PV and QV Curves Approach for Voltage Instability Analysis on Mesh-Type Electrical Power Networks Using DIgSILENT

Marizan Sulaiman and Ahmad Fateh Mohamad Nor

Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Malaysia

Abstract

The analysis of voltage instability in electric power system is very crucial in order to maintain the equilibrium of the system. This paper presents the analysis of voltage instability of electric power system by using power-voltage (PV) curve and reactive power-voltage (QV) curve. This research focuses on the voltage instability analysis using PV and QV curves for mesh-type power networks. The power flow analysis for mesh-type power network will be done by using DIgSILENT and the plotting of PV and QV curve will be done by using Microsoft Excel.

***Keywords**:* Voltage Instability, Mesh-Network, PV and QV Curves, DIgSILENT.

1. Introduction

Voltage stability is defined as the ability of a power system to keep the voltage at all busses in the system remain unchanged right after the system is being subjected to a disturbance. Voltage instability on the other hand is the opposite of voltage stability. Voltage instability occurs due to the failure of the power system to supply ample power to cover the increased demand of load [1-4]. Hence, the analysis of voltage instability should be implemented in order to make sure that the voltage level at all busses is at stable state. A number of methods to analyze voltage stability have been proposed including the PV and QV curves method [5-10]. PV and QV curves are widely used for this purpose [2,7]. Therefore, the PV and QV curves for mesh-type power network will be presented in this paper. A 16-bus power system [11] has been chosen as the mesh-type power network. The load flow analysis of the system will be done by using DIgSILENT. Meanwhile the method of plotting PV and QV curves will be done with the help of Microsoft Excel.

2. Mesh-Type Electrical Power System

For mesh-type electrical power system, the voltage instability analysis process involves a series of power flow solutions. The value of real power (MW) and reactive power (MVAR) of load will be increased constantly for every series of power flow. The bus voltages will change as a result of the series power flow [12-15]. Figure 1 shows the 16-bus power system constructed in DIgSILENT [11]. The data for bus the 16-bus power system as shown in Figure 1 are presented in Table 1 to Table 4 [11].

(DOI: dx.doi.org/14.9831/1444-8939.2015/3-6/MAGNT.04)

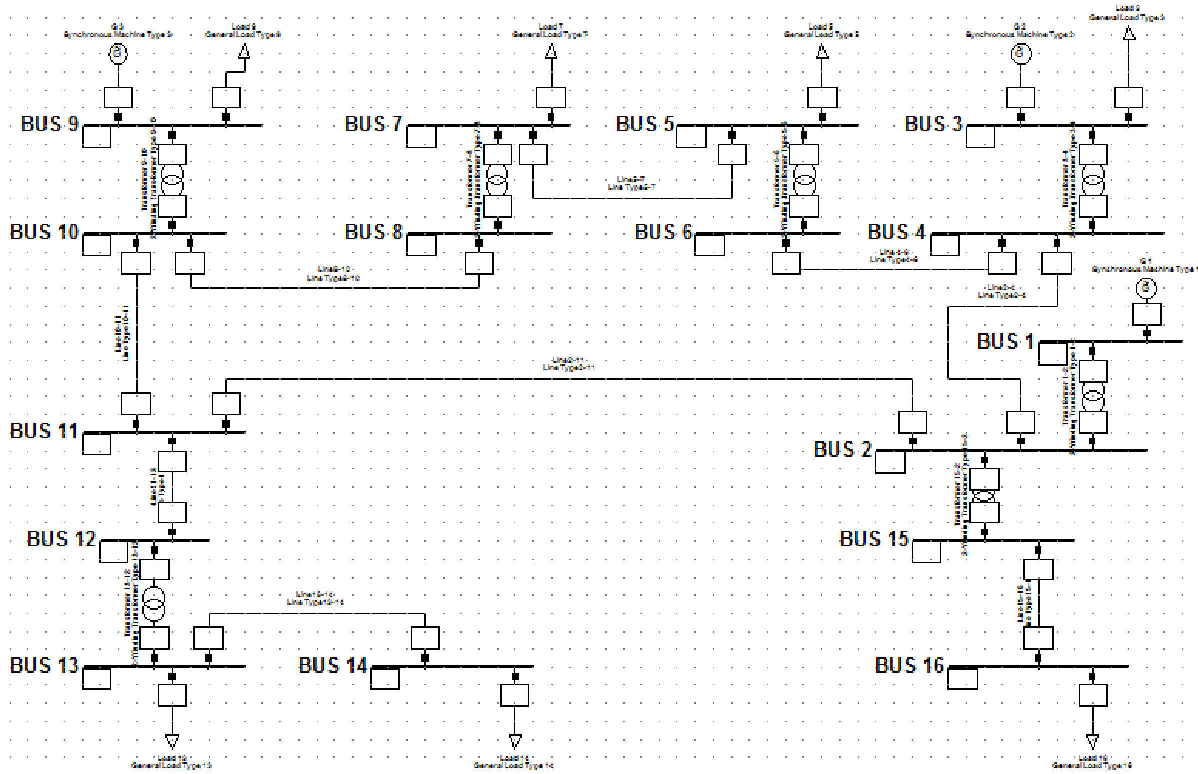

Figure 1: 16-bus Electric Power System Constructed in DIgSILENT

Table 1: Generator Data

Bus	Rated MVA	kV	Rated Real Power (MW)	Q_{max} (MVAR)	Q_{min} (MVAR)
1	220, P.F=0.85	345	170	105.4	-
3	120, P.F=0.85	13.8	110	80	-40
9	250, P.F=0.85	13.8	220	140	-100

Table 2: Transformer Data in Per-Unit

From Bus	To Bus	R	X	S_{Rating}	Tap
1	2	0.003500	0.035000	2.0	1.0
15	2	0.002722	0.032670	2.0	1.0
13	12	0.002083	0.041670	1.2	1.025
3	4	0.003846	0.038460	1.3	1.0
5	6	0.001667	0.041670	1.2	1.0
7	8	0.001667	0.041670	1.2	1.0
9	10	0.001200	0.024000	2.5	1.0

Table 3: Transmission Line Data in Per-Unit

From Bus	To Bus	R	X	B	S_{Rating}
4	6	0.006650	0.035190	0.074580	3.585
8	10	0.006650	0.035190	0.074580	3.585
10	11	0.009980	0.052790	0.111900	3.585
2	4	0.016640	0.087980	0.186440	3.585
2	11	0.016640	0.087980	0.186440	3.585

(DOI: dx.doi.org/14.9831/1444-8939.2015/3-6/MAGNT.04)

5	7	0.008302	0.045550	0.008129	2.012
15	6	0.027680	0.151800	0.027100	2.012
11	12	0.006656	0.035192	0.074576	3.585
13	14	0.052100	0.177300	0.003707	0.872

Table 4: Load Data

Bus	P (MW)	Q(MVAR)
3	10	55
5	75	15
7	90	20
9	15	4
13	50	2
14	35	3
16	150	20

Table 5: Shunt Capacitor Data

Bus	Capacitance (MVAR)
16	60

The methodological steps of plotting the PV and QV curves for the 16-bus electric power system are listed as follows [2,3,10,14,17]:

Step 1: Select a bus. The PV and QV curve will be plotted at this selected bus. Bus 16 has been chosen for this case due to low bus voltage.

Step 2: Run the power flow program by using DIgSILENT.

Step 3: Increase the value of real power of load (P) by 5 MW in order to plot PV curve while maintaining constant reactive power of load (Q). Similarly, increase the value of Q by 5 MVAR while maintaining fixed P in order to plot QV curve. Then run the power flow program again. A new voltage value at the selected bus will be obtained. Record the values of P or Q and voltages.

Step 4: Repeat Step 3 until the value of desired P or Q cannot be delivered by the generation system.

Step 5: Finally, use all the recorded value of P or Q obtained in Step 3 and Step 4 and plot it against the voltage of the selected bus by using Microsoft Excel.

This paper studies the performance of voltage instability analysis based on PV and QV curves of the 16-bus system. The load is assumed of constant power load characteristics as this type of load is favorable to voltage instability problems [2].

3. Results and Discussion

3.1 Result without shunt capacitor.

Figure 2 shows the DIgSILENT's load flow result for Bus 16. Meanwhile Figure 3 shows the generated PV and QV curve for bus 16 without shunt capacitor being connected to the system. The recorded value of P and Q of the curves are shown in Table 6. Real power and reactive power are being represented by the blue curve and red curve, respectively.

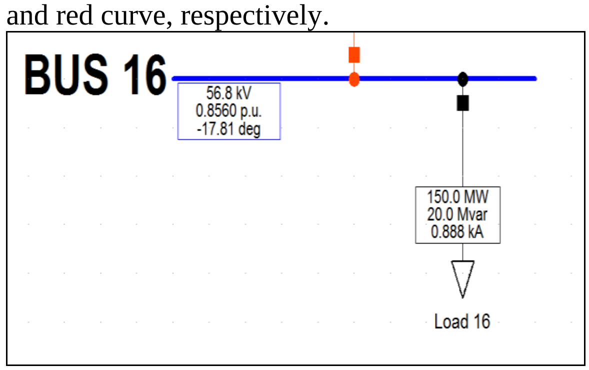

Figure 2: DIgSILENT's load flow result for Bus 16

Table 6: Recorded Value of P and Q for PV and QV Curve at Bus 16

PV CURVE		QV CURVE	
P (MW)	V (PER-UNIT)	Q (MVAR)	V (PER-UNIT)
150	0.8560	20	0.8560
155	0.8483	25	0.8425
160	0.8400	30	0.8283
165	0.8312	35	0.8133
170	0.8217	40	0.7975
175	0.8114	45	0.7806
180	0.8001	50	0.7624
185	0.7876	-	-

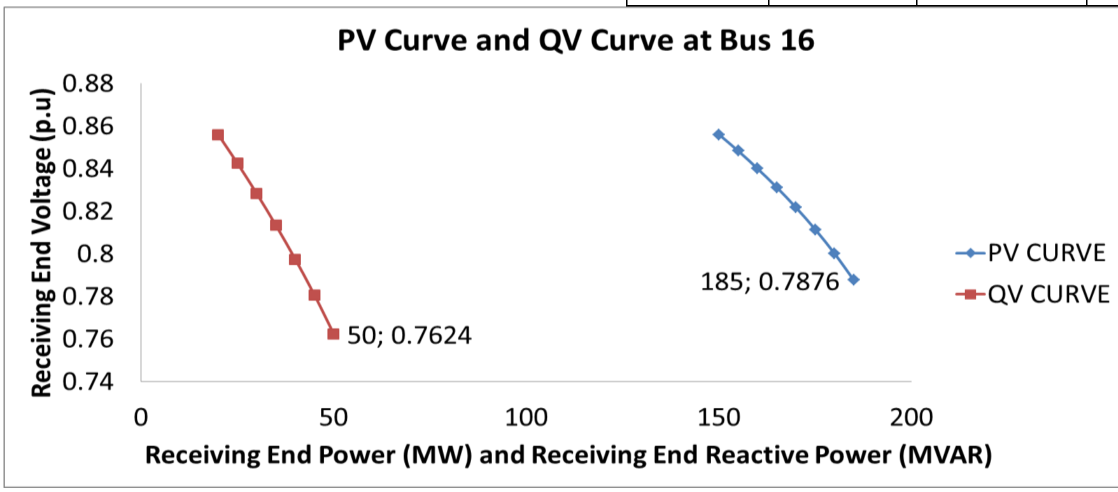

Figure 3: PV and QV curve at bus 16 (without shunt capacitor)

It can be seen from Figure 2 that the voltage at Bus 16 is 0.86 per unit which is very low [11]. From Figure 3, the critical voltage points for both PV and QV curves are 0.7876 per unit and 0.7624 per unit, respectively. The system will reach critical voltage point if the load demand for real power P is increases until 185 MW and the reactive power Q for load is increased up to 50 Mvar. In both cases the bus voltages drop below 0.80 per-unit.

3.2 Result with shunt capacitor.

A shunt capacitor has been added to Bus 16 in order to increase the value of voltage. Both Figure 4 and Figure 5 show the DIgSILENT's load flow result for Bus 16 and the generated PV and QV curve for bus 16 after the shunt capacitor had been connected to the system. The recorded value of P and Q of the curves are shown in Table 7. Similarly, the real power and reactive power are being represented by the blue curve and red curve, respectively.

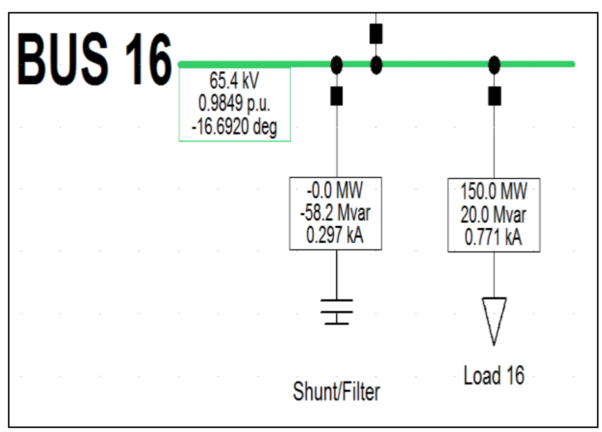

Figure 4: DIgSILENT's load flow result for Bus 16 (with shunt capacitor)

(DOI: dx.doi.org/14.9831/1444-8939.2015/3-6/MAGNT.04)

Table 7: Recorded Value of P and Q for PV and QV Curve at Bus 16 (with shunt capacitor)

PV CURVE		QV CURVE	
P (MW)	V (PER-UNIT)	Q (MVAR)	V (PER-UNIT)
150	0.9849	20	0.9849
155	0.9782	25	0.9725
160	0.9726	30	0.9597
165	0.9638	35	0.9465
170	0.9559	40	0.9327
175	0.9477	45	0.9183
180	0.9390	50	0.9032
185	0.9297	55	0.8874
190	0.9197	60	0.8706
195	0.9091	65	0.8528
-	-	70	0.8335
-	-	75	0.8126
-	-	80	0.7892
-	-	85	0.7625

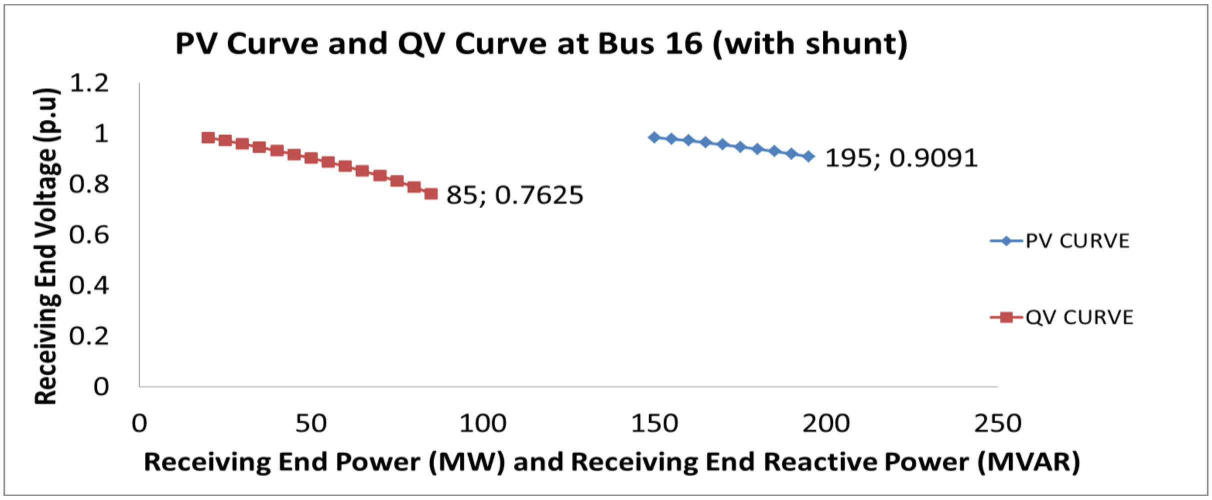

Figure 5: PV and QV curve at bus 16 (with shunt capacitor)

Figure 4 shows that the voltage at Bus 16 is 0.9849 per unit which is much better than the value shown in Figure 2 [11]. The critical voltage points for both PV and QV curves as shown in Figure 5 are 0.9091 per unit and 0.7625 per unit, respectively. The system will reach critical voltage point if the real power P for load is increased until 195 MW and the reactive power Q for load is increased up to 85 Mvar. The real power P for load cannot be larger than 195 MW because the generation is not able to supply the demand even the bus voltage only reaches 0.9091. At this point, the generated real power of Generator 1 (at Bus 1) hits its maximum limit of 170 MW as obtained from the load flow.

4. Conclusion

Voltage instability analysis is an important parameter for monitoring the bus voltage in the electrical power system. To maintain the voltage stability of the system, the bus voltages must not be operated close to the critical voltage point at the PV and QV curves. The studies conducted using DIgSILENT have shown that the starting voltage at Bus 16 had been increased from 0.86 per unit to 1.00 per unit after the shunt capacitor had been added to Bus 16. In addition of the shunt capacitor causes the incremental values of load of real and reactive powers at Bus 16 become higher.

Acknowledgement

The authors are grateful to the Universiti Teknikal Malaysia Melaka for providing the necessary platform for this research.

References

[1] Kundur and et, al., Definition and Classification of Power System Stability IEEE/CIGRE Joint Task Force on Stability Terms and Definitions, *IEEE Transactions on Power Systems*, Vol. 19, No. 2, pp. 1387 – 1401, (August 2004).

[2] Marizan Sulaiman, Ahmad Fateh Mohamad Nor, Ropidah Bujal, Voltage Instability Analysis on PV and QV Curves for Radial-Type and Mesh-Type Electrical Power Networks, *International Review of Electrical Engineering (IREE)*, Vol. 10, No. 1, pp. 109 – 115, (2015).

[3] Marizan Sulaiman, Ropidah Bujal, Rosli Omar, A Graphical User Interface (GUI) Approach of Voltage Instability Analysis Based on P-V and Q-V curves in Radial Power System Networks, *MAGNT Research Report*, Vol. 3, No. 3, pp. 1271-1283, (2015).

[4] Morison, Gao, Kundur, Voltage Stability Analysis using Static and Dynamic Approaches, *IEEE Transactions on Power Systems*, Vol. 8, No. 3, pp. 1159 – 1171, (August 1993).

[5] Gao, Morison, Kundur, Voltage Stability Evaluation using Modal Analysis, *IEEE Transactions on Power Systems*, Vol. 7, No. 4, pp. 1529 – 1542 (1992).

[6] Gao, Kundur, Morison, Towards The Development of A Systematic Approach for Voltage Stability Assessment of Large-Scale Power Systems, *IEEE Transactions on Power Systems*, Vol. 11, No. 3, pp. 1314 – 1324 (August 1996).

[7] Khan, A. A., A Simple Method For Tracing PV Curve Of A Radial Transmission Line, *World Academy of Science, Engineering and Technology*, Vol. 2, No. 11, pp. 347 – 350 (July 2008).

[8] Noor Ropidah Bujal, Marizan Sulaiman, Rosli Omar, A graphical user interface (GUI) for voltage stability analysis, *Conference In Education - Technical Vocational Education and Training Cie-TVET 2014*, August 25-26, 2014, Malaysia.

[9] Taylor, C.W., Power System Voltage Stability (McGraw-Hill, Inc., 1994).

[10] Chen, M.S., Energy Systems Research Center (University of Texas at Arlington, 1996).

[11] Gross, C.A., Power System Analysis, 2nd ed. John Wiley & Sons, 1986.

[12] Willis, H.L., Power Distribution Planning Reference Book (Marcel Dekker, Inc., 2004).

[13] Saadat, H., Power System Analysis (McGraw-Hill Inc., 2004).

[14] Kundur, P., Power System Stability and Control (McGraw-Hill Inc., 1994).

[15] Anderson, Fouad, Power System Control and Stability (John Wiley & Sons, Inc., 2003).

[16] Aydin, B., Voltage security assessment using P-V and Q-V curves, Master's thesis, Department of Electrical and Electronic Eng., Bahcesehir University, Istanbul, Turkey, 2008.

AUTHORS' INFORMATION

Marizan Sulaiman obtained B.Sc. in Electrical Engineering in 1984, M.Sc. in Electrical Engineering in 1985 and Ph.D. in Electrical Engineering in 1989 from the University of Missouri, USA. He is currently the Dean of Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Malaysia. He has published 8 books, authored and co-authored more than 55 journal articles and authored and co-authored more than 85 conference papers. His research interests include power systems, energy efficiency and control & automation. Prof. Marizan is a registered

(DOI: dx.doi.org/14.9831/1444-8939.2015/3-6/MAGNT.04)

member of Board of Engineers, Malaysia (BEM) and a graduate member of Institutes of Engineers, Malaysia (IEM).

Ahmad Fateh Mohamad Nor received his bachelor degree and master's degree in Electrical Engineering from Universiti Teknikal Malaysia Melaka (UTeM), Malaysia in 2011 and 2013, respectively. Currently he is a Ph.D. candidate at the Faculty of Electrical Engineering in Universiti Teknikal Malaysia Melaka (UTeM), Malaysia. His research interests include electrical power systems and solar electricity.