

EENG 577 M3 Synchronous Generator

E. Hildenbrandt
D. Davis
J. Brownlee

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PART 1

1

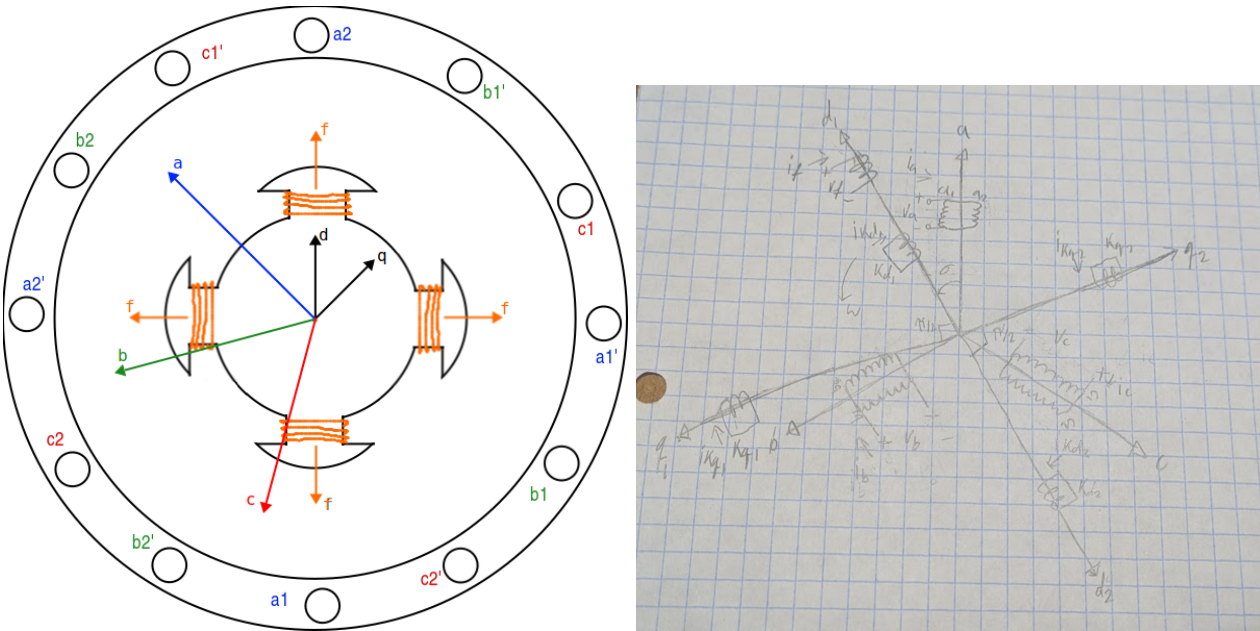


Fig. 1. Cross-section of generator, not to scale. The quadrature (q) axis is 90° electrical from the direct (d) axis. Because this is a 4-pole generator, there are 720° electrical for every 360° mechanical. The analysis would be the same if a, b, c, d, and q were rotated a multiple of 90° mechanical (180° electrical).

2.1: State Space, Case 1 (no damping)

Assuming the generator is balanced and rotating at $f_s=60\text{Hz}$:

$$\begin{aligned} L_{aa} &\cong L_{bb} \cong L_{cc} \cong L_{sa} + L_{sv} \cos(2\theta + \phi) \\ \text{where } [\phi_a, \phi_b, \phi_c] &= [0, -\frac{4\pi}{3}, -\frac{2\pi}{3}] \text{ and } \theta = \omega t = 377 \cdot t \end{aligned}$$

Ignoring the damping windings the state space equations can be written as such:

$$\begin{aligned} \begin{bmatrix} v_a \\ v_b \\ v_c \\ v_f \\ v_{kd} \\ v_{kq} \end{bmatrix} &= \begin{bmatrix} r_s + r_l & 0 & 0 & 0 & 0 & 0 \\ 0 & r_s + r_l & 0 & 0 & 0 & 0 \\ 0 & 0 & r_s + r_l & 0 & 0 & 0 \\ 0 & 0 & 0 & r_f & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \\ i_f \\ i_{kd} \\ i_{kq} \end{bmatrix} + \\ \frac{d}{dt} \begin{bmatrix} L_{sa} + L_{sv} \cos(2\theta) + L_l & -L_{ma} + L_{mv} \cos(2\theta - 2\pi/3) & -L_{ma} + L_{mv} \cos(2\theta - 4\pi/3) & L_{afm} \cos(2\theta) & 0 & 0 \\ -L_{ma} + L_{mv} \cos(2\theta - 2\pi/3) & L_{sa} + L_{sv} \cos(2\theta - 4\pi/3) + L_l & -L_{ma} + L_{mv} \cos(2\theta) & L_{afm} \cos(2\theta - 2\pi/3) & 0 & 0 \\ -L_{ma} + L_{mv} \cos(2\theta - 4\pi/3) & -L_{ma} + L_{mv} \cos(2\theta) & L_{sa} + L_{sv} \cos(2\theta - 2\pi/3) + L_l & L_{afm} \cos(2\theta - 4\pi/3) & 0 & 0 \\ L_{afm} \cos(2\theta) & L_{afm} \cos(2\theta - 2\pi/3) & L_{afm} \cos(2\theta - 4\pi/3) & L_{ff} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \\ i_f \\ i_{kd} \\ i_{kq} \end{bmatrix} \end{aligned}$$

2.2: State Space, Case 2

$$\begin{aligned} \begin{bmatrix} v_a \\ v_b \\ v_c \\ v_f \\ v_{kd} \\ v_{kq} \end{bmatrix} &= \begin{bmatrix} r_s + r_l & 0 & 0 & 0 & 0 & 0 \\ 0 & r_s + r_l & 0 & 0 & 0 & 0 \\ 0 & 0 & r_s + r_l & 0 & 0 & 0 \\ 0 & 0 & 0 & r_f & 0 & 0 \\ 0 & 0 & 0 & 0 & r_k d & 0 \\ 0 & 0 & 0 & 0 & 0 & r_k q \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \\ i_f \\ i_{kd} \\ i_{kq} \end{bmatrix} + \\ \frac{d}{dt} \begin{bmatrix} L_{sa} + L_{sv} \cos(2\theta) + L_l & -L_{ma} + L_{mv} \cos(2\theta - 2\pi/3) & -L_{ma} + L_{mv} \cos(2\theta - 4\pi/3) & L_{afm} \cos(2\theta) & L_{adkm} \cos(2\theta) & -L_{akqm1} \cos(2\theta) \\ -L_{ma} + L_{mv} \cos(2\theta - 2\pi/3) & L_{sa} + L_{sv} \cos(2\theta - 4\pi/3) + L_l & -L_{ma} + L_{mv} \cos(2\theta) & L_{afm} \cos(2\theta - 2\pi/3) & L_{akdm} \cos(2\theta - 2\pi/3) & -L_{akqm1} \cos(2\theta - 2\pi/3) \\ -L_{ma} + L_{mv} \cos(2\theta - 4\pi/3) & -L_{ma} + L_{mv} \cos(2\theta) & L_{sa} + L_{sv} \cos(2\theta - 2\pi/3) + L_l & L_{afm} \cos(2\theta - 4\pi/3) & L_{akdm} \cos(2\theta - 4\pi/3) & -L_{akqm1} \cos(2\theta - 4\pi/3) \\ L_{afm} \cos(2\theta) & L_{afm} \cos(2\theta - 2\pi/3) & L_{afm} \cos(2\theta - 4\pi/3) & L_{ff} & L_{kdf} & L_{kqf} \\ L_{adkm} \cos(2\theta) & L_{akdm} \cos(2\theta - 2\pi/3) & L_{akdm} \cos(2\theta - 4\pi/3) & L_{kdf} & L_{kd1kd1} & 0 \\ -L_{akqm1} \cos(2\theta) & -L_{akqm1} \cos(2\theta - 2\pi/3) & -L_{akqm1} \cos(2\theta - 4\pi/3) & L_{kqf} & 0 & L_{kq1kq1} \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \\ i_f \\ i_{kd} \\ i_{kq} \end{bmatrix} \end{aligned}$$

3.1

$$V = RI + \frac{d}{dt} LI \tag{1}$$

$$A = -L^{-1}R \tag{2}$$

$$B = L^{-1} \tag{3}$$

In compact matrix from.

$$X' = AX + BU$$

Where without damping

$$A = - \begin{bmatrix} 1.95 + 0.05 \cos(2\theta) + L_l & -0.80 - 0.05 \cos(2\theta - \frac{2\pi}{3}) & -0.80 - 0.05 \cos(2\theta - \frac{4\pi}{3}) & 26.1 \cos(2\theta) \\ -0.80 - 0.05 \cos(2\theta - \frac{2\pi}{3}) & 1.95 + 0.05 \cos(2\theta) + L_l & -0.80 - 0.05 \cos(2\theta - \frac{4\pi}{3}) & 26.1 \cos(2\theta - \frac{2\pi}{3}) \\ -0.80 - 0.05 \cos(2\theta - \frac{4\pi}{3}) & -0.80 - 0.05 \cos(2\theta - \frac{2\pi}{3}) & 1.95 + 0.05 \cos(2\theta) + L_l & 26.1 \cos(2\theta - \frac{4\pi}{3}) \\ 26.1 \cos(2\theta) & 26.1 \cos(2\theta - \frac{2\pi}{3}) & 26.1 \cos(2\theta - \frac{4\pi}{3}) & 444 \end{bmatrix} - 1 \cdot$$

$$\left(\begin{bmatrix} 7.4 \cdot 10^{-4} + r_l & 0 & 0 & 0 \\ 0 & 7.4 \cdot 10^{-4} + r_l & 0 & 0 \\ 0 & 0 & 7.4 \cdot 10^{-4} + r_l & 0 \\ 0 & 0 & 0 & 0.086 \end{bmatrix} + \begin{bmatrix} -0.1 \sin(2\theta) + L_l & -0.1 \sin(2\theta - \frac{2\pi}{3}) & -0.1 \sin(2\theta - \frac{4\pi}{3}) & -52.2 \sin(2\theta) \\ -0.1 \sin(2\theta - \frac{2\pi}{3}) & -0.1 \sin(2\theta) + L_l & -0.1 \sin(2\theta - \frac{4\pi}{3}) & -52.2 \sin(2\theta - \frac{2\pi}{3}) \\ -0.1 \sin(2\theta - \frac{4\pi}{3}) & -0.1 \sin(2\theta - \frac{2\pi}{3}) & -0.1 \sin(2\theta) & -52.2 \sin(2\theta - \frac{4\pi}{3}) \\ -52.2 \sin(2\theta) & -52.2 \sin(2\theta - \frac{2\pi}{3}) & -52.2 \sin(2\theta - \frac{4\pi}{3}) & 0 \end{bmatrix} \right) \cdot 10^{-3} H^{-1}$$

and

$$B = \begin{bmatrix} 1.95 + 0.05 \cos(2\theta) + L_l & -0.80 - 0.05 \cos(2\theta - \frac{2\pi}{3}) & -0.80 - 0.05 \cos(2\theta - \frac{4\pi}{3}) & 26.1 \cos(2\theta) \\ -0.80 - 0.05 \cos(2\theta - \frac{2\pi}{3}) & 1.95 + 0.05 \cos(2\theta) + L_l & -0.80 - 0.05 \cos(2\theta - \frac{4\pi}{3}) & 26.1 \cos(2\theta - \frac{2\pi}{3}) \\ -0.80 - 0.05 \cos(2\theta - \frac{4\pi}{3}) & -0.80 - 0.05 \cos(2\theta - \frac{2\pi}{3}) & 1.95 + 0.05 \cos(2\theta) + L_l & 26.1 \cos(2\theta - \frac{4\pi}{3}) \\ 26.1 \cos(2\theta) & 26.1 \cos(2\theta - \frac{2\pi}{3}) & 26.1 \cos(2\theta - \frac{4\pi}{3}) & 444 \end{bmatrix}^{-1} \cdot 10^{-3} H^{-1}$$

With damping

$$A = - \begin{bmatrix} 7.4 \cdot 10^{-4} + r_l & 0 & 0 & 0 & 0 & 0 \\ 0 & 7.4 \cdot 10^{-4} + r_l & 0 & 0 & 0 & 0 \\ 0 & 0 & 7.4 \cdot 10^{-4} + r_l & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.086 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1.58 \cdot 10^{-4} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1.227 \cdot 10^{-4} \end{bmatrix}$$

$$\begin{bmatrix} -0.1 \sin(2\theta) + L_l & -0.1 \sin(2\theta - \frac{2\pi}{3}) & -0.1 \sin(2\theta - \frac{4\pi}{3}) & -52.2 \sin(2\theta) & -0.894 \sin(2\theta) & 0.894 \sin(2\theta) \\ -0.1 \sin(2\theta - \frac{2\pi}{3}) & -0.1 \sin(2\theta) + L_l & -0.1 \sin(2\theta - \frac{4\pi}{3}) & -52.2 \sin(2\theta - \frac{2\pi}{3}) & -0.894 \sin(2\theta - \frac{2\pi}{3}) & 0.894 \sin(2\theta - \frac{2\pi}{3}) \\ -0.1 \sin(2\theta - \frac{4\pi}{3}) & -0.1 \sin(2\theta - \frac{2\pi}{3}) & -0.1 \sin(2\theta) + L_l & -52.2 \sin(2\theta - \frac{4\pi}{3}) & -0.894 \sin(2\theta - \frac{4\pi}{3}) & 0.894 \sin(2\theta - \frac{4\pi}{3}) \\ -52.2 \sin(2\theta) & -52.2 \sin(2\theta - \frac{2\pi}{3}) & -52.2 \sin(2\theta - \frac{4\pi}{3}) & 0 & 0 & 0 \\ -0.894 \sin(2\theta) & -0.894 \sin(2\theta - \frac{2\pi}{3}) & -0.894 \sin(2\theta - \frac{4\pi}{3}) & 0 & 0 & 0 \\ 0.894 \sin(2\theta) & 0.894 \sin(2\theta - \frac{2\pi}{3}) & 0.894 \sin(2\theta - \frac{4\pi}{3}) & 0 & 0 & 0 \end{bmatrix}$$

$$\times 10^{-3} H^{-1}.$$

and

$$b = \begin{bmatrix} 1.95 + 0.05 \cos(2\theta) + L_l & -0.80 - 0.05 \cos(2\theta - 2\pi/3) & -0.08 - 0.05 \cos(2\theta - 4\pi/3) & 26.1 \cos(2\theta) & 0.447 \cos(2\theta) & -0.670 \cos(2\theta) \\ -0.80 - 0.05 \cos(2\theta - 2\pi/3) & 1.95 + 0.05 \cos(2\theta - 4\pi/3) + L_l & -0.80 - 0.05 \cos(2\theta) & 26.1 \cos(2\theta - 2\pi/3) & 0.447 \cos(2\theta - 2\pi/3) & -0.670 \cos(2\theta - 2\pi/3) \\ -0.80 - 0.05 \cos(2\theta - 4\pi/3) & 1.95 + 0.05 \cos(2\theta) & -0.80 - 0.05 \cos(2\theta - 2\pi/3) + L_l & 26.1 \cos(2\theta - 4\pi/3) & 0.447 \cos(2\theta - 4\pi/3) & -0.670 \cos(2\theta - 4\pi/3) \\ 26.1 \cos(2\theta) & 26.1 \cos(2\theta - 2\pi/3) & 26.1 \cos(2\theta - 4\pi/3) & 444 & 6.29 & 5.05 \\ 0.447 \cos(2\theta) & 0.447 \cos(2\theta - 2\pi/3) & 0.447 \cos(2\theta - 4\pi/3) & 6.29 & 0.1254 & 0 \\ -0.670 \cos(2\theta) & -0.670 \cos(2\theta - 2\pi/3) & -0.670 \cos(2\theta - 4\pi/3) & 5.05 & 0 & 0.3762 \end{bmatrix}^{-1} \times 10^{-3} H^{-1}$$

PART 2

1.1

The necessary excitation field current is given by $i_f = \frac{V_f}{r_f} = \frac{338}{0.0860} = 3930[A]$. The initial conditions at time $t = 0$ can be calculated by dividing the given phase voltages on the bus bar with the magnitude of the load resistance and reactance.

1.2

$$I_a = \frac{S}{\sqrt{3}V_{phi}} = 32950[A]$$

$$Rl = \frac{S \cdot pf}{I_A^2} = 0.5463[\Omega]$$

$$Xl = \frac{S \cdot \sqrt{1 - pf^2}}{I_a^2} = 0.2646[\Omega]$$

$$V_a = \frac{20 * 10^3}{\sqrt{(3)}} \sqrt{(2)} \cos(\omega t) = V_m \cos(0)$$

$$V_b = V_m \cos(0 - 2\pi/3)$$

$$V_c = V_m \cos(0 - 4\pi/3)$$

$$i_a = \frac{V_a}{\sqrt{R_l^2 + X_l^2}}$$

$$i_b = \frac{V_b}{\sqrt{R_l^2 + X_l^2}}$$

$$i_c = \frac{V_c}{\sqrt{R_l^2 + X_l^2}}$$

The initial conditions are put into a column vector as follows.

$$\begin{bmatrix} 26904 \\ -13452 \\ -13452 \\ 3930 \\ 0 \\ 0 \end{bmatrix}$$

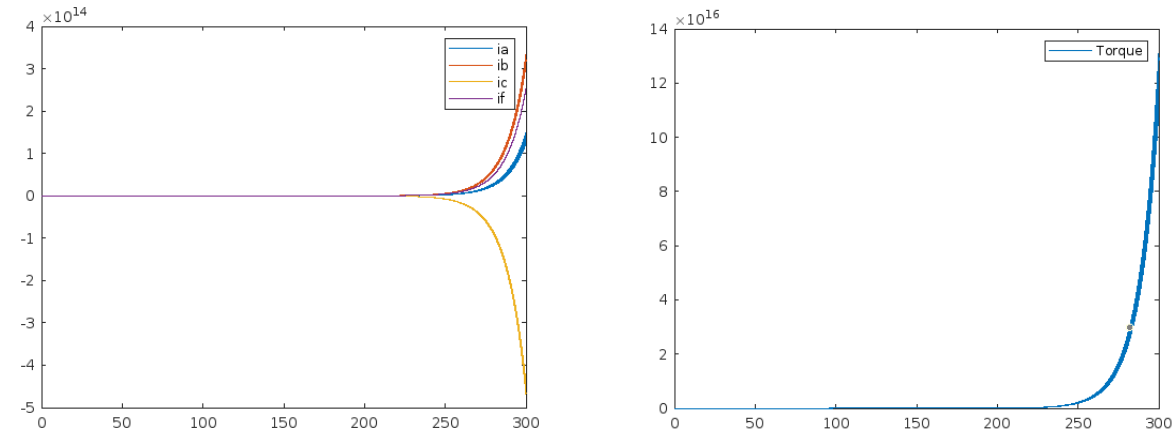


Fig. 2. Current values for i_a, i_b, i_c , and i_f (left) and the torque (right)

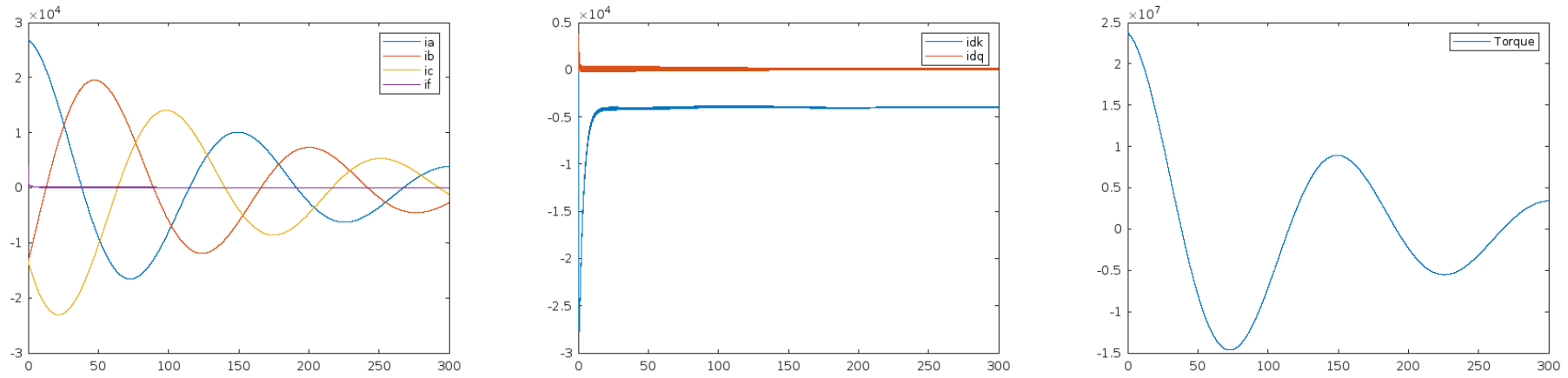


Fig. 2. Current values for i_a, i_b, i_c , and i_f (left) i_{kd} and i_{kq} (center) and the torque (right)

We found that without the damping windings, the generator speeds out of control which would effectively grenade itself once the mechanical limit of the structural components is reached. This is likely because of undamped resonance in the system causing instability. But with the damping windings the generator stays at a reasonable current. The Matlab code for both models can be viewed at the end of this document.

1 Appendix: MATLAB Code

```
1 %-----
2 % Code for SS Model without dampers
3 %-----
4 % define synch gen values
5 fq = 60;
6 vf = 377;
7 nrpm = fq*120/4; % speed of rotor in rev/min
8 n = nrpm * 0.10472; % speed of rotor in rad/s
9
10 S = 659*10^6;
11 vline = 20*10^3;
12 vphi = vline/sqrt(3);
13 pf = 0.9;
14 w = 377;
15
16 Ia = S/sqrt(3)/vphi;
17 P = pf*S;
18 R = P/(Ia^2);
19 Q = S*sqrt(1-pf^2);
20 Xl = Q/(Ia^2);
21 L = Xl / w;
22
23 Vm = (20*10^3/sqrt(3))*sqrt(2);
24 iao = Vm/(sqrt(R^2 + Xl^2));
25 ibo = Vm*cos(-2*pi/3)/(sqrt(R^2 + Xl^2));
26 ico = Vm*cos(-4*pi/3)/(sqrt(R^2 + Xl^2));
27
28 ifo = 338 / 0.0860;
29 % ikdo = 0;
30 % ikqo = 0;
31
32 iniCon = [iao;ibo;ico;ifo]
33 tspan = [0 300];
34 [t,x] = ode45(@myOde, tspan, iniCon);
35
36
37 plot(t,x(:,1),t,x(:,2),t,x(:,3),t,x(:,4));
38 legend('ia','ib','ic','if')
39
40 plot(t,((x(:,1).*(3*Vm*pf))./(n*Xl)))
41 legend('Torque')
42
43 %plot(t,((3.*x(:,1).*Vm)./(n*Xl)))
```

```

44
45 function dx = myOde(t,x)
46
47     w = 377;
48     S = 659*10^6;
49     pf = 0.9;
50     Ia = S/ 20*10^3;
51     P = 0.9*S;
52     Rl = P/(Ia^2);
53     Q = S*sqrt(1-pf^2);
54     Xl = Q/(Ia^2);
55     L = Xl / w;
56
57     % angle given time t
58
59     theta = w*t;           % (2 theta)
60     a = -1*(2*pi/3);       % (2 theta - 2pi/3)
61     b = -1*(4*pi/3);       % (2 theta - 4pi/3)
62     % define values for resistance matrix
63     rs = 7.4*10^(-4);
64     rf = 0.0860;
65     rkd1 = 1.58*10^(-4);
66     rkq1 = 1.227*10^(-4);
67
68     % R = [rs+Rl, 0, 0, 0, 0;
69     %      0, rs+Rl, 0, 0, 0;
70     %      0, 0, rs+Rl, 0, 0;
71     %      0, 0, 0, rf, 0;
72     %      0, 0, 0, 0, 0;
73     %      0, 0, 0, 0, 0];
74     R = diag([rs+Rl rs+Rl rs+Rl rf]);
75
76     % define values for inductance matrix
77     pwr = 10^(-3);
78     Lsa = 1.95*pwr;
79     Lma = 0.80*pwr;
80     Lsv = 0.05*pwr;
81     Lmv = 0.05*pwr;
82
83     Lafm = 26.1*pwr;
84     % Lakdm1 = 0.447*pwr;
85     % Lakqm1 = 0.670*pwr;
86     %
87     % Lfkdl = 5.05*pwr;
88     % Lkd1f = 6.29*pwr;

```

```

89
90 Lff = 444*pwr;
91 % Lkd1kd1 = 0.1254*pwr;
92 % Lkq1kq1 = 0.3762*pwr;
93
94 %-----
95 Laa = Lsa + Lsv*cos(2*theta);
96 Lab = -Lma + Lmv*cos(2*theta + a);
97 Lac = -Lma + Lmv*cos(2*theta + b);
98 Laf = Lafm*cos(2*theta);
99 % Lakd = Lakdm1*cos(2*theta1);
100 % Lakq = -Lakqm1*cos(2*theta1);
101
102 % derivative values
103 dLaa = -2*Lsv*sin(2*theta);
104 dLab = -2*Lmv*sin(2*theta + a);
105 dLac = -2*Lmv*sin(2*theta + b);
106 dLaf = -2*Lafm*sin(2*theta);
107 % dLakd = -2*Lakdm1*sin(2*theta1);
108 % dLakq = 2*Lakqm1*sin(2*theta1);
109
110 %-----
111 Lba = -Lma + Lmv*cos(2*theta + a);
112 Lbb = Lsa + Lsv*cos(2*theta + b);
113 Lbc = -Lma + Lmv*cos(2*theta);
114 Lbf = Lafm*cos(2*theta + a);
115 % Lbk d = Lakdm1*cos(2*theta2);
116 % Lbk q = -Lakqm1*cos(2*theta2);
117
118 % derivative
119 dLba = -2*Lmv*sin(2*theta + a);
120 dLbb = -2*Lsv*sin(2*theta + b);
121 dLbc = -2*Lmv*sin(2*theta);
122 dLbf = -2*Lafm*sin(2*theta + a);
123 % dLbk d = -2*Lakdm1*sin(2*theta2);
124 % dLbk q = 2*Lakqm1*sin(2*theta2);
125
126 %-----
127 Lca = -Lma + Lmv*cos(2*theta + b);
128 Lcb = -Lma + Lmv*cos(2*theta);
129 Lcc = Lsa + Lsv*cos(2*theta + a);
130 Lcf = Lafm*cos(2*theta + b);
131 % Lck d = Lakdm1*cos(2*theta3);
132 % Lck q = -Lakqm1*cos(2*theta3);
133

```

```

134 % derivative
135 dLca = -2*Lmv*sin(2*theta + b);
136 dLcb = -2*Lmv*sin(2*theta);
137 dLcc = -2*Lsv*sin(2*theta + a);
138 dLcf = -2*Lafm*sin(2*theta + b);
139 % dLckd = -2*Lakdm1*sin(2*theta3);
140 % dLckq = 2*Lakqm1*sin(2*theta3);
141
142 %-----
143 Lfa = Lafm*cos(2*theta);
144 Lfb = Lafm*cos(2*theta + a);
145 Lfc = Lafm*cos(2*theta + b);
146
147 % derivative
148 dLfa = -2*Lafm*sin(2*theta);
149 dLfb = -2*Lafm*sin(2*theta + a);
150 dLfc = -2*Lafm*sin(2*theta + b);
151
152 % %-----
153 % Lkda = Lakdm1*cos(2*theta1);
154 % Lkdb = Lakdm1*cos(2*theta2);
155 % Lkdc = Lakdm1*cos(2*theta3);
156 %
157 % % derivative
158 % dLkda = -2*Lakdm1*sin(2*theta1);
159 % dLkdb = -2*Lakdm1*sin(2*theta2);
160 % dLkdc = -2*Lakdm1*sin(2*theta3);
161 %
162 % %-----
163 % Lkqa = -Lakqm1*cos(2*theta1);
164 % Lkqb = -Lakqm1*cos(2*theta2);
165 % Lkqc = -Lakqm1*cos(2*theta3);
166 %
167 % % derivative
168 % dLkqa = 2*Lakqm1*sin(2*theta1);
169 % dLkqb = 2*Lakqm1*sin(2*theta2);
170 % dLkqc = 2*Lakqm1*sin(2*theta3);
171
172 % phew that was a lot
173
174 % define inductance matrix and derivative inductance matrix
175
176 L = [Laa+L, Lab, Lac, Laf;
177      Lba, Lbb+L, Lbc, Lbf;
178      Lca, Lcb, Lcc+L, Lcf;

```

```

179         Lfa, Lfb, Lfc,    Lff];
180
181     dL = [dLaa, dLab, dLac, dLaf;
182          dLba, dLbb, dLbc, dLbf;
183          dLca, dLcb, dLcc, dLcf;
184          dLfa, dLfb, dLfc, 0];
185
186     %  $V = RI + dL*I + L*dI$ 
187     %  $L*dI = V - RI - dL*I$ 
188     %  $dI = -invL(R + dL)*I + invL*V$ 
189
190     A = -1*(R+dL)\L;
191     B = 1\L;
192     Vm = (20*10^3/sqrt(3))*sqrt(2);
193     u = [Vm*sin(w.*t+pi/2); Vm*sin(w.*t + pi/2 - 2*pi/3); Vm*sin(w.*t + pi/2 - 4*pi/3); 338];
194     %K = [Vm*cos(w.*t); Vm*cos(w.*t - (2*pi/3)); Vm*cos(w.*t - (4*pi/3)); 338];
195     %K = [0;0;0;377];
196     %u = K.*sin(w*t + pi/2);
197
198     dx = A*x + B*u;
199 end

```

```

1 %-----
2 % Code for SS Model with dampers
3 %-----
4 % define synch gen values
5 fq = 60;
6 vf = 377;
7 nrpm = fq*120/4; % speed of rotor in rev/min
8 n = nrpm * 0.10472; % speed of rotor in rad/s
9
10 S = 659*10^6;
11 vline = 20*10^3;
12 vphi = vline/sqrt(3);
13 pf = 0.9;
14 w = 377;
15
16 Ia = S/(sqrt(3)*vphi)
17 P = pf*S;
18 R = P/(Ia^2)
19 Q = S*sqrt(1-pf^2);
20 Xl = Q/(Ia^2)
21 L = Xl / w;
22
23 Vm = (20*10^(3)/sqrt(3))*sqrt(2);
24 iao = Vm/(sqrt(R^2 + Xl^2));
25 ibo = Vm*cos(-2*pi/3)/(sqrt(R^2 + Xl^2));
26 ico = Vm*cos(-4*pi/3)/(sqrt(R^2 + Xl^2));
27 ifo = 338 / 0.0860;
28 ikdo = 0;
29 ikqo = 0;
30
31 iniCon = [iao;ibo;ico;ifo;ikdo;ikqo]
32 tspan = [0 300];
33 [t,x] = ode45(@myOde, tspan, iniCon);
34
35 plot(t,x(:,1),t,x(:,2),t,x(:,3),t,x(:,4));
36 legend('ia','ib','ic','if')
37
38 plot(t,x(:,5),t,x(:,6));
39 legend('idk','idq')
40
41 plot(t,((x(:,1).*(3*Vm*pf))./(n*Xl)))
42 legend('Torque')
43
44 function dx = myOde(t,x)

```

```

45
46 w = 377;
47 S = 659*10^6;
48 vline = 20*10^3;
49 vphi = vline / sqrt(3);
50 pf = 0.9;
51 Ia = S/(sqrt(3) * vphi);
52 P = 0.9*S;
53 Rl = P/(Ia^2);
54 Q = S*sqrt(1-pf^2);
55 Xl = Q/(Ia^2);
56 L = Xl / w;
57
58 % angle given time t
59
60 theta = w*t; % (2 theta)
61 a = -1*(2*pi/3); % (2 theta - 2pi/3)
62 b = -1*(4*pi/3); % (2 theta - 4pi/3)
63 % define values for resistance matrix
64 rs = 7.4*10^(-4);
65 rf = 0.0860;
66 rkd1 = 1.58*10^(-4);
67 rkq1 = 1.227*10^(-4);
68
69 % R = [rs+Rl, 0, 0, 0, 0, 0;
70 %      0, rs+Rl, 0, 0, 0, 0;
71 %      0, 0, rs+Rl, 0, 0, 0;
72 %      0, 0, 0, rf, 0, 0;
73 %      0, 0, 0, 0, rkd1, 0;
74 %      0, 0, 0, 0, 0, rkq1];
75 R = diag([rs+Rl, rs+Rl, rs+Rl, rf, rkd1, rkq1]);
76
77 % define values for inductance matrix
78 pwr = 10^(-3);
79 Lsa = 1.95*pwr;
80 Lma = 0.80*pwr;
81 Lsv = 0.05*pwr;
82 Lmv = 0.05*pwr;
83
84 Lafm = 26.1*pwr;
85 Lakdm1 = 0.447*pwr;
86 Lakqm1 = 0.670*pwr;
87
88 Lfkdm1 = 5.05*pwr;
89 Lkdm1f = 6.29*pwr;

```

```

90
91 Lff = 444*pwr;
92 Lkd1kd1 = 0.1254*pwr;
93 Lkq1kq1 = 0.3762*pwr;
94
95 %-----
96 Laa = Lsa + Lsv*cos(2*theta);
97 Lab = -Lma + Lmv*cos(2*theta + a);
98 Lac = -Lma + Lmv*cos(2*theta + b);
99 Laf = Lafm*cos(2*theta);
100 Lakd = Lakdm1*cos(2*theta);
101 Lakq = -Lakqm1*cos(2*theta);
102
103 % derivative values
104 dLaa = -2*Lsv*sin(2*theta);
105 dLab = -2*Lmv*sin(2*theta + a);
106 dLac = -2*Lmv*sin(2*theta + b);
107 dLaf = -2*Lafm*sin(2*theta);
108 dLakd = -2*Lakdm1*sin(2*theta);
109 dLakq = 2*Lakqm1*sin(2*theta);
110
111 %-----
112 Lba = -Lma + Lmv*cos(2*theta + a);
113 Lbb = Lsa + Lsv*cos(2*theta + b);
114 Lbc = -Lma + Lmv*cos(2*theta);
115 Lbf = Lafm*cos(2*theta + a);
116 Lbkd = Lakdm1*cos(2*theta + a);
117 Lbkq = -Lakqm1*cos(2*theta + a);
118
119 % derivative
120 dLba = -2*Lmv*sin(2*theta + a);
121 dLbb = -2*Lsv*sin(2*theta + b);
122 dLbc = -2*Lmv*sin(2*theta);
123 dLbf = -2*Lafm*sin(2*theta + a);
124 dLbkd = -2*Lakdm1*sin(2*theta + a);
125 dLbkq = 2*Lakqm1*sin(2*theta + a);
126
127 %-----
128 Lca = -Lma + Lmv*cos(2*theta + b);
129 Lcb = -Lma + Lmv*cos(2*theta);
130 Lcc = Lsa + Lsv*cos(2*theta + a);
131 Lcf = Lafm*cos(2*theta + b);
132 Lckd = Lakdm1*cos(2*theta + b);
133 Lckq = -Lakqm1*cos(2*theta + b);
134

```

```

135 % derivative
136 dLca = -2*Lmv*sin(2*theta + b);
137 dLcb = -2*Lmv*sin(2*theta);
138 dLcc = -2*Lsv*sin(2*theta + a);
139 dLcf = -2*Lafm*sin(2*theta + b);
140 dLckd = -2*Lakdm1*sin(2*theta + b);
141 dLckq = 2*Lakqm1*sin(2*theta + b);
142
143 %-----
144 Lfa = Lafm*cos(2*theta);
145 Lfb = Lafm*cos(2*theta + a);
146 Lfc = Lafm*cos(2*theta + b);
147
148 % derivative
149 dLfa = -2*Lafm*sin(2*theta);
150 dLfb = -2*Lafm*sin(2*theta + a);
151 dLfc = -2*Lafm*sin(2*theta + b);
152
153 %-----
154 Lkda = Lakdm1*cos(2*theta);
155 Lkdb = Lakdm1*cos(2*theta + a);
156 Lkdc = Lakdm1*cos(2*theta + b);
157
158 % derivative
159 dLkda = -2*Lakdm1*sin(2*theta);
160 dLkdb = -2*Lakdm1*sin(2*theta + a);
161 dLkdc = -2*Lakdm1*sin(2*theta + b);
162
163 %-----
164 Lkqa = -Lakqm1*cos(2*theta);
165 Lkqb = -Lakqm1*cos(2*theta + a);
166 Lkqc = -Lakqm1*cos(2*theta + b);
167
168 % derivative
169 dLkqa = 2*Lakqm1*sin(2*theta);
170 dLkqb = 2*Lakqm1*sin(2*theta + a);
171 dLkqc = 2*Lakqm1*sin(2*theta + b);
172
173 % phew that was a lot
174
175 % define inductance matrix and derivative inductance matrix
176
177 L = [Laa+L, Lab, Lac, Laf, Lakd, Lakq;
178      Lba, Lbb+L, Lbc, Lbf, Lbkd, Lbkq;
179      Lca, Lcb, Lcc+L, Lcf, Lckd, Lckq;

```

```

180         Lfa, Lfb, Lfc,         Lff,   Lfkd1,   0;
181         Lkda, Lkdb, Lkdc,         Lkd1f, Lkd1kd1, Lkq1kq1;
182         Lkqa, Lkqb, Lkqc,         0,       0,       Lkq1kq1];
183
184     dL = [dLaa, dLab, dLac, dLaf, dLakd, dLakq;
185           dLba, dLbb, dLbc, dLbf, dLbkd, dLbkq;
186           dLca, dLcb, dLcc, dLcf, dLckd, dLckq;
187           dLfa, dLfb, dLfc,       0,0,0;
188           dLkda, dLkdb, dLkdc, 0,0,0;
189           dLkqa, dLkqb, dLkqc, 0,0,0];
190
191     %  $V = RI + dL*I + L*dI$ 
192     %  $L*dI = V - RI - dL*I$ 
193     %  $dI = -invL(R + dL)*I + invL*V$ 
194
195     A = -1*(R+dL)\L;
196     B = 1\L;
197     Vm = (20*10^(3)/sqrt(3))*sqrt(2);
198     u = [Vm*sin(w.*t+pi/2), Vm*sin(w.*t + pi/2 - 2*pi/3), Vm*sin(w.*t + pi/2 - 4*pi/3), 338, 0, 0]';
199     %u = [Vm;Vm;Vm;377;0;0];
200     %u = K*sin(377.*t + pi/2);
201     dx = A*x + B*u;
202 end

```