Comparative Study in Enhancement of Voltage Stability Using Matlab and Power World Simulator

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Abstract-*In this paper P-V curve analysis is use to determine stability of power system. P-V curve is drawn for different load power factor condition. Load flow analysis is helps in calculating loadability limit and critical voltage collapse point at candidate load bus. Results were obtained using MATLAB applications software and power world simulator.*

Keywords: PV Curve, Voltage Stability, Newton Raphson, loadability.

I. INTRODUCTION

Due to increased loads and inter-utility power transfers transmission systems are operated at stressful condition. Eventually with growing size, the efficient operation of the power system is threatened due to problem of voltage instability and collapse. PV curves are most widely used voltage stability analysis tools and formed by increasing power at a particular area in steps and voltage (V) is observed at some critical load buses at constant power factor and then curves for those particular buses will be plotted. Maximum power transfer at critical voltage is calculated using PV curves.

Voltage corresponding to “maximum loading point” is called as critical voltage. If load is further increased, power flow equation doesn't converge. Thus load flow analysis along with singularity of Jacobian condition is used to calculate collapse point.

II. THEORETICAL BACKGROUND

Newton Raphson Method is an iterative technique for solving a set of various nonlinear equations with an equal number of unknowns. In this paper polar coordinate form is used. As shown in figure the current entering at bus i is given by equation

$$I_i = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j \qquad j \neq i$$

This equation can be rewritten in terms of the bus admittance matrix as

$I_i = \sum_{j=1}^{n} Y_{ij} V_j$, expressing in polar form we have

$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_j| \angle \theta_{ij} + \delta_j$$

Complex power at i^{th} bus is $P_i - j\,Q_i = V_i^{*} I_i$

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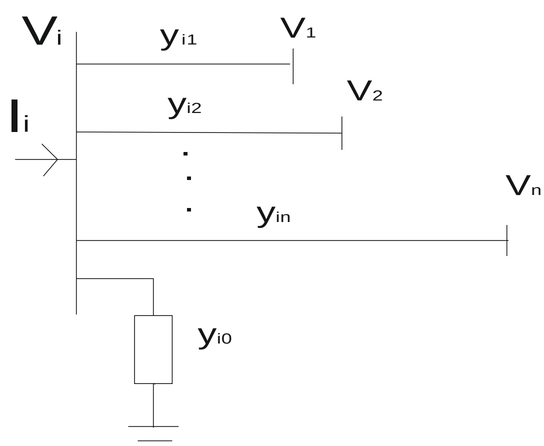


Figure 1 :i^{th} bus of the power system

Substituting the value of current in complex power equation we get

$P_i - j\,Q_i = |V_i| \angle -\delta_i \sum_{j=1}^{n} |Y_{ij}||V_j| \angle \theta_{ij} + \delta_j$, simplify and separating real and imaginary parts,

$$P_i = \sum_{j=1}^{n} |V_i||Y_{ij}||V_j| \cos(\theta_{ij} - \delta_i + \delta_j)$$

$$Q_i = -\sum_{j=1}^{n} |V_i||Y_{ij}||V_j| \sin(\theta_{ij} - \delta_i + \delta_j)$$

Elements of Jacobian matrix is obtained by taking partial derivatives of above equations with respect to magnitude and phase angle of voltages i.e., $|V|$ and δ. the jacobian matrix gives the linearised relationship between small changes in magnitude and phase angle of voltages i.e., $\Delta|V|$ and $\Delta\delta$ with the small changes in real and reactive power ΔP and ΔQ.

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_1 & J_2\\ J_3 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix}$$

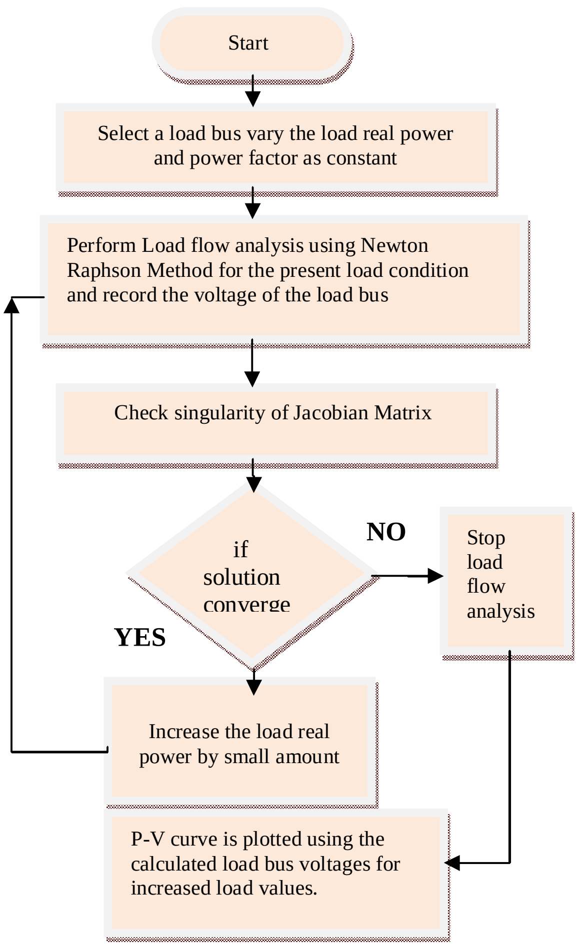
The term ΔP and ΔQ known as power residue or mismatch, given by

$$\Delta P = P_{schedule} - P$$

$$\Delta Q = Q_{schedule} - Q$$

$$\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} = \begin{bmatrix}J_1 & J_2\\ J_3 & J_4\end{bmatrix}^{-1}\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}$$

The new estimate for bus voltages are $\delta^{k+1} = \delta^k + \Delta\delta$ and $V^{k+1} = V^k + \Delta|V|$.



III. CASE STUDY

Consider a three bus power system as shown in figure generator at buses 1 and 3. The magnitude of voltage at slack bus 1 is 1.05 pu and voltage magnitude at bus 3 is 1.04 pu and real power generation at bus 3 is 200 MW. Bus 2 is a load bus consisting of 400 MW and 250 $Mvar$. Line impedances are marked in per unit on a 100 MVA base, and line charging suspectances are neglected.

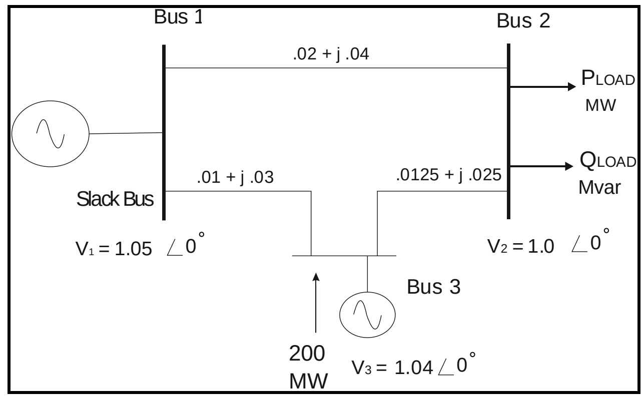


Figure 2 : Three Bus System Network

Load real power ($P_{LOAD} \backslash P_2$) is incremented and load reactive power is ($Q_{LOAD} \backslash Q_2$) is given by $Q_{LOAD} = P_{LOAD} \tan\phi$ and constant generator real power $P_3 = 200\ MW$.

CASE STUDY I: By varying load power P_2 and $Q_2 = P_2 \tan\phi$ and constant generator real power $P_3 = 200\ MW$ and power factor $\phi = 45°\ lag$. Results obtained using newton Raphson program is

Determinant of Jacobian = 557.666

critical voltage(V_2) = .5366 p. u.

$Real\ Power\ critical(\ P_2) = 11.3370\ p.u.$

$\delta\ critical(\ \delta_2\ ) = -17.7914°$

$Reactive\ Power\ critical(\ Q_2\ ) = 11.3370\ p.u.$

$Generator\ Reactive\ Power\ (Q_3\ ) = 19.42 p.u.$

$Slack\ Bus\ Real\ Power\ \ (P_1) = 17.20 p.u.$

$Slack\ Bus\ Reactive\ \ Power\ \ (Q_1) = 8.274\ p.u.$

$\delta_3 at\ blackout\ condition = -17.428°$

And curves obtained shown below:

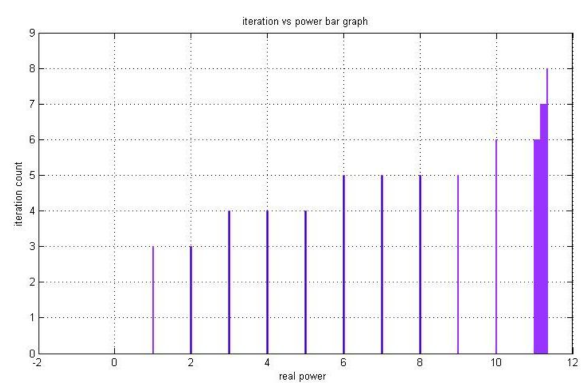


Figure 3 : Iteration Bar Graph At 45 Degree Lag

And the results obtained using power world simulator is shown below Table 1:

Table 1: Complex power, Voltage at 45 degree lagging

P_2 MW	Q_2 Mvar	V_2 $p.u$	δ_2 $Degre$	P_1 MW	Q_1 Mvar	Q_3 Mvar	δ_3 $Degree$
100	100	1.02	.76	-96	145	-36.4	1.92
300	300	.97	-1.12	115	181	149.1	.30
600	600	.89	-4.41	474	265	485.7	-2.53
900	900	.77	-8.85	933	418	961.3	-6.34
1000	1000	.71	-10.9	1140	506	1195.9	-8.16
1100	1100	.62	-14.2	1445	660	1569.3	-10.97
1130	1130	.56	-16.4	1642	777	1831.9	-12.91
1133	1133	.54	-17.2	1702	815	1916.2	-13.52
1134	1134	.53	-17.5	1729	833	1954.3	-13.79
BLACKOUT CONDITION IS REACHED							

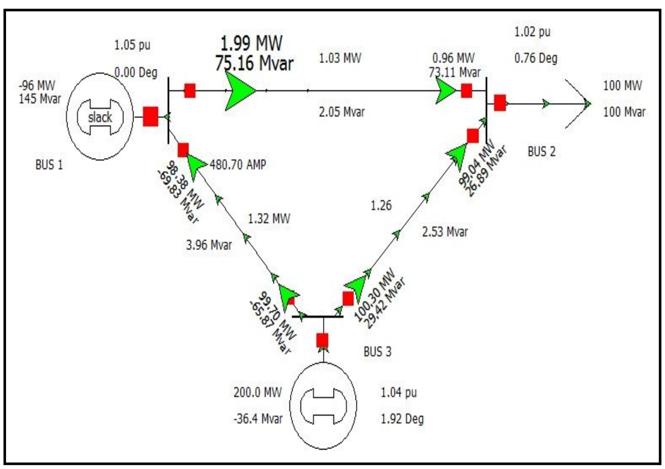


Figure 4 : Three Bus System At 45 Degree Lag

$P_{LOAD} = 100\ MW$ and $Q_{LOAD} = 100\ MVAR$

STUDY II: By varying load power P_2 and $Q_2 = P_2 \tan\phi$ and constant generator real power $P_3 = 200\ MW$ and power factor $\phi = 0°$ .Results obtained using Newton Raphson program is:

Determinant of Jacobian = 519.85

critical voltage = .6035 p. u.

$RealPowercritical = 20.8780\ p.u.$

$\delta critical = -47.3744°$

$ReactivePowercritical = 0\ p.u.$

$GeneratorReactivePower(Q_3) = 18.864\ p.u.$

$SlackBusRealPower(P_1) = 30.76 p.u.$

$SlackBusReactivePower(Q_1) = 6.96\ p.u.$

$\delta_3 atblackoutcondition = -24.96°$

And curves obtained shown below:

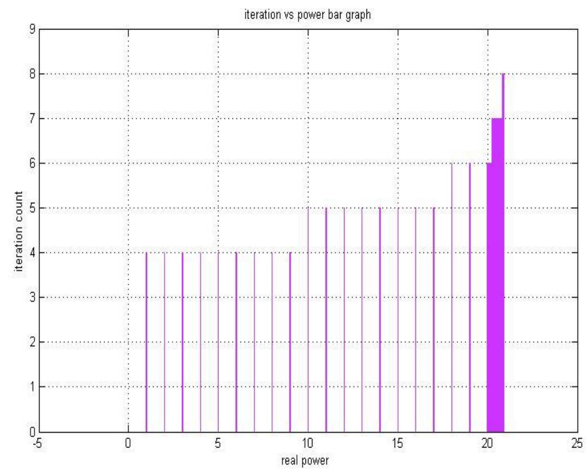


Figure 5 : Iteration Bar Graph At 0 Degree

And the results obtained using power world simulator is shown below Table 2 :

Table 2 : Complex power, Voltage at 0 degree

P_2 MW	Q_2 Mvar	V_2 $p.u$	δ_2 $Degree$	P_1 MW	Q_1 Mvar	Q_3 Mvar	δ_3 $Degree$
500	0	1	-4.99	320	24	16.8	-1.27
1000	0	.95	-12.47	903	-17	234.5	-5.74
1800	0	.80	-29.05	2117	180	934.5	-15.61
2000	0	.72	-36.66	2599	385	1344.7	-20.02
2085	0	.64	-44.54	3025	656	1818.4	-24.39
2087	0	.62	-45.82	3086	704	1899.5	-25.07
BLACKOUT CONDITION IS REACHED `							

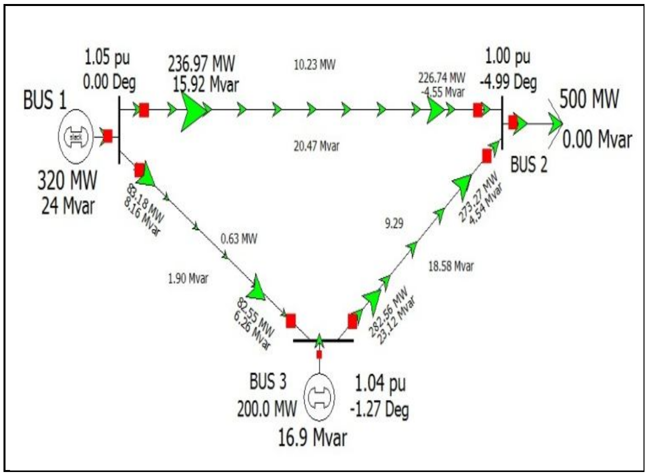


Figure 6: Three Bus System At 0 Degree
P_{LOAD} = 1500 MW and Q_{LOAD} = 0 $MVAR$

STUDY III: By varying load power P_2 and $Q_2 = P_2 \tan\phi$ and constant generator real power $P_3 = 200\ MW$ and power factor $\phi = 20°\ Lead$. Results obtained using Newton Raphson program is:

Determinant of Jacobian = 1434

critical voltage(V_2) = .7094 p.u.

$Real\ Power\ critical\ (P_2) = 24.75\ p.u.$

$\delta\ critical\ (\delta_2) = -58.2864°$

$Reactive\ Power\ critical(Q_2) = -9.0112\ p.u.$

$Generator\ Reactive\ Power\ (Q_3) = 18.05\ p.u.$

$Slack\ Bus\ Real\ Power\ (P_1) = 38.27 p.u$

$Slack\ Bus\ Reactive\ Power\ (Q_1) = 7.100 p.u.$

$\delta_3 at\ blackout\ condition = -31.01°$

And curves obtained shown below:

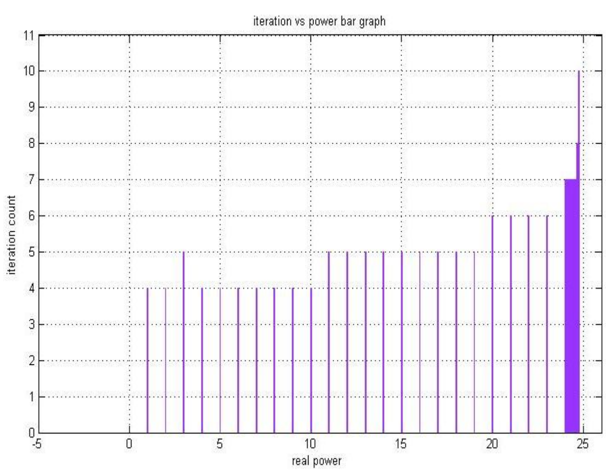


Figure 7: Iteration Bar Graph At 20 Degree Lead

And the results obtained using power world simulator is shown below Table 3:

Table 3 : Complex power, Voltage at 20 degree lead

P_2 MW	Q_2 Mvar	V_2 $p.u$	δ_2 $Degree$	P_1 MW	Q_1 Mvar	Q_3 Mvar	δ_3 $Degree$
500	-182	1.03	-5.63	322	-45	-93	-1.27
1000	-364	1.01	-13.44	903	-155	8.4	-5.63
1500	-546	.97	-22.29	1571	-176	209.4	-10.70
2000	-728	.91	-33.43	2383	-50	584.4	-17.16
2400	-873	.80	-48.49	3346	356	1281.9	-25.83
2470	-899	.73	-55.80	3731	628	1686.5	-29.91
2475	-900	.71	-58.25	3846	727	1830.9	-31.24
BLACKOUT CONDITION IS REACHED							

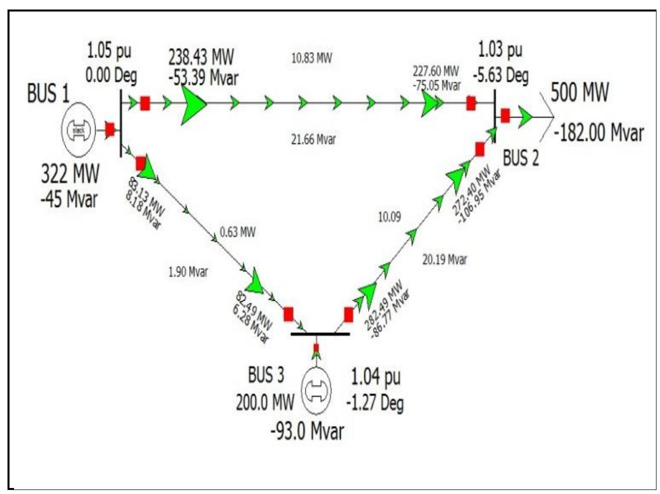


Figure 8: Three Bus System At 20 Degree Lead
P_{LOAD} = 500 MW and $Q_{LOAD} = -182\ MVAR$

STUDY IV: By varying load power P_2 and $Q_2 = P_2 \tan\phi$ and constant generator real power $P_3 = 200\ MW$ and power factor $\phi = 45°\ Lead$ .Results obtained using Newton Raphson program is

Determinant of Jacobian = 306.315

Critical voltage = .8831 p.u.

$Real\ Power\ critical = 28.5150\ p.u.$

$\delta\ critical = -75.56°$

$Reactive\ Power\ critical = -28.5150\ p.u.$

$Generator\ Reactive\ Power\ (Q_3) = 15.006\ p.u.$

$Slack\ Bus\ Real\ Power\ \ (P_1) = 49.64 p.u.$

$Slack\ Bus\ Reactive\ \ Power\ \ (Q_1) = 7.77 p.u.$

$\delta_3 at\ blackout\ condition = -39.60°$

And curves obtained shown below:

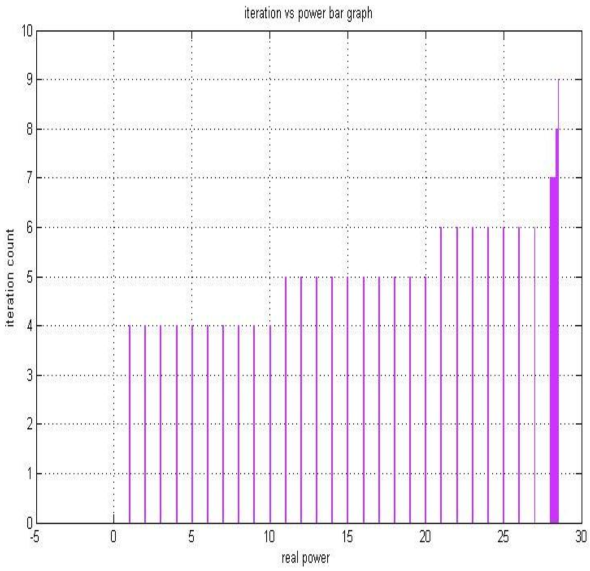


Figure 9 : Iteration Bar Graph At 45 Degree *LEAD*

And the results obtained using power world simulator is shown below Table 4:

Table 4 : Complex power, Voltage at 45 degree lead

P_2 MW	Q_2 Mvar	V_2 $p.u$	δ_2 $Degree$	P_1 MW	Q_1 Mvar	Q_3 Mvar	δ_3 $Degree$
1000	-1000	1.09	-15.26	947	-370	-324.1	-5.80
2000	-2000	1.08	-34.76	2478	-457	-92.7	-16.95
2500	-2500	1.04	-48.43	3524	-185	341.6	-25.24
2600	-2600	1.02	-52.15	3790	-67	494.8	-27.53
2820	-2820	.95	-65.31	4631	471	1143.5	-35.72
2840	-2840	.93	-68.22	4793	611	1306.6	-37.53
2850	-2850	.91	-71.24	4950	763	1483.5	-39.42
2860	-2860	.91	-72.60	5020	823	1555.3	-40.19
BLACKOUT CONDITION IS REACHED `							

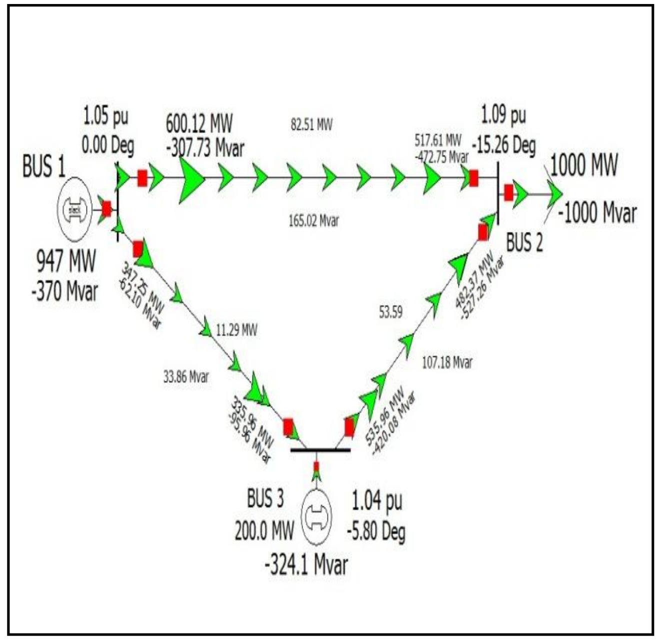
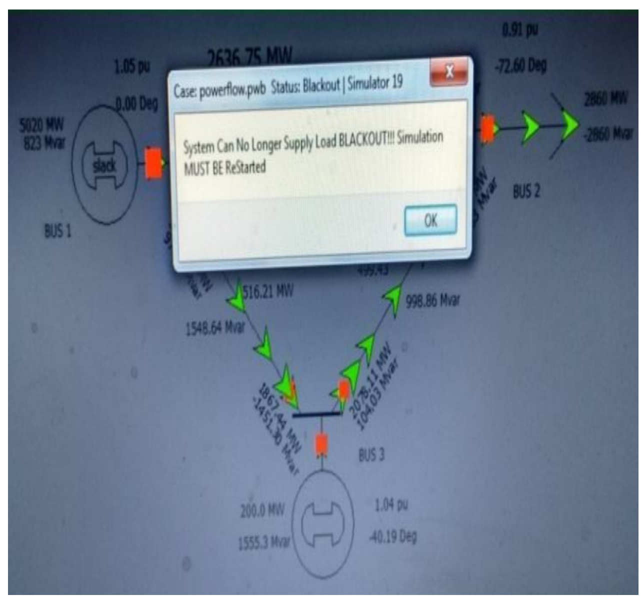


Figure 10: Three Bus System At 45 Degree Lead P_{LOAD} = $1000\ MW$ and $Q_{LOAD} = -1000\ MVAR$

When P_2 is increased further above voltage collapse point then simulation software generate message as shown below:



From graphs and tables it is observed that as the load side power factor varies from lagging to leading condition then the loadability of the system increases. Thus reactive power support is necessary for stable power system operation.

Combining all curves for different power factor we get:

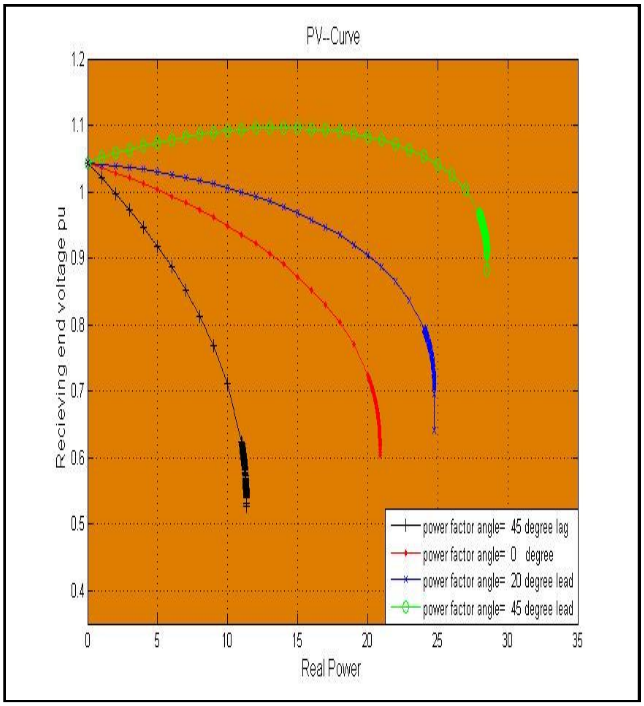


Figure 11: PV CURVES AT DIFFERENT POWER FACTORS

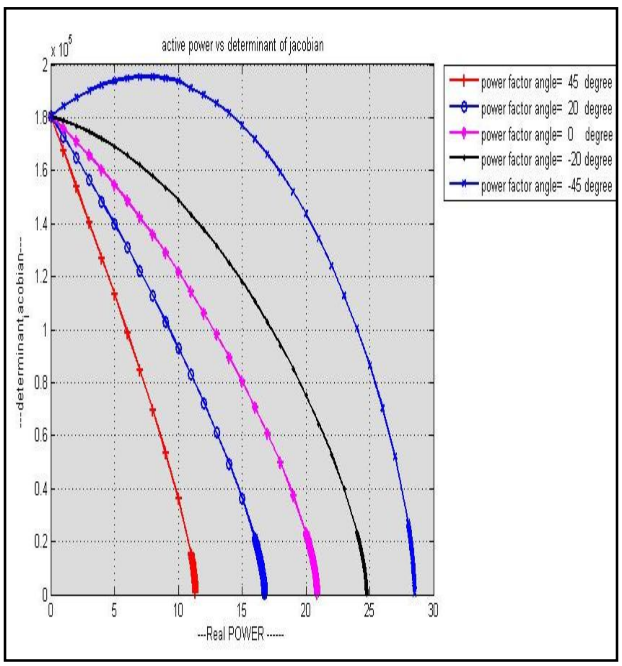


Figure 12: DETERNINANT OF JACOBIAN MATRIX AT DIFFERENT POWER FACTORS

IV. CONCLUSION

In this paper PV curve analysis shows that with increasing load, voltage profile of line dropped. Power flow program is developed using Matlab software and simulation in power world simulator to analyze power system network. It is shown that reactive power compensation at load side has significant effect on loadability, critical voltage point of the system.

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