = b_{62} = 0.0 \]
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Table A.1: Coefficient Expansion Variable Definitions
APPENDIX B

A-matrix Coefficients, Base Case

The $40 \times 40$ A-matrix for the Base Case load flow is given for the base case load flow as indicated in Figure 5.5. The matrix is divided into four parts on the following pages.
Table B.1: Columns 1-10 of State Matrix A

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Table B.4: Columns 31-40 of State Matrix A
APPENDIX C
MATLAB Source Code

C.1 initcond.m

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                                              
%  File Name: initcond.m                                                       
%                                                                              
%  Purpose:    Calculate initial conditions and internal machine parameters     
%             for state matrix development from given machine external         
%             parameters                                                       
%                                                                              
%  Notes:                                                                      
%                                                                              
%  1. Input Data                                                               
%                                                                              
%     This program uses the external machine parameters and time constants:    
%     ra        stator resistance, pu                                          
%     Xl        stator leakage inductance, pu                                  
%     Xd        d-axis synchronous reactance, pu                               
%     Xdp       d-axis transient reactance, pu                                 
%     Xdpp      d-axis sub-transient reactance, pu                             
%     Xq        q-axis reactance, pu                                           
%     Xqp       q-axis transient reactance, pu                                 
%     Xqpp      q-axis sub-transient reactance, pu                             
%     Tpdo      d-axis open circuit transient time constant, sec               
%     Tppdo     d-axis open circuit sub-transient time constant, sec           
%     Tpqo      q-axis open circuit transient time constant, sec               
%     Tppqo     q-axis open circuit sub-transient time constant, sec           
%                                                                              
%     From the Eurostag load flow:                                             
%     SN        nominal power (power base, MVA)                                
%     PN        turbine rated power, MW                                        
%     UN        nominal voltage (voltage base, kV)                             
%     Po        Polf/PN in pu                                                  
%     Qo        Qolf/PN in pu                                                  
%     U         Ulf/UN in pu                                                   
%     theta     voltage angle, degrees                                         
%                                                                              
%  2. Output                                                                   
%                                                                              
%     This program calculates the four-winding machine model values:            
%     ra        stator resistance, pu (Given, NOT calculated)                  
%     ld        d-axis armature flux, pu                                       
%     Md        d-axis mutual inductance, pu                                   
%     rD        d-axis damper winding resistance, pu                           
%     lD        d-axis damper winding reactance, pu                            
%     rf        rotor field resistance, pu                                     
%     lf        rotor field inductance, pu                                     
%     lq        q-axis armature flux, pu                                       
%     Mq        q-axis mutual inductance, pu                                   
%     rQ1       first q-axis damper winding resistance, pu                     
%     lQ1       first q-axis damper winding reactance, pu                      
%     rQ2       second q-axis damper winding resistance, pu                     
%     lQ2       second q-axis damper winding reactance, pu                      
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% This program calculates the initial conditions:
%
% UoR       real axis machine terminal voltage, pu
% UoI       imaginary axis machine terminal voltage, pu
% IoR       real axis machine node injection current, pu
% IoI       imaginary axis machine node injection current, pu
% thetaco  q-axis position, degrees
% udo       d-axis voltage, pu
% ugo       q-axis voltage, pu
% ido       d-axis current, pu
% iqo       q-axis current, pu
% lambdaado d-axis mutual flux
% lambdaaao q-axis mutual flux
% ifo       field excitation current, pu
% lambdaq1o first q-axis damper winding flux
% lambdaq2o second q-axis damper winding flux
% lambdaco d-axis damper winding flux
% lambdadco field flux
% cmo       shaft torque, pu
% efdo      field excitation voltage, pu

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%! Start of Program -----------------------------------------------------------%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%! Part One                                                                    %
%! Eurostag Machine Parameter Conversion - External to Internal               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%! Input Values ---------------------------------------------------------------% 
%! Machine Parameters (External)                                             

Xd = 1.8; 
Xpd = 0.3; 
Xppd = 0.25; 
Xq = 1.7; 
Xpq = 0.55; 
Xppq = 0.25; 
ra = 0.0025; 
Xl = 0.2; 
Tpdo = 8.0; 
Tppdo = 0.03; 
Tpqo = 0.4; 
Tppqo = 0.05; 

inputd = [Xd Xpd Xppd Tpdo Tppdo]; inputq = [Xq Xpq Xppq Tpqo Tppqo]; inputmut = [ra Xl];

%---------------------------------------------------------------End of Parameter Input %
%! Eurostag 4-winding calculations --------------------------------------------% 
%! d-axis values -------------------------------------------------------------% 

omegaco = 120*pi; 
Tpd = Xpd*(Tpdo/Xd); 
Tppd = Xppd*(Tppdo/Xpd); 

dB1 = (Tpdo + Tppdo)*omegaco; 
 dB2 = (Tpqo + Tppqo)*omegaco; 
 dC1 = (Tpdo*Tpddo)*(omegaco*omegaco); 
 dC2 = (Tpqo*Tppqo)*(omegaco*omegaco); 

ld = Xl; 
Md = Xd - Xl; 

 dX = (Md*ld)/Xd;
\[ dP = \left( \frac{dB1}{Md} \right) - \left( \frac{dB2}{dX} \right); \]
\[ dQ = \left( \frac{1}{dX} \right) - \left( \frac{1}{Md} \right); \]
\[ dB = dC2 - dC1 \cdot \left( \frac{ld}{Xd} \right); \]
\[ dRAD = \sqrt{1 - \left( 4 \cdot \frac{dB \cdot ld \cdot dQ}{dX \cdot dP} \right)^2}; \]
\[ dV1 = \left( \frac{-0.5 \cdot dP \cdot (1 + dRAD)}{dQ} \right); \]
\[ dV2 = \left( \frac{-0.5 \cdot dP \cdot (1 - dRAD)}{dQ} \right); \]
\[ dV = [dV1; dV2]; \]
\[ dU1 = \left( \frac{dB \cdot ld}{dX \cdot dV1} \right); \]
\[ dU2 = \left( \frac{dB \cdot ld}{dX \cdot dV2} \right); \]
\[ dU = [dU1; dU2]; \]
\[ dZ1 = \left( \frac{dB \cdot ld}{dX} \right) + \left( \frac{Md \cdot dV1 \cdot (dB2 + (dP/dQ))}{dX} \right); \]
\[ dZ2 = \left( \frac{dB \cdot ld}{dX} \right) + \left( \frac{Md \cdot dV2 \cdot (dB2 + (dP/dQ))}{dX} \right); \]
\[ dE1 = \left( \frac{dC1 - (dZ1/dX)}{Md \cdot (dU1 - dV1)} \right); \]
\[ dE2 = \left( \frac{dC1 - (dZ2/dX)}{Md \cdot (dU2 - dV2)} \right); \]
\[ dE = [dE1; dE2]; \]
\[ drf1 = \frac{1}{dE1}; \]
\[ drf2 = \frac{1}{dE2}; \]
\[ drf = [drf1; drf2]; \]
\[ dalf = \frac{(Tpd \cdot Md - Tpdo \cdot dX)}{(Tpdo - Tpd)}; \]
\[ darf = \frac{(Md + dalf)}{(Tpdo \cdot \omega_m)}; \]
% selection of rf value
\[ dummyd1 = \text{abs}(darf - drf1); \]
\[ dummyd2 = \text{abs}(darf - drf2); \]
if dummyd1 < dummyd2
  selectiond = 1;
else
  selectiond = 2;
end
\[ dF = \left( \frac{((dB2 + (dP/dQ))}{dX} \right) - \left( dE(\text{selectiond}) \right); \]
\[ rD = \frac{1}{dF}; \]
\[ lD = rD \cdot (dU(\text{selectiond})); \]
\[ rf = drf(\text{selectiond}); \]
\[ lf = rf \cdot (dV(\text{selectiond})); \]
% d-axis output
\[ outputd = [Md \; ld \; rf \; lf \; rD \; lD]; \]
%----------------------------------------------End of d-axis calculations %
% q-axis values ---------------------------------------------------------%
\[ Tpq = Xpq \cdot (Tpqo/Xq); \]
\[ Tppq = Xppq \cdot (Tpqo/Xpq); \]
\[ qB1 = (Tpqo + Tppqo) \cdot \omega_m; \]
\[ qB2 = (Tpq + Tppq) \cdot \omega_m; \]
\[ qC1 = (Tpqo \cdot Tppqo) \cdot (\omega_m \cdot \omega_m); \]
\[ qC2 = (Tpq \cdot Tppq) \cdot (\omega_m \cdot \omega_m); \]
\[ lq = Xl; \]
\[ Mq = Xq - Xl; \]
\[ qX = (Mq \cdot lq)/Xq; \]
\[ qP = (qB1/Mq) - (qB2/qX); \]
\[ qQ = (1/qX) - (1/Mq); \]
\[ qB = qC2 - qC1 \cdot (lq/Xq); \]
\[ qRAD = \sqrt{1 - \left( 4 \cdot qB \cdot lq \cdot qQ / \left( qX \cdot qP \cdot qP \right) \right)^2}; \]
\[ qV1 = \left( \frac{-0.5 \cdot qP \cdot (1 + qRAD)}{qQ} \right); \]
\[ qV2 = \left( \frac{-0.5 \cdot qP \cdot (1 - qRAD)}{qQ} \right); \]
\[ qV = [qV1; qV2]; \]
qU1 = (qB*lq)/(qX*qV1);
qU2 = (qB*lq)/(qX*qV2);
qU = [qU1; qU2];

qZ1 = (qB*lq) + (Mq*qV1)*(qB2+(qP/qQ));
qZ2 = (qB*lq) + (Mq*qV2)*(qB2+(qP/qQ));

qE1 = (qC1 - (qZ1/qX))/(Mq*(qU1-qV1));
qE2 = (qC1 - (qZ2/qX))/(Mq*(qU2-qV2));
qE = [qE1; qE2];

qrQ1 = 1/qE1;
qrQ2 = 1/qE2;
qrQ = [qrQ1; qrQ2];

qalQ1 = (Tpq*Mq - Tpqo*qX)/(Tpqo-Tpq);
qarQ1 = (Mq+qalQ1)/(Tpqo*omegao);

% selection of rQ value

dummyq1 = abs(qarQ1-qrQ1);
dummyq2 = abs(qarQ1-qrQ2);
if dummyq1 < dummyq2
    selectionq = 1;
else
    selectionq = 2;
end

qF = ((qB2+(qP/qQ))/qX) - (qE(selectionq));
rQ2 = 1/qF;
lQ2 = rQ2*(qU1(selectionq));
rQ1 = qrQ1(qU1(selectionq));
lQ1 = rQ1*(qV1(selectionq));

% q-axis output
outputq = [Mq lq rQ1 lQ1 rQ2 lQ2];

%----------------------------------------------End of q-axis calculations %
%----------------------------------------------End of External Value to Internal Value Conversion %
% Part Two %
% Eurostag Initial Conditions Calculation %
%----------------------------------------------End of Load Flow Values Input %
% Initial Conditions Calculation %
% machine terminal voltage

UoR = U*sin(theta);
UoI = U*cos(theta);

% machine node injection current
IoR = (Po*UoR + Qo*UoI) / (UoR*UoR + UoI*UoI);
IoI = (Po*UoI - Qo*UoR) / (UoR*UoR + UoI*UoI);

% q-axis position
thetao = atan((UoI+omegao*(Mq+lq)*IoR+ra*IoI)/(UoR+ra*IoR-omegao*(Mq+lq)*IoI));

% Park voltages and currents
udo = (UoR*sin(thetao)) - (UoI*cos(thetao));
uqo = (UoR*cos(thetao)) + (UoI*cos(thetao));
ido = ((IoR*sin(thetao)) - (IoI*cos(thetao)))*(100/SN);
jqo = ((IoR*sin(thetao)) + (IoI*cos(thetao)))*(100/SN);

% mutual fluxes
lambdaado = (-1.0/omegao)*uqo + ra*jqo + omegao*ld*ido;
lambdaaqo = (-1.0/omegao)*udo + ra*ido - omegao*lq*jqo;

% field excitation current
ifo = (lambdaado/Md) - ido;

% winding fluxes
lambdaQ1o = lambdaaqo;
lambdaQ2o = lambdaQ1o;
lambdado = lambdaado + ifo;
lambdafo = (lambdaado + (lf*ifo));

% shaft torque
cmo = ((-lambdaado*jqo) + (lambdaaqo*ido))*(100/SN);

% field excitation voltage
efdo = -Md*ifo;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% End of Initial Values Calculations %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% End of Program %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% 1996  A.F.Snyder, VPI&SU/LEG %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C.2 matrixab.m

\begin{verbatim}
% File Name: matrixab.m
% Purpose: Calculate Eurostag A and B Matrix coefficients from machine data and load flow initial conditions parameters
% Follows: initcond.m, using the output variables of:
% ra stator resistance, pu (Given, NOT calculated)
% ld d-axis armature flux, pu
% Md d-axis mutual inductance, pu
% rD d-axis damper winding resistance, pu
% lD d-axis damper winding reactance, pu
% rf rotor field resistance, pu
% 1f rotor field inductance, pu
% lq q-axis armature flux, pu
% Mq q-axis mutual inductance, pu
% rQ1 first q-axis damper winding resistance, pu
% 1Q1 first q-axis damper winding reactance, pu
% rQ2 second q-axis damper winding resistance, pu
% 1Q2 second q-axis damper winding reactance, pu
% UoR real axis machine terminal voltage, pu
% IoI imaginary axis machine terminal voltage, pu
% thetao q-axis position, degrees
% udo d-axis voltage, pu
% ugo q-axis voltage, pu
% ido d-axis current, pu
% iqo q-axis current, pu
% lambdaado d-axis mutual flux
% lambdaa0q q-axis mutual flux
% ifo field excitation current, pu
% lambdaQ1o first q-axis damper winding flux
% lambdaQ2o second q-axis damper winding flux
% lambdado d-axis damper winding flux
% cmo shaft torque, pu
% efdo field excitation voltage, pu
% Notes:
% Uses differential and algebraic state equation derivation from Eurostag V2.3 theory manual
% System in the form of DXdot = A DX + B DU, with DXdot consisting of:
% omega
% theta
% lambdaf
% lambdaad
% lambdaQ1
% lambdaQ2
% Start of Program

freqo = 60.0;
\end{verbatim}

H = 6.5;

% Temporary Variable Calculation

LppMD = (1/Md) + (1/lf) + (1/lD);
LppMQ = (1/Mq) + (1/lQ1) + (1/lQ2);
r2denom = (r2*r2) + (lq + LpMQ)*(ld + LppMD);
Lnumer = LpMQ - LppMD + lq - ld;

%------------------------------------------End of Variable Initialization %

% A Matrix Coefficients -------------------------------------------%

A11 = 0;
A12 = ((LppMD)/(2*H*lf))*lambdafo*dIQtheta + ((LppMD)/(2*H*lD))*lambdado*dIQtheta - ((LpMQ)/(2*H*lQ1))*lambdaQ1o*dIDtheta - ((LpMQ)/(2*H*lQ2))*lambdaQ2o*dIDtheta - ((Lnumer)/(2*H))*ido*dIQtheta - ((Lnumer)/(2*H))*iqo*dIDtheta;
A13 = ((LppMD)/(2*H*lf))*iqo + ((LppMD)/(2*H*lD))*lambdafo*dIQf + ((LpMQ)/(2*H*lQ1))*lambdaQ1o*dIDf - ((LpMQ)/(2*H*lQ2))*lambdaQ2o*dIDf - ((Lnumer)/(2*H))*ido*dIQf - ((Lnumer)/(2*H))*iqo*dIDf;
A14 = ((LppMD)/(2*H*lf))*lambdafo*dIQd + ((LppMD)/(2*H*lD))*lambdado*dIQd - ((LpMQ)/(2*H*lQ1))*lambdaQ1o*dIDd - ((LpMQ)/(2*H*lQ2))*lambdaQ2o*dIDd - ((Lnumer)/(2*H))*ido*dIQd - ((Lnumer)/(2*H))*iqo*dIDd;
A15 = ((LppMD)/(2*H*lf))*lambdafo*dIQQ1 + ((LppMD)/(2*H*lf))*lambdafo*dIQQ2 - ((LpMQ)/(2*H*lQ1))*lambdaQ1o*dIDQ1 - ((LpMQ)/(2*H*lQ2))*lambdaQ2o*dIDQ1 - ((Lnumer)/(2*H))*ido*dIQQ1 - ((Lnumer)/(2*H))*iqo*dIDQ1;
A16 = ((LppMD)/(2*H*lf))*lambdafo*dIQQ2 + ((LppMD)/(2*H*lf))*lambdafo*dIQQ2 - ((LpMQ)/(2*H*lQ1))*lambdaQ1o*dIDQ2 - ((LpMQ)/(2*H*lQ2))*lambdaQ2o*dIDQ2 - ((Lnumer)/(2*H))*ido*dIQQ2 - ((Lnumer)/(2*H))*iqo*dIDQ2;

%----------------------------------------------------------End of row one %

% The partial of d/dt(omega) with respect to each of the variables, row two

A21 = omegao;
A22 = 0.0;
A23 = 0.0;
A24 = 0.0;
A25 = 0.0;
A26 = 0.0;

%----------------------------------------------------------End of row two %

% The partial of d/dt(lambda) with respect to each of the variables, row 3
omo = 2*freqo*pi;
A31 = 0.0;
prelf = (omo*rf*LppMD)/lf;
A32 = prelf*dIDtheta;
A33 = -((omo*rf)/lf) + ((omo*rf*LppMD)/(lf*lf)) - prelf*dIDf;
A34 = ((omo*rf*LppMD)/(lf*1D)) - prelf*dIDD;
A35 = prelf*dIDQ1;
A36 = prelf*dIDQ2;
%------------------------------------------------------------End of row 3 %
% The partial of d/dt(lambda mad) with respect to each of the variables, row 4
A41 = 0.0;
prelD = (omo*rD*LppMD)/lD;
A42 = prelD*dIDtheta;
A43 = ((omo*rD*LppMD)/(lf*1D)) - prelD*dIDf;
A44 = ((omo*rD*LppMD)/(lD*1D)) - ((omo*rD)/lD) - prelD*dIDD;
A45 = prelD*dIDQ1;
A46 = prelD*dIDQ2;
%------------------------------------------------------------End of row 4 %
% The partial of d/dt(lambdaQ1) with respect to each of the variables, row 5
A51 = 0.0;
prelQ1 = (omo*rQ1*LpMQ)/(lQ1);
A52 = prelQ1*dIQtheta;
A53 = prelQ1*dIQf;
A54 = prelQ1*dIQd;
A55 = ((omo*rQ1*LpMQ)/(lQ1*lQ1)) - ((omo*rQ1)/lQ1) - prelQ1*(-dIQQ1);
A56 = ((omo*rQ1*LpMQ)/(lQ1*lQ2)) - prelQ1*(-dIQQ2);
%------------------------------------------------------------End of row 5 %
% The partial of d/dt(lambdaQ2) with respect to each of the variables, row 6
A61 = 0.0;
prelQ2 = (omo*rQ2*LpMQ)/(lQ2);
A62 = prelQ2*dIQtheta;
A63 = prelQ2*dIQf;
A64 = prelQ2*dIQd;
A65 = ((omo*rQ2*LpMQ)/(lQ1*lQ2)) - prelQ2*(-dIQQ1);
A66 = ((omo*rQ2*LpMQ)/(lQ2*lQ2)) - ((omo*rQ2)/lQ2) - prelQ2*(-dIQQ2);
%------------------------------------------------------------End of row 6 %
%-------------------------------------------------------------End of A Matrix Coefficient Calculation %
% B Matrix Coefficients -------------------------------------------------------------------% 
B11 = (PN/200*H)*cmo;
B12 = 0.0;
B21 = 0.0;
B22 = 0.0;
B31 = 0.0;
B32 = -(omo*rf)/Md;
B41 = 0.0;
B42 = 0.0;
B51 = 0.0;
B52 = 0.0;
B61 = 0.0;
B62 = 0.0;
%-------------------------------------------------------------End of B Matrix Coefficient Calculation %
% Matrix Formulation ---------------------------------------% 
MatrixA = [A11 A12 A13 A14 A15 A16
A21 A22 A23 A24 A25 A26
A31 A32 A33 A34 A35 A36
A41 A42 A43 A44 A45 A46
A51 A52 A53 A54 A55 A56
A61 A62 A63 A64 A65 A66];
MatrixB = [B11 B12
B21 B22
B31 B32
B41 B42
B51 B52
B61 B62];
NDIFF = 6;
%-------------------------------------------------------------End of Matrix Formulation %
%-------------------------------------------------------------End of Program %
% 1996 A.F. Snyder, VPI&SU/LEG

---
C.3  eigval.m

$%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%$
$% File Name: eigval.m
$% Purpose: Eigenvalues, Frequency, Damping, Left and Right Eigenvector
$% and Participation Factor calculation for a given a Matrix
$% Follows: matrixab.m
$% Variable Name          Definition
$% ----------------      ----------
$% MatrixA              A Matrix from matrixab.m
$% REV                  Right Eigenvector
$% LEV                  Scaled Left Eigenvector
$% eigenvalue(i)        Column Vector of i Eigenvalues (Eval)
$% wdn(i)               Damped Natural Frequency of ith Eval, rad/sec
$% fdn(i)               Damped Natural Frequency of ith Eval, Hz
$% damping(i)           Damping Coefficient of ith eval
$% PF(i,j)              Participation Factor, REV*LEV
$% MODE(i)              Oscillatory Modes
$%PFMODE(i,j)           Participation Factor of Mode(i)
$%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%$

% Start of Program------------------------------------------------------------%
% Eigenvalue and Right Eigenvector Calculation -----------------------------%
[REV, EVR] = eig(MatrixA);
% [REV, EVR] = eig(FULL_ARED) returns the matrices EVR and REV where
% EVR is a diagonal matrix of the eigenvalues of FULL_ARED and
% REV is a full matrix whose columns are the corresponding
% right eigenvectors so that FULL_ARED * REV = REV * EVR

eigenvalue = diag(EVR);
% *eigenvalue* is a column vector containing the eigenvalues
%------Matlab Default Function, Left Eigenvector not Normalized-------------%
[LEV, EVL] = eig(FULL_ARED');
%LEV = LEV';
% Creates diagonal matrix EVL of eigenvalues and a full matrix
% LEV whose columns are the corresponding left eigenvectors satisfying
% LEV * FULL_ARED = EVL * LEV
% The eigenvalues in EVR and EVL are the same, but not in the same order
%--------------------------------------------------------------------------%
% Normalized Left Eigenvector Calculation -----------------------------------%
LEV = inv(REV);
%--------------------------------------------------------------------------End of Eigenvector Calcuulation %
% Participation Factor Calculation -----------------------------------------%
% Note: NOT for each Mode, but for each Eigenvalue
for i = 1:NDIFF
    for j = 1:NDIFF
        PF(i,j) = REV(i,j) * LEV(j,i);
    end
end
% Calculates the participation factors, dimensionless measures of the
% state xk in mode i (Pki = pki * qki, p = right eigenvector, 
% q = left eigenvector)

% Oscillatory Mode Participation Factor Calculation -------------------------%
% Eliminate the conjugate eigenvalues and calculate the participation 
% factor associated with each mode of oscillation
% LOOP allows the elimination of the conjugate eigenvalues 
% (The complex conjugate existing in "eigenvalue")
% OSC = number of oscillatory modes
% MODE = vector with one eigenvalue associated with each oscillatory 
% mode
% PFMODE = matrix with the participation factor of each oscillatory mode

LOOP=0;
OSC=1;
for i=1:NDIFF-1
    if LOOP == 0 % do not eliminate the eigenvalue
        if abs(imag(eigenvalue(i))) > 0
            % complex eigenvalue
            if (eigenvalue(i) == conj(eigenvalue(i+1)))
                % conjugate eigenvalue
                MODE(OSC)=eigenvalue(i);
                for j=1:NDIFF
                    PFMODE(j,OSC)=PF(j,i)+PF(j,i+1);
                    % sum of the two participation factors
                    % of the two eigenvalues
                end
                LOOP=1;
                % allow the elimination of the conjugate 
                % during the next iteration
            else
                % real eigenvalue case
                MODE(OSC)=eigenvalue(i);
                for j=1:NDIFF
                    PFMODE(j,OSC)=PF(j,i);
                end
            end
            OSC=OSC+1;
        else
            LOOP=0;
        end
    end
end
OSC=OSC-1;
%---------------------------------End of Participation Factor Calculation %

% Results Output --------------------------------------------------------%
% Save Participation Factors in the file "eigvalpf.afs"
% lines = oscillatory modes 
% columns = state variables

fid = fopen('eigvalpf.afs','w');
i=0;
fprintf(fid,'%8.4f',i);
for i=1:NDIFF
    fprintf(fid,'%8.4f',i);
end
fprintf(fid,'
');
for i=1:OSC
    fprintf(fid,'%8.4f ',i);
    for j=1:NDIFF
        fprintf(fid,'%8.4f',i);
    end
end

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fprintf(fid,'%8.4f',PFMODE(j,i));
end
fprintf(fid,"
");
fclose(fid);

% Save the eigenvalues, oscillation frequency and damping in the file
% "eigvaldamp.afs"

fid = fopen('eigvaldamp.afs','w');
for i=1:OSC
    wdn(i)=abs(imag(MODE(i)));% wdn(i) = oscillation corresponding to each (eigenvalue) MODE(i)
    sgma(i)=real(MODE(i));% sgma(i) = real part of each MODE(i)
    fdn(i)=wdn(i)/(2*pi);% fdn(i) = frequency of the oscillatory mode of each (eigenvalue) MODE(i)
    damping(i)=-sgma(i)/sqrt(sgma(i)*sgma(i)+wdn(i)*wdn(i));% damping(i) = damping coefficient corresponding to each (eigenvalue) MODE(i)
    fprintf(fid,'%8.0f %10.4f %10.4f %10.4f %10.4f
',i, sgma(i), imag(MODE(i)), fdn(i),
    damping(i));
end

%---------------------------------------------------End of Results Output %
%---------------------------------------------------------------End of Program %

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                                              %
%  1996  A.F.Snyder, VPI&SU/LEG                                              %
%                                                                              %
%  In collaboration with:                                                     %
%    M. P. Houry, EDF                                                         %
%    J. C. Passerelergue, LEG                                                 %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C.4  eigalyze.m

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                                              
%      Filename: eigalyze.m                                                    
%                                                                              
%       Purpose:  Eigenvalues, Frequency, Damping, Left and Right Eigenvector  
%                 and Participation Factor calculation for the Eurostag-       
%                 provided state-space system                                  
%                                                                              
%      Variable Name          Definition                                       
%      -------------          ----------                                       
%      AREDReduced A Matrix                                 
%      REV Ri ght Eigenvector                                
%      LEV Scaled Left Eigenvector                          
%      eigenvalue(i) Column Vector of i Eigenvalues (Eval)            
%      wdn(i) Damped Natural Frequency of ith Eval, rad/sec    
%      fdn(i) Damped Natural Frequency of ith Eval, Hz         
%      damping(i) Damping Coefficient of ith eval                  
%      PF(i,j) Participation Factor, REV*LEV                    
%      MODE(i) Oscillatory Modes                                
%      PFMODE(i,j) Participation Factor of Mode(i)                  
%                                                                              
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Eurostag Interface Notes:

Using the Eurostag algebraic-differential state equations, the state equations are linearized, yielding the system
\[
Xdot = f(X,Y) -> xdot = f0 + Mx + Ny \\
0 = g(X,Y) -> 0 = g0 + Px + Qy
\]

where \( x = X - X0 \)  
\( y = Y - Y0 \)  
\( f0 = f(X0, Y0) \)  
\( g0 = g(X0, Y0) \)

The linearized system information from Eurostag is available in three different file types:
- .linear ASCII file with all variables
- .lineared ASCII file, algebraic equations are eliminated
- .mat Matlab readable file

The .linear and .mat files contain the following:

- NDIFF = Number of differential variables (dimension X)
- NVAR = Total number of variables (differential and algebraic, dimension X + Y)
- A matrix = \[
\begin{bmatrix}
M & N \\
P & Q
\end{bmatrix}
\] = sparse matrix formed by I J A(I,J)
- V0 vector = X0  
y0  
f0
- F0 vector = f0  
g0

The .lineared file contains the same information except that the matrix ARED = M-N*invQ*P is created in lieu of the matrix A.

The information derived from the .linear, .lineared and .mat files is complemented by another ASCII file, .keylin, which contains the information for the differential state equations and their corresponding macroblocks.

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Start of Program


load lpmu_gen212.mat

% Load "filename.mat" (must be changed for each case)

% Eurostag V2.4 output file containing linearized state variable data

NDIM = NVAR;

% NDIM = Total number of variables

jaco = sparse(I,J,A);

% sparse - Builds sparse matrix jaco (Jacobian) with matrix coefficient A(i) at the Jth column and the Ith row

% Matrix A Sub-Matrix Formation -----------------------------------------%

M = jaco(1:NDIFF,1:NDIFF);
N = jaco(1:NDIFF,NDIFF+1:NDIM);
P = jaco(NDIFF+1:NDIM,1:NDIFF);
Q = jaco(NDIFF+1:NDIM,NDIFF+1:NDIM);

% Sparse sub-matrices M, N, P and Q built from Jacobian matrix

% Reduced A Matrix Calculation ------------------------------------------%

ARED = (M-N*inv(Q)*P);

% Reduced A matrix calculation (ARED) = elimination of the algebraic state variables

FULL_ARED = full(ARED);

% FULL - Conversion of "sparse" matrix ARED into "full" matrix FULL_ARED

%--------------------------------------------End of A Matrix Construction %

% Eigenvalue and Right Eigenvector Calculation --------------------------%

[REV,EVR] = eig(FULL_ARED);

% [REV,EVR] = eig(FULL_ARED) returns the matrices EVR and REV where EVR is a diagonal matrix of the eigenvalues of FULL_ARED and REV is a full matrix whose columns are the corresponding right eigenvectors so that FULL_ARED * REV = REV * EVR

for i=1:NDIFF
    for j=1:NDIFF
        rrev(i,j) = real(REV(i,j));
        irev(i,j) = imag(REV(i,j));
    end
end

eigenvalue = diag(EVR);

% "eigenvalue" is a column vector containing the eigenvalues

%-------Matlab Default Function, Left Eigenvector not Normalized---------%

[LEV,EVL] = eig(FULL_ARED');%

LEV = LEV';

% Creates diagonal matrix EVL of eigenvalues and a full matrix LEV whose columns are the corresponding left eigenvectors satisfying LEV * FULL_ARED = EVL * LEV

% The eigenvalues in EVR and EVL are the same, but not in the same order

%--------------------------------------------End of A Matrix Construction %

% Normalized Left Eigenvector Calculation -------------------------------%
LEV=inv(REV);

%------------------------------------------End of Eigenvector Calculation %

% Participation Factor Calculation ---------------------------------------------%

% Note: NOT for each Mode, but for each Eigenvalue

for i = 1:NDIFF
    for j = 1:NDIFF
        PF(i,j) = abs(REV(i,j) * LEV(j,i));
    end
end

% Calculates the participation factors, dimensionless measures of the
% state xk in mode i (Pki = pki * qki, p = right eigenvector,
% q = left eigenvector). Returns the magnitude of the complex number,
% the value of interest (Kundur, p. 777)

% Oscillatory Mode Participation Factor Calculation --------------------------%

% Eliminate the conjugate eigenvalues and calculate the participation
% factor associated with each mode of oscillation
% LOOP allows the elimination of the conjugate eigenvalues
% (The complex conjugate existing in "eigenvalue")
% OSC = number of oscillatory modes
% MODE = vector with one eigenvalue associated with each oscillatory mode
% PFMODE = matrix with the participation factor of each oscillatory mode

LOOP=0;
OSC=1;
for i=1:NDIFF-1
    if LOOP == 0 % do not eliminate the eigenvalue
        if abs(imag(eigenvalue(i))) > 0 % complex eigenvalue
            if (eigenvalue(i) == conj(eigenvalue(i+1))) % conjugate eigenvalue
                MODE(OSC)=eigenvalue(i);
                for j=1:NDIFF
                    PFMODE(j,OSC)=PF(j,i)+PF(j,i+1);
                end
                LOOP=1;
            end
        else % real eigenvalue case
            MODE(OSC)=eigenvalue(i);
            for j=1:NDIFF
                PFMODE(j,OSC)=PF(j,i);
            end
        end
    else % allow the elimination of the conjugate during the next iteration
        LOOP=0;
    end
    OSC=OSC+1;
end
OSC=OSC-1;

%---------------------------------End of Participation Factor Calculation %

% Results Output -----------------------------------------------

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% Save the Eigenvalues in:
% "FILENAME-eig.afs"

fid = fopen('1pmu_gen212-eig.afs','w');
for i=1:NDIFF
  re(i) = real(eigenvalue(i));
  ie(i) = imag(eigenvalue(i));
  fprintf(fid,'%8.0f %11.5f %11.5f\n', i, re(i), ie(i));
end

% Save the Modes, Oscillation Frequency and Damping in:
% "FILENAME-frdm.afs"

fid = fopen('1pmu_gen212-frdm.afs','w');
for i=1:OSC
  wdn(i)=abs(imag(MODE(i)));  % wdn(i) = oscillation corresponding to each (eigenvalue) MODE(i)
  sgma(i)=real(MODE(i));       % sgma(i) = real part of each MODE(i)
  fdn(i)=wdn(i)/(2*pi);        % fdn(i) = frequency of the oscillatory mode of each (eigenvalue) MODE(i)
  damping(i)=-sgma(i)/sqrt(sgma(i)*sgma(i)+wdn(i)*wdn(i));  % damping(i) = damping coefficient corresponding to each (eigenvalue) MODE(i)
  fprintf(fid,'%8.0f %10.4f %10.4f %10.4f %10.4f\n',i, sgma(i), imag(MODE(i)), fdn(i), damping(i));
end

% Save Right Eigenvectors in:
% "FILENAME-rev.afs"
% columns = vector corresponding to each eigenvalue

fid = fopen('1pmu_gen212-rev.afs','w');
for i=1:NDIFF
  fprintf(fid,'%8.4f',i);
  for j=1:NDIFF
    fprintf(fid,'%8.4f %8.4f',rrev(j,i),irev(j,i));
  end
  fprintf(fid,'
');
end
fclose(fid);

% Save Participation Factors in:
% "FILENAME-pf.afs"
% lines = oscillatory modes
% columns = state variables

fid = fopen('1pmu_gen212-pf.afs','w');
i=0;
i=0;
for i=1:OSC
  fprintf(fid,'%8.4f',i);
  for j=1:NDIFF
    fprintf(fid,'%8.4f %8.4f',PFMODE(j,i));
  end
  fprintf(fid,'
');
for i=1:OSC
  fprintf(fid,'%8.4f',i);
  for j=1:NDIFF
    fprintf(fid,'%8.4f %8.4f',PFMODE(j,i));
  end
  fprintf(fid,'
');
end
fclose(fid);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
End of Results Output %
Aaron F. Snyder was born in Parkersburg, West Virginia, and graduated from Parkersburg South High School in 1988. He attended Virginia Polytechnic Institute and State University (Virginia Tech) in Blacksburg, Virginia, where he obtained his Bachelor of Science in Electrical Engineering degree in 1993, with minors in math and music. He then decided to continue his studies at Virginia Tech, returning in the fall of 1993 as a Master of Science candidate in electrical engineering. To pursue his interest in music, he auditioned to enter into the music program at Virginia Tech, and was accepted in the spring of 1994 as a candidate for the Bachelor of Arts in Music Performance.

At the end of his coursework for his master's degree, he applied for and was accepted as the first student in an exchange program between Virginia Tech and the Institut National Polytechnique de Grenoble (I.N.P.G.) in Grenoble, France. Through this program, he completed a Diplôme d'Etudes Approfondies (master’s equivalent degree) in June 1996 at I.N.P.G. He is currently a Doctorat de l'I.N.P.G. (Ph.D.) candidate in electrical engineering at I.N.P.G.

He is a member of the Institute of Electrical and Electronics Engineers, the National Society for Professional Engineers, and a founding member of the Virginia Tech Gamma Mu Chapter of Delta Omicron International Music Fraternity.