EE 523: Power System Stability and Control Report

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Summary of Work Completed:

	Type 3	Type 2	Type 1	Remarks
Dynamic Initialization	✅	✅	✅	
Small Signal Stability Analysis	✅	🟨	✅	
Transient Stability Analysis	✅	🟨	🔶	
Small Signal Stability with PSS from chosen Project Paper	NA	NA	🟨	Proposed PSS is a higher order transfer function block. MATLABs fsolve seems to be unable to solve for double derivatives. Of course, suitable modifications could have been made, but due to lack of time, couldn't be implemented. A set of hand-written equations is presented which if implemented, should be sufficient for modelling the PSS in MATLAB.
Remarks		Infeasible Eigenvalues for Type 2		

Legend:

✅	Implemented and Successfully Running
🟨	Implemented but NOT giving expected results
🔶	NOT Implemented

Questions for Assignment 08

Question 01:

Powerflow:

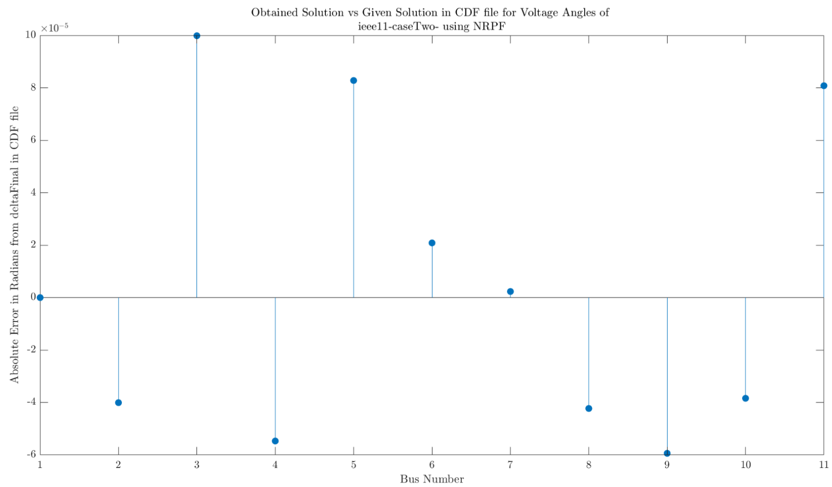
Consider the Kundur system in example 12.6 of Kundur book. Assume there are three lines connecting buses 7 and 8 and two lines connecting buses 8 and 9. Assume the capacities of the shunt capacitors have been increased to be 400 MVar each at buses 7 and 9. Resolve the power-flow using the Newton-Raphson algorithm.

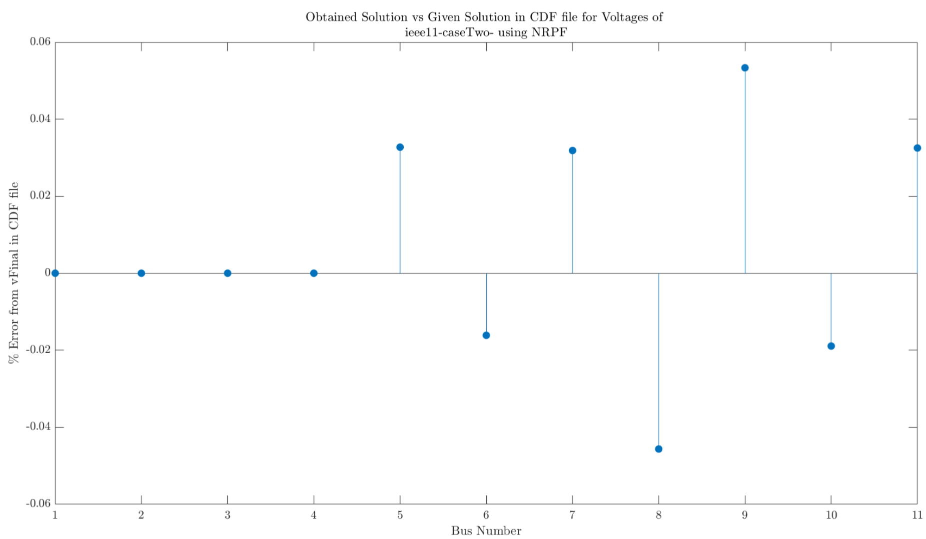
CDF File:

```
??/??/?? UW ARCHIVE          100.0  IEEE 11 Bus Test Case
BUS DATA FOLLOWS             11 ITEMS
 1 Bus 1     HV  1  1  3 1.030  20.20    0.0      0.0      700.0  185.0   0.0  1.030   0.0        0.0  0.0    0.0       0
 2 Bus 2     HV  1  1  2 1.010  10.86    0.0      0.0      700.0  235.0   0.0  1.010   0.0        0.0  0.0    0.0       0
 3 Bus 3     HV  2  1  2 1.030   1.18    0.0      0.0      719.0  176.0   0.0  1.030   0.0        0.0  0.0    0.0       0
 4 Bus 4     HV  2  1  2 1.010  -8.88    0.0      0.0      700.0  202.0   0.0  1.010   0.0        0.0  0.0    0.0       0
 5 Bus 5     HV  1  1  0 1.020  13.90    0.0      0.0      0.0     0.0    0.0  1.000   0.0        0.0  0.0    0.0       0
 6 Bus 6     LV  1  1  0 1.012   4.30    0.0      0.0      0.0     0.0    0.0  1.000   0.0        0.0  0.0    0.0       0
 7 Bus 7     ZV  1  1  0 1.021  -3.45    967.0    100.0    0.0     0.0    0.0  1.000   0.0        0.0  0.0    4.0       0
 8 Bus 8     TV  3  1  0 1.010 -11.46    0.0      0.0      0.0     0.0    0.0  1.000   0.0        0.0  0.0    0.0       0
 9 Bus 9     LV  2  1  0 1.002 -23.60   1767.0   100.0    0.0      0.0    0.0  1.000   0.0        0.0  0.0    4.0       0
 10 Bus 10   LV  2  1  0 1.001 -15.51    0.0      0.0      0.0     0.0    0.0  1.000   0.0        0.0  0.0    0.0       0
 11 Bus 11   LV  2  1  0 1.015  -5.40    0.0      0.0      0.0     0.0    0.0  1.000   0.0        0.0  0.0    0.0       0
-999
BRANCH DATA FOLLOWS          10 ITEMS
 1           5  1  1 1 0  0.00000  0.01667   0.0      0    0    0    0 0  0.0   0.0 0.0   0.0   0.0   0.0  0.0
 2           6  1  1 1 0  0.00000  0.01667   0.0      0    0    0    0 0  0.0   0.0 0.0   0.0   0.0   0.0  0.0
 3  11  2  1 1 0  0.00000  0.01667   0.0     0    0    0    0 0  0.0   0.0 0.0   0.0   0.0   0.0  0.0
 4  10  2  1 1 0  0.00000  0.01667   0.0     0    0    0    0 0  0.0   0.0 0.0   0.0   0.0   0.0  0.0
 5           6  1  1 1 0  0.00250  0.02500   0.04375  0    0    0    0 0  0.0   0.0 0.0   0.0   0.0   0.0  0.0
 6           7  1  1 1 0  0.00100  0.01000   0.01750  0    0    0    0 0  0.0   0.0 0.0   0.0   0.0   0.0  0.0
 7           8  1  1 1 0  0.00367  0.03667   0.57750  0    0    0    0 0  0.0   0.0 0.0   0.0   0.0   0.0  0.0
 8           9  2  1 1 0  0.00550  0.05500   0.38500  0    0    0    0 0  0.0   0.0 0.0   0.0   0.0   0.0  0.0
 9  10  2  1 1 0  0.00100  0.01000   0.01750  0    0    0    0 0  0.0   0.0 0.0   0.0   0.0   0.0  0.0
 10  11  2  1 1 0  0.00250  0.02500   0.04375  0    0    0    0 0  0.0   0.0 0.0   0.0   0.0   0.0  0.0
-999
LOSS ZONES FOLLOWS           1 ITEMS
 1 IEEE 9 BUS
-99
INTERCHANGE DATA FOLLOWS                1 ITEMS
 1           2 Bus 2        HV          0.0  999.99  IEEE11  IEEE 11 Bus Test Case
-9
```

TIE LINES FOLLOWS	0 ITEMS
-999	
END OF DATA	

Power Flow Results Plots:





Power Flow Results Table:

resultTable = 11×4 table

	P	Q	V	delta
1 Bus 1	6.9125	0.9763	1.0300	0
2 Bus 2	6.9999	0.2874	1.0100	-0.1631
3 Bus 3	7.1900	1.3188	1.0300	-0.3319
4 Bus 4	6.9999	0.9600	1.0100	-0.5076
5 Bus 5	-0.0003	0.0001	1.0203	-0.1099
6 Bus 6	0.0001	0.0004	1.0118	-0.2775
7 Bus 7	-9.6704	-0.9992	1.0213	-0.4128
8 Bus 8	-0.0002	0.0006	1.0095	-0.5526
9 Bus 9	-17.6690	-0.9991	1.0025	-0.7645
10 Bus 10	0.0003	0.0005	1.0008	-0.6233
11 Bus 11	0	0.0001	1.0153	-0.4467

Y_Bus values:

ybusSparse =

(1,1) 0 - 59.988i

(5,1) 0 + 59.988i

(2,2) 0 - 59.988i

(6,2)	0 + 59.988i
(3,3)	0 - 59.988i
(11,3)	0 + 59.988i
(4,4)	0 - 59.988i
(10,4)	0 + 59.988i
(1,5)	0 + 59.988i
(5,5)	3.9604 - 99.57i
(6,5)	-3.9604 + 39.604i
(2,6)	0 + 59.988i
(5,6)	-3.9604 + 39.604i
(6,6)	13.861 - 198.57i
(7,6)	-9.901 + 99.01i
(6,7)	-9.901 + 99.01i
(7,7)	12.603 - 121.71i
(8,7)	-2.7022 + 27i
(7,8)	-2.7022 + 27i
(8,8)	4.5024 - 44.52i
(9,8)	-1.8002 + 18.002i
(8,9)	-1.8002 + 18.002i
(9,9)	11.701 - 112.81i

(10,9)	-9.901 + 99.01i
(4,10)	0 + 59.988i
(9,10)	-9.901 + 99.01i
(10,10)	13.861 - 198.57i
(11,10)	-3.9604 + 39.604i
(3,11)	0 + 59.988i
(10,11)	-3.9604 + 39.604i
(11,11)	3.9604 - 99.57i

Question 02:

Small-signal stability:

For the Kundur system from above, we want to study the small-signal stability properties. Assume KD = 2 pu for all generators. Assume a first order exciter control model with KA=50 and TA = 0.01 sec. Assume Vrmin = -4 and VRmax = +4. Efdmin = 0 and Efdmax = 2.0. For the governor model, assume that Tsg = 100 and Ksg = 1 with Psgmin=0 and Psgmax = 1 pu. R=5%. Then carry out initialization and small-signal analysis for each of Type 1, 2 and 3 models. For Type 1, assume the loads to be 50% P and 50% Z. Represent the equations in the standard DAE form for Type 1 and ODE form for Type 2.

1) Starting from the power-flow solution, initialize the steady-state values of all the dynamic variables.
2) Linearize the equations and find the system Jacobian matrix. You can use numerical differencing to compute the Jacobian entries numerically.
3) Find all eigenvalues and eigenvectors.
4) Compute all the participation factors and analyze each mode.
5) Design Power System Stabilizers (PSSs) as needed to render the damping ratios of all modes to be over 5% for each of Type 1 and Type 2 models.

Type 3:

DynInit:

```
ode_Type3_Init =
```

$$\begin{pmatrix} 0 = 376.9911\,\omega_2 - 376.9911 \\ 0 = 376.9911\,\omega_3 - 376.9911 \\ 0 = 376.9911\,\omega_4 - 376.9911 \\ 0 = 0.0085\,P_{\mathrm{m2}} - 0.1538\,\omega_2 + 0.0940 \\ 0 = 0.0090\,P_{\mathrm{m3}} - 0.1619\,\omega_3 + 0.0973 \\ 0 = 0.0090\,P_{\mathrm{m4}} - 0.1619\,\omega_4 + 0.0990 \end{pmatrix}$$

resultGen = 4×2 table

	E'	theta
Gen 1	1.0300	0
Gen 2	1.0745	0.1465
Gen 3	1.1392	-0.0383
Gen 4	1.1045	-0.2068

yGenTable = 4×4 table

	1	2	3	4
1	3.2168 -11.5866i	1.6434 + 7.9619i	0.9492 + 1.0023i	1.3592 + 1.3569i
2	1.6434 + 7.9619i	1.3830 -10.5241i	0.6581 + 0.6164i	0.9393 + 0.8316i
3	0.9492 + 1.0023i	0.6581 + 0.6164i	1.6473 - 8.1778i	1.9706 + 4.2053i
4	1.3592 + 1.3569i	0.9393 + 0.8316i	1.9706 + 4.2053i	2.9049 - 9.8799i

Type 2:

DynInit:

```
unknowns0_Type2_Gens_Vals_Table = 36×1 table
```

	Values
1 theta2	0.7510
2 omega2	1
3 E_prime_q2	0.7998
4 E_prime_d2	0.5411
5 V_R2	1.7154
6 P_m2	6.9999
7 V_ref2	1.0443
8 P_C2	6.9999
9 V_q2	0.6166
10 V_d2	0.7999

11 **I_q2**	4.2349
12 **I_d2**	5.4936
13 **theta3**	0.5838
14 **omega3**	1
15 **E_prime_q3**	0.8151
16 **E_prime_d3**	0.5525
17 **V_R3**	1.7531
18 **P_m3**	7.1900
19 **V_ref3**	1.0651
20 **P_C3**	7.1900
21 **V_q3**	0.6275
22 **V_d3**	0.8168
23 **I_q3**	4.3240

24 I_d3	5.6277
25 theta4	0.4106
26 omega4	1
27 E_prime_q4	0.7986
28 E_prime_d4	0.5428
29 V_R4	1.7249
30 P_m4	6.9999
31 V_ref4	1.0445
32 P_C4	6.9999
33 V_q4	0.6134
34 V_d4	0.8024
35 I_q4	4.2482
36 I_d4	5.5578

```
x0_Type2_Gens_Table = 18×1 table
```

	Values
1 theta2	0.7510
2 omega2	1
3 E_prime_q2	0.7998
4 E_prime_d2	0.5411
5 V_R2	1.7154
6 P_m2	6.9999
7 theta3	0.5838
8 omega3	1
9 E_prime_q3	0.8151
10 E_prime_d3	0.5525
11 V_R3	1.7531
12 P_m3	7.1900

13 theta4	0.4106
14 omega4	1
15 E_prime_q4	0.7986
16 E_prime_d4	0.5428
17 V_R4	1.7249
18 P_m4	6.9999

Small Signal Stability:

Jacobian:

theta2 omega2 E_prime_q2 E_prime_d2 V_R2 P_m2

theta3 omega3 E_prime_q3 E_prime_d3 V_R3 P_m3 theta4

omega4 E_prime_q4 E_prime_d4 V_R4 P_m4

_______ _______ ___________ __________ _____

______ _______ ______ __________ __________ _____ _____

_______ ______ ___________ __________ _____ _____

theta2 0 376.99 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0

omega2 -0.0725 -0.0171 -0.095 0.0263 0

0.0085 0.004 0 -0.0028 -0.0069 0 0 0.0037

0 -0.0058 -0.0086 0 0

E_prime_q2 -0.1855 0 -0.3443 -0.0288 0.125

0 0.0185 0 0.0104 -0.0157 0 0 0.0247 0

0.0098 -0.0242 0 0

E_prime_d2 1.4614 0 0.4418 -5.8619 0 0

0.0029 0 0.2401 0.1592 0 0 0.0817 0

0.3715 0.1502 0 0

V_R2 -4439.9 0 -5316.6 377.54 -100

0 -242.38 0 -136.03 205.15 0 0 -323.24 0

-128.38 317.5 0 0

P_m2 0 -0.2 0 0 0 -0.01 0

0 0 0 0 0 0 0 0 0 0 0

theta3 0 0 0 0 0 0 0

376.99 0 0 0 0 0 0 0 0 0 0

omega3 0.0061 0 -0.00044056 -0.008 0

0 -0.0479 -0.018 -0.0818 0.0033 0 0.009 0.0325

0 -0.00064669 -0.0411 0 0

E_prime_q3 0.0172 0 0.0149 -0.0114 0 0

-0.1334 0 -0.2954 -0.0343 0.125 0 0.0874 0

0.0792 -0.0555 0 0

E_prime_d3 -0.0888 0 0.1745 0.2292 0 0

0.6998 0 0.5262 -5.1123 0 0 -0.5079 0

0.8516 1.2148 0 0

V_R3 -225.72 0 -196.24 149.45 0 0

-5037.2 0 -5969.5 450.63 -100 0 -1147 0

-1040.3 729.24 0 0

P_m3 0 0 0 0 0 0 0 -0.2

0 0 0 -0.01 0 0 0 0 0 0

theta4 0 0 0 0 0 0 0 0

0 0 0 0 0 376.99 0 0 0 0

omega4 0.0092 0 0.00099266 -0.0109 0 0

0.0384 0 0.0131 -0.0381 0 0 -0.0618 -0.018

-0.0992 0.0099 0 0.009

E_prime_q4 0.0225 0 0.0229 -0.0127 0 0

0.0722 0 0.0934 -0.0253 0 0 -0.1331 0

-0.3308 -0.0605 0.125 0

E_prime_d4 -0.1753 0 0.1942 0.3506 0 0

-0.9523 0 0.3886 1.4317 0 0 1.3585 0

0.9279 -5.6561 0 0

V_R4 -296.41 0 -301.22 166.81 0 0

-951.76 0 -1230.1 333.85 0 0 -4977.2 0

-5522.2 797.27 -100 0

P_m4 0 0 0 0 0 0 0 0

0 0 0 0 0 -0.2 0 0 0 -0.01

```
Je_Type2_Gens_Table = 18×18 table
```

	het a2	me ga2	_prim e_q2	_prim e_d2	_R2	_m 2	het a3	me ga3	_prim e_q3	_prim e_d3	_R3	_m 3	het a4	me ga4	_prim e_q4	_prim e_d4	_R4	_m 4
thet a2		76.9 911																

omega2	0.0725	0.0171	0.0950	.0263		.0085	.0040		0.0028	0.0069			.0037		0.0058	0.0086		
E_prime_q2	0.1855		0.3443	0.0288	.1250		.0185		.0104	0.0157			.0247		.0098	0.0242		
E_prime_d2	.4614		.4418	5.8619			.0029		.2401	.1592			.0817		.3715	.1502		
V_R2	4.4399e+03		5.3166e+03	77.5412	100		242.3760		136.0339	05.1494			323.2366		128.3760	17.4983		
P_m2		0.2000				0.0100												
theta3								76.9911										
omega3	.0061		4.4056e-04	0.0080			0.0479	0.0180	0.0818	.0033		.0090	.0325		6.4669e-04	0.0411		

E_prime_q3	.0172		.0149	0.0114			0.1334		0.2954	0.0343	.1250		.0874		.0792	0.0555		
0 E_prime_d3	0.0888		.1745	.2292			.6998		.5262	5.1123			0.5079		.8516	.2148		
1 V_R3	225.7156		196.2388	49.4509			5.0372e+03		5.9695e+03	50.6272	100		1147		1.0403e+03	29.2441		
2 P_m3								0.2000				0.0100						
3 theta4														76.9911				
4 omega4	.0092		.9266e-04	0.0109			.0384		.0131	0.0381			0.0618	0.0180	0.0992	.0099		.0090

5 E_prime_q4	.0225		.0229	0.0127			.0722		.0934	0.0253			0.1331		0.3308	0.0605	.1250	
6 E_prime_d4	0.1753		.1942	.3506			0.9523		.3886	.4317			.3585		.9279	5.6561		
7 V_R4	296.4063		301.2165	66.8143			951.7605		1.2301e+03	33.8473			4.9772e+03		5.5222e+03	97.2723	100	
8 P_m4														0.2000				0.0100

lambdasType2 = 18×1 complex

-90.3864 + 0.0000i

-92.8899 + 0.0000i

-93.8844 + 0.0000i

3.7230 + 0.0000i

-3.3880 + 5.0894i

-3.3880 - 5.0894i

-4.0915 + 4.2569i

-4.0915 - 4.2569i

-5.8262 + 3.0605i

-5.8262 - 3.0605i

So eigenvalues are coming in the RHP, which makes it small signal unstable.

Type 1:

Jacobian:

1.0e+03 *

Columns 1 through 15

0 0 0 0.3770 0 0 0 0 0 0

0 0 0 0 0

0 0 0 0 0.3770 0 0 0 0 0

0 0 0 0 0

0 0 0 0 0 0.3770 0 0 0 0

0 0 0 0 0

-0.0002 -0.0000 -0.0000 -0.0000 0 0 -0.0002 -0.0000

-0.0000 0.0001 0.0000 0.0000 0 0 0

-0.0000 -0.0002 -0.0000 0 -0.0000 0 -0.0000 -0.0002

-0.0000 -0.0000 0.0001 -0.0000 0 0 0

-0.0000 0.0000 -0.0002 0 0 -0.0000 -0.0000 -0.0000

-0.0002 -0.0000 -0.0000 0.0001 0 0 0

-0.0005 0.0001 0.0001 0 0 0 -0.0006 0.0001

0.0001 0.0001 -0.0001 -0.0001 0.0001 0 0

0.0000 -0.0006 0.0000 0 0 0 0.0000 -0.0006

0.0001 0.0000 0.0002 0.0001 0 0.0001 0

0.0000 -0.0000 -0.0005 0 0 0 0.0000

0.0001 -0.0005 0.0000 0.0001 0.0001 0 0 0.0001

0.0033 0.0016 0.0015 0 0 0 0.0020

0.0014 0.0013 -0.0064 -0.0007 -0.0007 0 0 0

0.0001 0.0025 0.0004 0 0 0 0.0003

0.0018 0.0015 0.0002 -0.0057 0.0006 0 0 0

0.0001 -0.0002 0.0036 0 0 0 0.0004

0.0009 0.0028 0.0002 0.0008 -0.0062 0 0 0

-0.1090 -1.9626 -1.8677 0 0 0 -2.4383 -1.6978 -1.5995

-1.5720 0.8448 0.8507 -0.1000 0 0

```
   -0.0826    0.8937   -0.5186         0         0         0   -0.3998   -2.2298   -1.7629
  -0.1898   -2.4640   -0.6783         0   -0.1000         0
   -0.1110    0.2445   -0.4961         0         0         0   -0.5376   -1.0931   -3.3175
  -0.2552   -1.0086   -1.7798         0         0   -0.1000
         0         0         0   -0.0002         0         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0   -0.0002         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0   -0.0002         0         0         0         0
         0         0         0         0         0

  Columns 16 through 18

         0         0         0
         0         0         0
         0         0         0
    0.0000         0         0
         0    0.0000         0
         0         0    0.0000
         0         0         0
```

```
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
   -0.0000         0         0
         0   -0.0000         0
         0         0   -0.0000
```

Eigenvalues:

lambdas_Type1 = 18×1 complex

```
  -0.6864 - 9.0045i
  -6.2148 + 0.0000i
  -5.7105 + 0.0000i
  -4.4652 + 2.2061i
```

-4.4652 - 2.2061i

-2.4172 + 0.0000i

-1.6255 + 0.0000i

-0.0100 + 0.0000i

-0.0100 + 0.0000i

-0.0100 + 0.0000i

Type 1:

Set of ODEs for DynInit.

$$\left(\begin{array}{c}
0 = 376.9911\,\omega_2 - 376.9911\\
0 = 376.9911\,\omega_3 - 376.9911\\
0 = 376.9911\,\omega_4 - 376.9911\\
0 = 0.0085\,P_{\mathrm{m2}} - 0.0171\,\omega_2 - 0.0427\\
0 = 0.0090\,P_{\mathrm{m3}} - 0.0180\,\omega_3 - 0.0467\\
0 = 0.0090\,P_{\mathrm{m4}} - 0.0180\,\omega_4 - 0.0450\\
0 = 0.1250\,V_{\mathrm{R2}} - 0.0208\,I_{\mathrm{d2}} - 0.1250\,{E'}_{\mathrm{q2}}\\
0 = 0.1250\,V_{\mathrm{R3}} - 0.0208\,I_{\mathrm{d3}} - 0.1250\,{E'}_{\mathrm{q3}}\\
0 = 0.1250\,V_{\mathrm{R4}} - 0.0208\,I_{\mathrm{d4}} - 0.1250\,{E'}_{\mathrm{q4}}\\
0 = 0.3194\,I_{\mathrm{q2}} - 2.5000\,{E'}_{\mathrm{d2}}\\
0 = 0.3194\,I_{\mathrm{q3}} - 2.5000\,{E'}_{\mathrm{d3}}\\
0 = 0.3194\,I_{\mathrm{q4}} - 2.5000\,{E'}_{\mathrm{d4}}\\
0 = 5000\,V_{\mathrm{ref2}} - 100\,V_{\mathrm{R2}} - 5050\\
0 = 5000\,V_{\mathrm{ref3}} - 100\,V_{\mathrm{R3}} - 5150\\
0 = 5000\,V_{\mathrm{ref4}} - 100\,V_{\mathrm{R4}} - 5050
\end{array}\right.$$

$$
\left|\begin{array}{c}
0 = 0.0100\,P_{\mathrm{C2}} - 0.0100\,P_{\mathrm{m2}} - 0.2000\,\omega_2 + 0.2000 \\
0 = 0.0100\,P_{\mathrm{C3}} - 0.0100\,P_{\mathrm{m3}} - 0.2000\,\omega_3 + 0.2000 \\
0 = 0.0100\,P_{\mathrm{C4}} - 0.0100\,P_{\mathrm{m4}} - 0.2000\,\omega_4 + 0.2000 \\
0 = I_{\mathrm{d2}} - 6.9364\,\sin\left(\theta_2 + 0.1631\right) \\
0 = I_{\mathrm{d3}} - 7.0970\,\sin\left(\theta_3 + 0.3319\right) \\
0 = I_{\mathrm{d4}} - 6.9954\,\sin\left(\theta_4 + 0.5076\right) \\
0 = I_{\mathrm{q2}} - 6.9364\,\cos\left(\theta_2 + 0.1631\right) \\
0 = I_{\mathrm{q3}} - 7.0970\,\cos\left(\theta_3 + 0.3319\right) \\
0 = I_{\mathrm{q4}} - 6.9954\,\cos\left(\theta_4 + 0.5076\right) \\
0 = V_{\mathrm{q2}} - 1.0100\,\cos\left(\theta_2 + 0.1631\right) \\
0 = V_{\mathrm{q3}} - 1.0300\,\cos\left(\theta_3 + 0.3319\right) \\
0 = V_{\mathrm{q4}} - 1.0100\,\cos\left(\theta_4 + 0.5076\right) \\
0 = V_{\mathrm{d2}} - 1.0100\,\sin\left(\theta_2 + 0.1631\right) \\
0 = V_{\mathrm{d3}} - 1.0300\,\sin\left(\theta_3 + 0.3319\right) \\
0 = V_{\mathrm{d4}} - 1.0100\,\sin\left(\theta_4 + 0.5076\right)
\end{array}\right|
$$

$$
\left.\begin{array}{c}
0 = I_{\mathrm{d2}} - 30\,{E'}_{\mathrm{q2}} + 30\,V_{\mathrm{q2}} \\
0 = I_{\mathrm{d3}} - 30\,{E'}_{\mathrm{q3}} + 30\,V_{\mathrm{q3}} \\
0 = I_{\mathrm{d4}} - 30\,{E'}_{\mathrm{q4}} + 30\,V_{\mathrm{q4}} \\
0 = 16.3636\,{E'}_{\mathrm{d2}} + I_{\mathrm{q2}} - 16.3636\,V_{\mathrm{d2}} \\
0 = 16.3636\,{E'}_{\mathrm{d3}} + I_{\mathrm{q3}} - 16.3636\,V_{\mathrm{d3}} \\
0 = 16.3636\,{E'}_{\mathrm{d4}} + I_{\mathrm{q4}} - 16.3636\,V_{\mathrm{d4}}
\end{array}\right)
$$

Participation Factors and remarks on inter-area oscillation:

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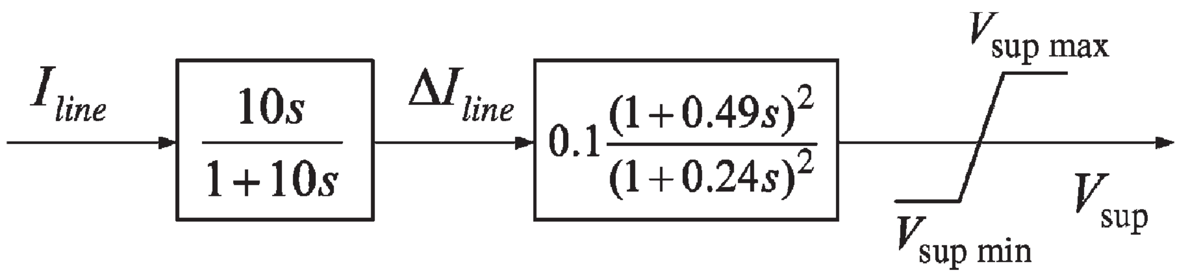
Mode	Type of Oscillation	Coupling State Variables
1.062 Hz	Local oscillation	Theta 2 vs Omega 2
0.892 Hz	Local oscillation	Theta 3 vs Omega 3
0.452 Hz	Inter-area oscillation	Theta 4 vs Theta 2

Project: Implement a PSS in the Type 1 System



Inputs of the PSS: Current flowing between the two areas 1 and 2. Here, the current between buses 7 and 8 is chosen as the input to the PSS.

The first block is a washout filter which negates any steady state values (DC Offset) in the line current, and only allows high frequency signal noise to pass through.

The second block can actually be thought of as two separate lead compensator blocks.

Both Type 1 and Type 2 do not require PSS.

Question 03:

Transient Stability:

We want to study a fault on one of the transmission lines between buses 7 and 8. Assume a solid fault in the middle of the line. Assume Euler integration method with a step size of 1 msec.

1) For tc = 3 cycles, check if the system is stable.
2) Find the critical clearing time.

Repeat for each of Type 1, Type 2 and Type 3 models from your small-signal stability homework solutions.

Type 3:

yGen during Fault:

yGenTable = 4×4 table

	1	2	3	4
1	1.8186 -14.5133i	0.6173 + 6.1083i	0.2689 + 0.3831i	0.3889 + 0.5223i
2	0.6173 + 6.1083i	0.6414 -11.6926i	0.1903 + 0.2393i	0.2740 + 0.3253i
3	0.2689 + 0.3831i	0.1903 + 0.2393i	1.4033 - 8.2672i	1.6277 + 4.0905i
4	0.3889 + 0.5223i	0.2740 + 0.3253i	1.6277 + 4.0905i	2.4236 -10.0261i

ode_Type3_TransientFaultOn =

$$\begin{pmatrix} 0 = 376.9911\,\omega_2 - 376.9911 \\ 0 = 376.9911\,\omega_3 - 376.9911 \\ 0 = 376.9911\,\omega_4 - 376.9911 \\ 0 = 0.0706 - 0.0043\cos(\theta_4 - \theta_2 + 0.8707) - 0.0032\cos(\theta_3 - \theta_2 + 0.8988) - 0.0581\cos(\theta_2 - 1.4701) - 0.0171\,\omega_2 \\ 0 = 0.0663 - 0.0498\cos(\theta_4 - \theta_3 + 1.1921) - 0.0034\cos(\theta_2 - \theta_3 + 0.8988) - 0.0049\cos(\theta_3 - 0.9587) - 0.0180\,\omega_3 \\ 0 = 0.0544 - 0.0498\cos(\theta_3 - \theta_4 + 1.1921) - 0.0045\cos(\theta_2 - \theta_4 + 0.8707) - 0.0067\cos(\theta_4 - 0.9307) - 0.0180\,\omega_4 \end{pmatrix}$$

ode_Type3_TransientPostFault =

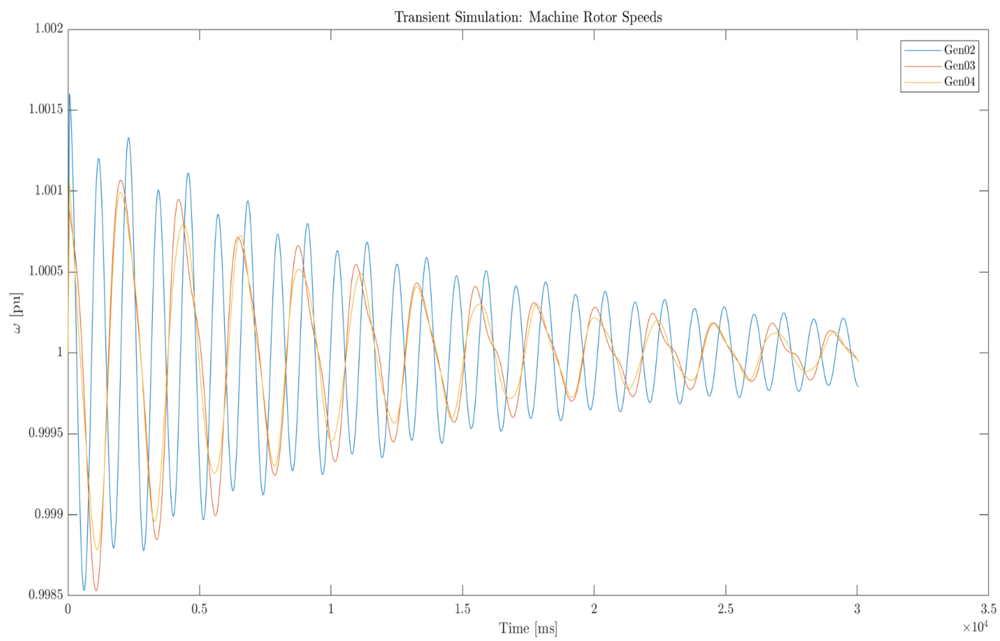
$$\begin{pmatrix} 0 = 376.9911\,\omega_2 - 376.9911 \\ 0 = 376.9911\,\omega_3 - 376.9911 \\ 0 = 376.9911\,\omega_4 - 376.9911 \\ 0 = 0.0629 - 0.0116\cos(\theta_4 - \theta_2 + 0.6973) - 0.0086\cos(\theta_3 - \theta_2 + 0.7254) - 0.0787\cos(\theta_2 - 1.3658) - 0.0171\,\omega_2 \\ 0 = 0.0626 - 0.0537\cos(\theta_4 - \theta_3 + 1.1187) - 0.0090\cos(\theta_2 - \theta_3 + 0.7254) - 0.0133\cos(\theta_3 - 0.7853) - 0.0180\,\omega_3 \\ 0 = 0.0475 - 0.0537\cos(\theta_3 - \theta_4 + 1.1187) - 0.0122\cos(\theta_2 - \theta_4 + 0.6973) - 0.0179\cos(\theta_4 - 0.7572) - 0.0180\,\omega_4 \end{pmatrix}$$

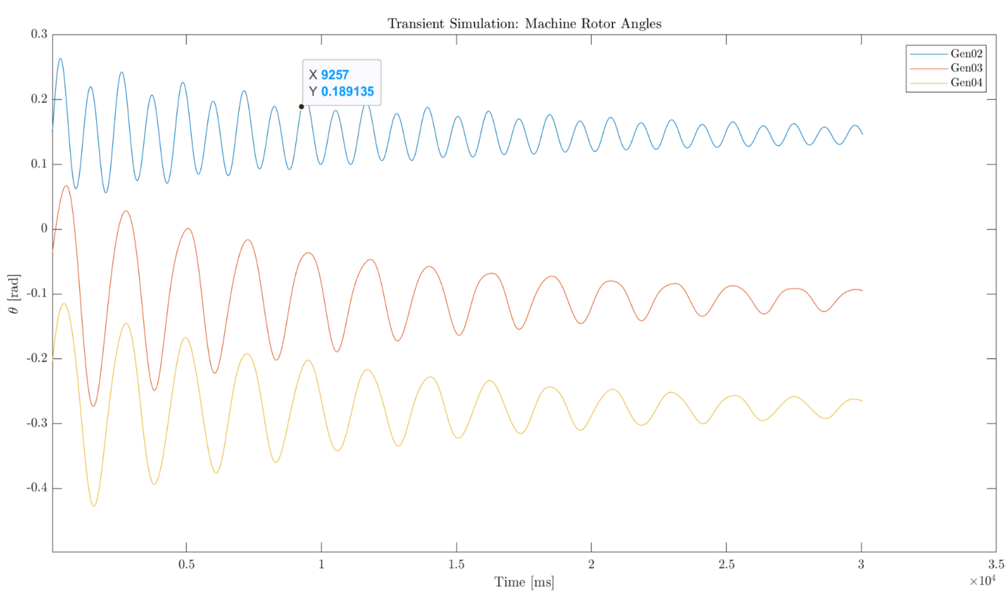
yGen after clearing the fault:

yGenTable = 4×4 table

	1	2	3	4
1	3.2766 -11.3047i	1.6935 + 8.1434i	0.8894 + 0.8893i	1.2717 + 1.2020i
2	1.6935 + 8.1434i	1.4228 -10.4077i	0.6147 + 0.5451i	0.8762 + 0.7340i
3	0.8894 + 0.8893i	0.6147 + 0.5451i	1.7186 - 8.1324i	2.0714 + 4.2656i
4	1.2717 + 1.2020i	0.8762 + 0.7340i	2.0714 + 4.2656i	3.0475 - 9.8000i

Transient Simulation





Critical Clearing Time was found to be 7 cycles.

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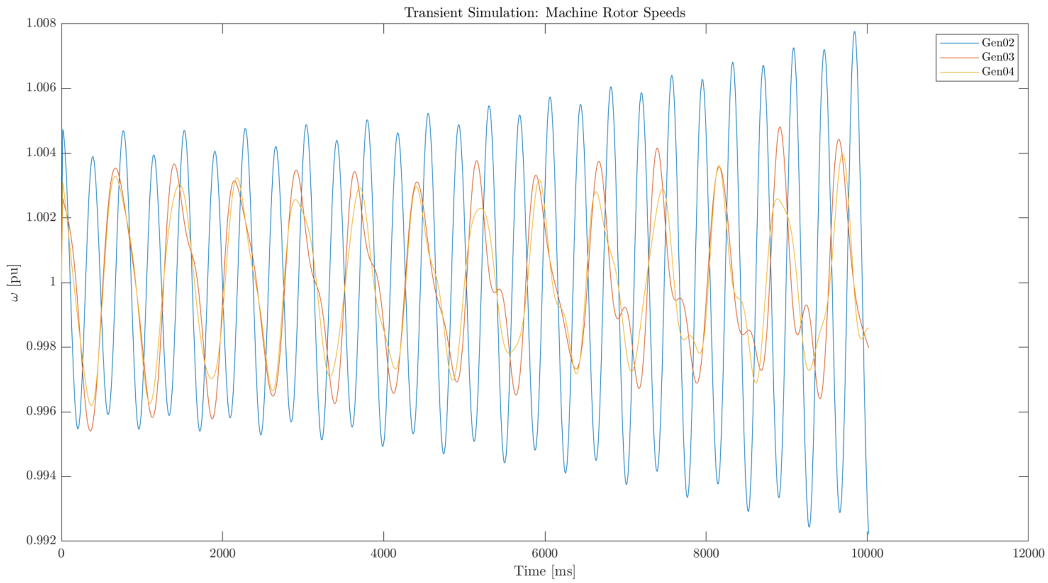
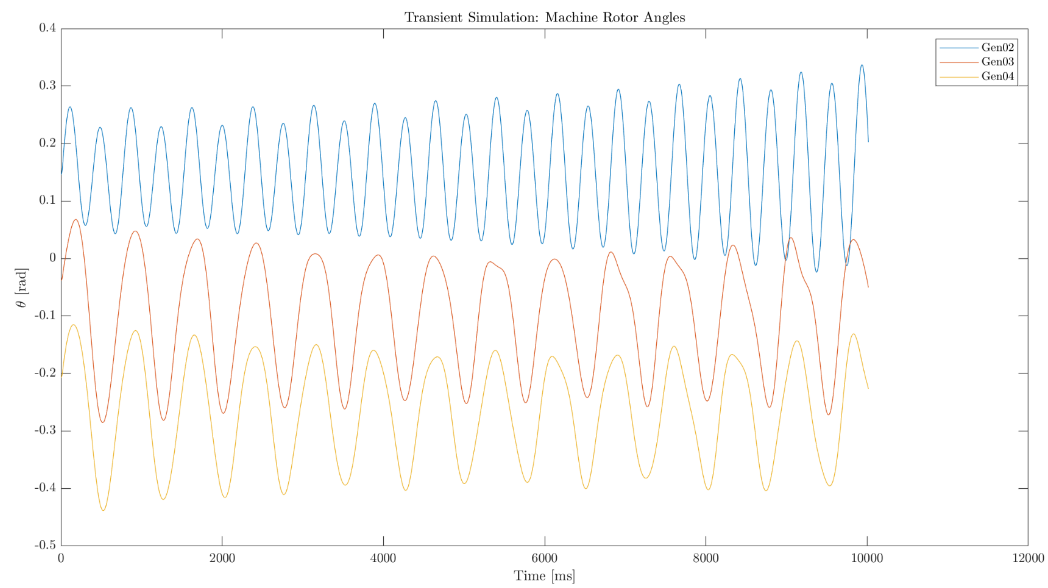
Transient simulation for Type 2 blew up.





Transient simulation for Type 1 was NOT implemented for lack of time.

References

Kundur, P. S., & Malik, O. P. (2022). Power System Stability and Control. McGraw-Hill Education. Retrieved from https://www.accessengineeringlibrary.com/content/book/9781260473544

Appendix: