POWER SYSTEM SIMULATION LABORATARIES

Development of a Comprehensive Power System Simulation Laboratory (PSS-L) at the University of Queensland– Project Funded by Australian Power Institute (API)

Investigators: Dr.Nadarajah Mithulananthan
Prof.Tapan Saha

Prepared by- Md.Rakibuzzaman Shah
Ruifeng Yan

Power and Energy Research Group
School of Information Technology and Electrical Engineering
The University of Queensland, Australia

April, 2011

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Lab 01: Load Flow Analysis

Questions:
First build the following IEEE 14 Bus System in your power system analysis software for load flow analysis study. (System Base: 100 MVA)
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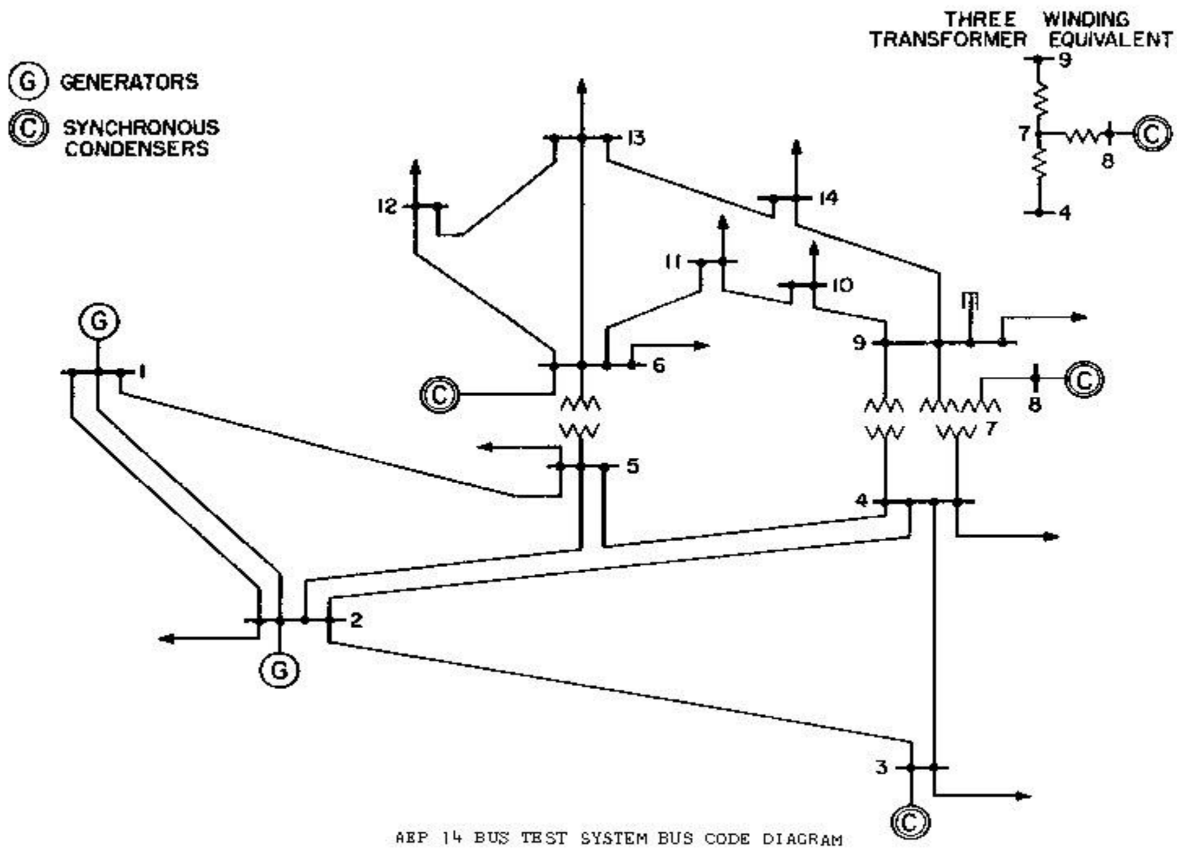

(i) Bus Data

Bus No.	Type	Real Power Load (MW)	Reactive Power Load (MVAR)	Shunt Admittance Nominal Power at 1.0 pu Voltage
1	Slack	0	0	0
2	PV	21.7	12.7	0
3	PV	94.2	19	0
4	PQ	47.8	-3.9	0
5	PQ	7.6	1.6	0
6	PV	11.2	7.5	0
7	PQ	0	0	0
8	PV	0	0	0
9	PQ	29.5	16.6	19 MVAR
10	PQ	9	5.8	0
11	PQ	3.5	1.8	0
12	PQ	6.1	1.6	0

13	PQ	13.5	5.8	0
14	PQ	14.9	5	0

(ii) Generator and Synchronous Condenser Data

Bus No.	Pg	Vg	Q_{max} (MVAR)	Q_{min} (MVAR)
1	Slack (not specified)	1.060	None	None
2	40	1.045	50	-40
3	0	1.010	40	0
6	0	1.070	24	-6
8	0	1.090	24	-6

(iii) Branch Data

From Bus	To Bus	r	x	b
1	2	0.03876	0.11834	0.0264
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1	5	0.05403	0.22304	0.0492
2	3	0.04699	0.19797	0.0438
2	4	0.05811	0.17632	0.0340
2	5	0.05695	0.17388	0.0346
3	4	0.06701	0.17103	0.0128
4	5	0.01335	0.04211	0
6	11	0.09498	0.19890	0
6	12	0.12291	0.25581	0
6	13	0.06615	0.13027	0
9	10	0.03181	0.08450	0
9	14	0.12711	0.27038	0
10	11	0.08205	0.19207	0
12	13	0.22092	0.19988	0
13	14	0.17093	0.34802	0

(iv) Transformer Data

From Bus	To Bus	r	x	b	Tap Ratio
4	7	0.0	0.20912	0	0.978
4	9	0.0	0.55618	0	0.969
5	6	0.0	0.25202	0	0.932
7	8	0.0	0.17615	0	1
7	9	0.0	0.11001	0	1

(1) Load Flow Basics

a) Build the IEEE 14 bus network based on the data provided above.
b) Check the load flow results – bus voltage magnitudes and angles, real and reactive power generation and consumption.
c) Check the line real and reactive power losses.

(2) Impacts of Compensation Devices on Load Flow

a) **Tap changing regulation:** Change the tap ratio between Bus 7 and Bus 9 from 1 to 0.98. Check the load flow results.
b) **Shunt reactive power compensation:** Undo the changes made in a). Connect a nominal 10MVar shunt capacitor to the lowest voltage bus – Bus 14. Check the load flow results.

c) **Parallel transmission line construction:** Undo the changes made in b). Construct an extra transmission line from Bus 4 to Bus 5, which is exactly the same as the existing one. Check the load flow results.

(3) Impacts of Network Contingencies on Load Flow

a) **Loading level increase:** Change the loads connected to Bus 13 and Bus 14 to 18MW/8MVar and 20MW/8MVar. Check the load flow results.

b) **Non-slack bus generator out of service:** Undo the changes made in a). Disconnect Generator 2 from the network. Check the load flow results.

c) **A major transmission line out of service:** Undo the changes made in b). Disconnect one of the transmission lines from Bus 1 to Bus 2. Check the load flow results.

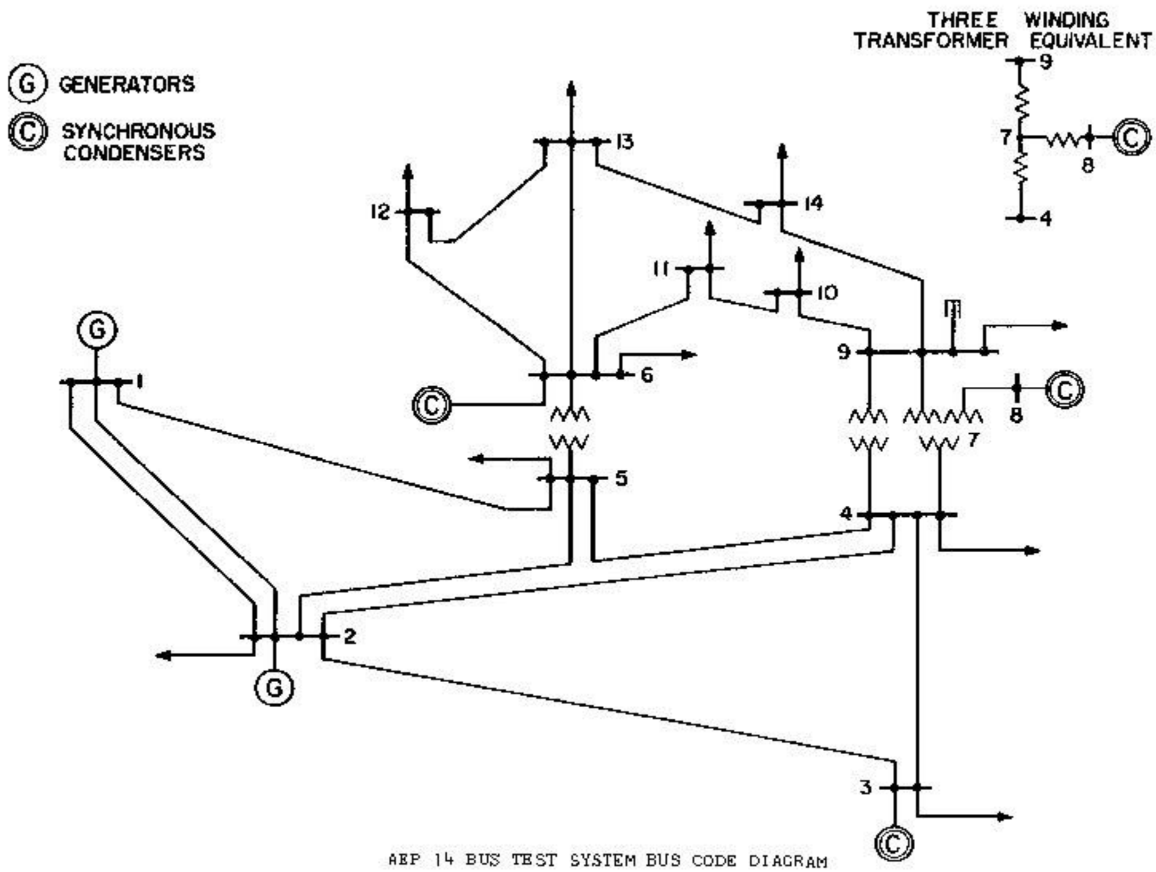
Recommended software:

- **Power World.**
- **Powertech Dynamic Security Assessment Software (DSA Tools).**
- **Power System Analysis Toolbox (PSAT).**

Lab 02: Fault Analysis in IEEE-14 Bus Test System

Questions:

First build the following IEEE 14 Bus System in your power system analysis software for fault analysis study. (System Base: 100 MVA)



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(v) Transformer Connection Notations

Wye-Grounded	YG
Wye	Y
Delta	Δ

(1) Balanced Fault

a) Perform three-phase balanced fault for six different buses (one at the slack bus, one at Bus 2, one at a synchronous condenser connected bus, one at a load bus, one at the lowest voltage bus and one bus of your choice). Check voltage profiles at the non-fault buses and fault currents.

(2) Unbalanced Fault

a) Change all five transformer connections to YG-YG. Perform single-line-to-ground, line-to-line and double-line-to-ground faults for eight different buses (at the slack bus, Bus 2, Bus 4, Bus 6, Bus 8, Bus 9, Bus 14, and one of your choices). Check voltage profiles at the non-fault buses and fault currents.

b) Change all five transformer connections to Y-Y. Perform single-line-to-ground, line-to-line and double-line-to-ground faults for eight different buses (at the slack bus, Bus 2, Bus 4, Bus 6, Bus 8, Bus 9, Bus 14, and one of your choices). Check voltage profiles at the non-fault buses and fault currents.

c) Change all five transformer connections to Δ-Δ. Perform single-line-to-ground, line-to-line and double-line-to-ground faults for eight different buses (at the slack bus, Bus 2, Bus 4, Bus 6, Bus 8, Bus 9, Bus 14, and one of your choices). Check voltage profiles at the non-fault buses and fault currents.

d) Change transformer connections as shown in the table below. Perform single-line-to-ground, line-to-line and double-line-to-ground faults for eight different buses (at the slack bus, Bus 2, Bus 4, Bus 6, Bus 8, Bus 9, Bus 14, and one of your choices). Check voltage profiles at the non-fault buses and fault currents.

Transformer	Connections
Bus 5 to Bus 6	YG - Y
Bus 4 to Bus 9	YG - Δ
Bus 4 to Bus 7	Δ - Δ
Bus 9 to Bus 7	Δ - Δ
Bus 8 to Bus 7	Δ - Δ

e) Change transformer connections as shown in the table below. Perform single-line-to-ground, line-to-line and double-line-to-ground faults for eight different buses (at the slack bus, Bus 2, Bus 4, Bus 6, Bus 8, Bus 9, Bus 14, and one of your choices). Check voltage profiles at the non-fault buses and fault currents.

Transformer	Connections
Bus 5 to Bus 6	YG - YG
Bus 4 to Bus 9	YG - Δ
Bus 4 to Bus 7	YG - YG
Bus 9 to Bus 7	YG - YG
Bus 8 to Bus 7	Δ - YG

f) Change transformer connections as shown in the table below. Perform single-line-to-ground, line-to-line and double-line-to-ground faults for eight different buses (at the slack bus, Bus 2, Bus 4, Bus 6, Bus 8, Bus 9, Bus 14, and one of your choices). Check voltage profiles at the non-fault buses and fault currents.

Transformer	Connections
Bus 5 to Bus 6	Δ - YG
Bus 4 to Bus 9	Δ - YG
Bus 4 to Bus 7	YG - Y
Bus 9 to Bus 7	YG - Y
Bus 8 to Bus 7	Δ - Y

Recommended software:

- **Power World.**
- **Powertech Dynamic Security Assessment Software (DSA Tools).**

Lab 03: Transient Stability Analysis of a Single Machine Infinite Bus System

Questions:

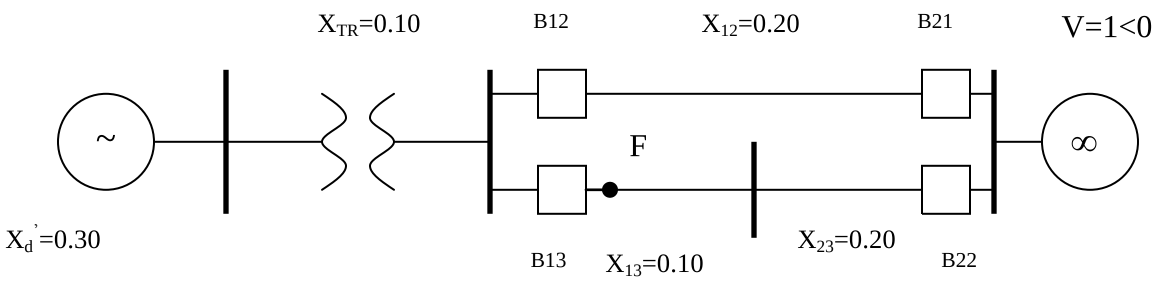

Figure 1: Single line diagram of simple power system I.

1. The synchronous generator in figure 1 delivers 0.9 p.u. real power at 0.95 power factor lagging at voltage at infinite bus (1.0 p.u. voltage). Determine
   The reactive power output of the generator.
   - The generator internal voltage.
   - An equation for the electrical power delivered by the generator as a function of δ.
   - For a three-phase-to ground bolted short circuit at F, determine the power delivered by the generator as a function of δ.
   - The fault is cleared by opening the circuit breakers B13 and B22 simultaneously, find the power delivered by the generator as a function of δ.
   - Draw the power angle curves for post-fault, during the fault and pre-fault conditions and determine the critical clearing angle.

2. The power system shown in figure 2 consists of four 555 MVA, 24 kV, 50 Hz units supplying power to infinite bus through two transmission circuits. The network reactances shown in the figure are in p.u. on 2220 MVA, 24 kV base. Resistances are assumed to be negligible.

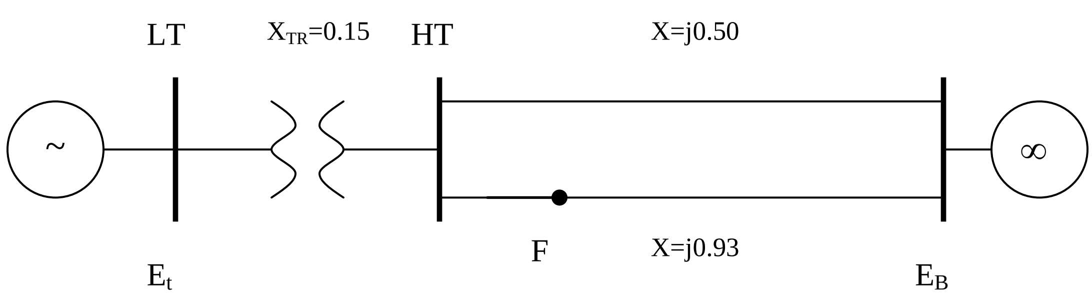

Figure 2: Single line diagram of simple power system II.

The initial operating condition, with quantities expressed in p.u. on 2220 MVA and 24 kV base, is as follows:

P=0.9, Q=0.436 (leading p.f), E_t=1.0 and 28.34^o, E_B=0.9008 and 0^o.

The generators are modeled as single equivalent generator represented by the classical model with the following parameters expressed in p.u. on the same bases as above.

X_d'=0.3, H=3.5 MW.s/MVA and K_D=0 (Damping coefficient).

System experienced a solid three-phase fault at point F. The fault is cleared by isolating the faulted circuit.

(a) Determine the critical-fault clearing time and critical clearing angle by computing the time response of the rotor angle, using numerical integration (**you also can use the ode23, or ode45 functions in MATLAB to check your program**).
(b) Check the above value of critical clearing angle, using the equal area criterion.

Recommended software:

- MATLAB-Simulink.
- Power System Analysis Toolbox (PSAT).
- Powertech Dynamic Security Assessment Software (DSA Tools).

Lab 04: Small Signal Stability Analysis of Two-area Test System

Questions:

Use any analytical software tools to study the small signal stability of the following test system. The basic data both static and dynamic can be obtained from [1].

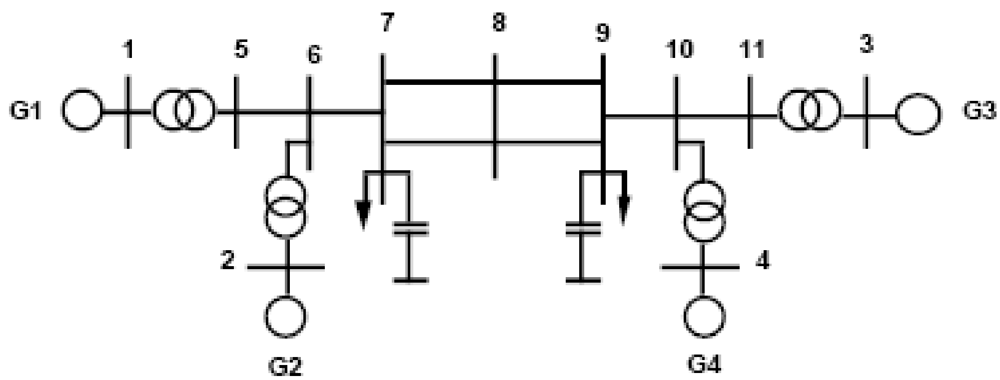

Figure 3: A single line diagram of two-area test system.

The figure 1 shows a single line diagram of two-area power system, typically, used for power system oscillation studies. The system consists of eleven nodes, including four generators and two loads, and thirteen braches, including four transformers.

(a) Model all the generators as classical models and study the small signal performance of the system.
(b) Model all the generators in detail; all the generators have identical parameters, calculate the eigenvalues of the system at the base case loading point.
(c) Introduce exciters (may be a simple model) in each of those generators and repeat the eigenvalue calculation.
(d) Now introduce governor models and repeat the calculation again.
(e) Using the participation factor analysis, find out what are the state variables dominant in the critical mode and the corresponding machine (problematic one).
(f) Introduce a Power System Stabilizer (PSS) in the problematic machine and calculate the eigenvalues again.

Present all the eigenvalues results, using tables and/or graphs, and comment on the stability of the system.

Recommended software:

- Power System Analysis Toolbox (PSAT).
- Powertech Dynamic Security Assessment Software (DSA Tools).

- Mudpack (An Interactive Software Package for Investigating Small Signal Stability).
- DigSILENT (Power Factory software).

Lab 05: Static Voltage Stability Analysis of WSCC-9 Bus Test System

Questions:

The main objective of the lab work is to study the static voltage stability of the WSCC 9 bus test system. The basic static data can be obtained from [4].

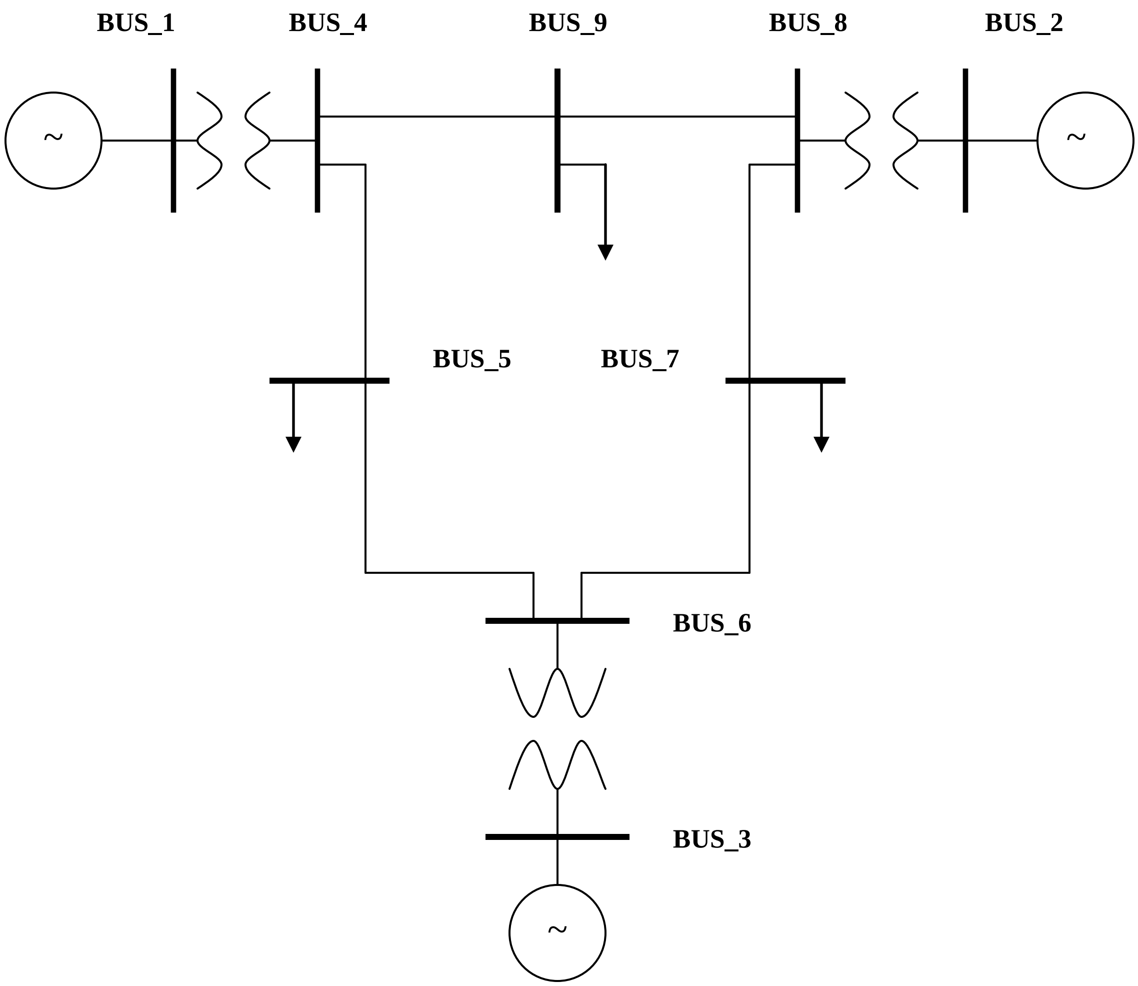

Figure 4: Single line diagram of 3-machine WSCC system.

Direct method, repeated power flow

(1) Increase the loading level of the system step by step, run a load flow and see whether you are getting convergence or not, report the maximum loading level. For loading "direction," assume all the loads are increased by the same ratio, and only generator at bus one is allowed to dispatch required additional real power.
(2) Plot the voltage against the total load at all the load buses; Find out which load bus having the highest dV/dP_{Total} at the point closer to divergence?

(3) Form the power flow Jacobian at several loading level up to the divergence point and plot the following curves.
    a) Singular value of power flow Jacobian against the total load in the system.
    b) Minimum eigenvalue of the power flow Jacobian against the total load in the system.
    c) Condition number of power flow Jacobian against the total load in the system.

(4) At the divergence point check the reactive power limits of the other two generators (other than swing bus).

Continuation Power Flow Method

(5) Run the continuation power flow, for the same generation and loading direction in the direct method, and obtain the static voltage stability margin of the system. Compare the results obtained in question 1 and comment on the results.

(6) Run the continuation power flow and produce PV curve assuming only load at bus 9 is allowed to be increased.

Recommended software:

- Power System Analysis Toolbox (PSAT).
- UWPFLWO software.
- Powertech Dynamic Security Assessment Software (DSA Tools).
- DigSILENT (Power Factory software).
- Power World software package.

Reference:

[1] P. Kundur, N. J. Balu and M. G. Lauby, "Power system stability and control," McGraw-Hill New York, 1994.

[2] N.Mithulananthan, "Hopf Bifurcation Control and Indices for Power System with Interacting Generator and FACTS Controllers", PhD dissertation, Department of Electrical and Computer Engineering, University of Waterloo, Canada,2002

[3] C.A.Canizares and F.L.Alvarado, "UWPFLOW Program," 2000, university of Waterloo, available on www.power.uwaterloo.ca.

[4] F.Milano, Power System Analysis Toolbox, Documentation for PSAT version 2.0, 2007, available on www.power.unwaterloo.ca.

[5] "Powertech DSATools," version 11.0, Powertechlabs.inc.

[6] "Power World Software Package," version 14.0, Power World Corporation.

[7] "An Interactive Software Package for Investigating the Small-Signal Dynamic Performance of Multi-Machine Power Systems (Mudpack)," School of Electrical and Electronic Engineering, The University of Adelaide, Australia.

[8] "DIgSILENTPowerFactory V14.0-User Manual," *DIgSILENT GmbH*,2008