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Plotting of Voltage Contours in P-Q Plane Using Contour Evaluation Program

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Abstract

In the current deregulated environment, determining loadability to various security limits is of great importance for the secure operation of a power system. The conventional P-V and Q-V curves are used to determine the voltage stability margin. This paper proposes to find the relationship between P and Q for a constant voltage on a particular bus using a contour evaluation program. The flexibility of this program allows generation of a family of curves which show the amount by which the reactive power loading on a particular bus needs to be modified so as to keep the voltage constant on that bus.

1. Introduction

The electrical load demand is growing day by day and in order to meet the increasing demand, the power generating plants are operating at their maximum capacity. In the operation of power systems, it is a matter of prime importance to maintain the system in a secure operating region. One of the major problems associated with such a stressed system is voltage collapse or instability. There are many incidents of system blackout reported due to voltage collapse [1]. It is thus very important to know the critical bus voltage and also how the reactive power loading on the bus needs to be modified so that the bus voltage remains constant.

A perturbation of conditions at one bus in a power system changes conditions at all other buses. In response to changes in the injected real and reactive powers at a particular bus, the response of voltage levels, power flows and electrical angles throughout the system is noted. The response of the system to such changes depends on the relative sizes of the real and reactive components involved. This is particularly true for system voltage levels because the voltage drop due to load increase can be counteracted by increased reactive generation. So, it is desirable to produce contours in the P-Q or Q-V plane.

It is known that when the system P and/or Q increases beyond a certain limit, voltage collapse is bound to occur. The voltage stability margin for a given operating point can be determined if the limiting values of P and Q are known. Using these values, the voltage stability boundary is plotted in

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the P-Q plane[3]. In this paper, the author has used the limiting or critical values of P and Q at the voltage collapse point for plotting the voltage stability boundary . But, the P-Q curve has been plotted for a two bus system and the typical values of collapse voltage for which this curve is plotted is not clear. Had a large system been considered, there would have been more complexities involved and the computational burden would also have been more.

The proposed paper helps plot the P-Q curves for different values of voltage making use of a contour evaluation program. This has been done for a two bus system and for the IEEE 14 bus system under normal base load and various contingent conditions. Results have been tabulated and various graphical representations shown. The information obtained from the contour evaluation program[5] is unmatched. It helps produce a family of P-Q curves i.e. contours of voltage for various operating conditions. Also the complicated behavior of a multi bus system can be visualized.

2. Contour evaluation program[5]

Any set of steady-state power flow equations constitutes a set of n nonlinear constraint functions F given by,

$$F(u,k)=0 \qquad (1)$$

Where u is a vector of n unknowns and k is a vector of m known parameters. Equation (1) gives the response of the unknown vector u to changes in the known vector k . For evaluating the important properties of this response, target functions of the type $T(u,k)$ are defined. The response of such target functions to simultaneous but independent changes in any of the two parameters of k is considered. All other parameters of k are kept constant . So, $T(u,k)$ can be considered as a function of these two variable parameters. The corresponding surface in three dimensions can be represented in two dimensions by its contour map, i.e. by curves upon which target function T is constant, drawn in the plane of the varying parameters[5].

Each such curve is defined by a set of equations

$$F(u,x,y,k')=0 \qquad \text{and}$$
$$T(u,x,y,k')=t \qquad (2)$$

where x and y are the variable parameters of k. k' is the result of k after removing x and y. t is the value taken by target function T on the contour.

For each value of t, equations (2) will define a contour. This is because the equations contain $n+2$ unknowns (u,x,y) and specify only $n+1$ constraints (F and T). So, not only one solution, but a family of solutions lying on a continuous curve results. Such a family of curves, for a set of values of t , constitutes a contour map of the target function T with respect to the variable parameters x and y.

3. Two bus system

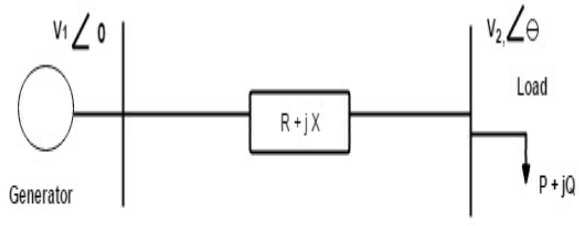

Figure 1: Two bus system

The target function for this system from the power flow equations is

$$P^2 + Q^2 = \left(\frac{V_1 V_2}{Z}\right)^2 \left[1 + \left(\frac{V_2}{V_1}\right)^2 - 2\frac{V_2}{V_1}\cos\theta\right]$$

Contours of constant voltage in the P-Q plane have been plotted for the two bus system using MATLAB programming. These contours are shown in the fig. 2 and 3. Results have been tabulated in table 1 and 2 respectively.

Sr No	V (pu)	Qmax (pu)	Corr. P (pu)	Pmax (pu)	Corr. Q (pu)
1	1.0	0.27	0.2	0.34	0
2	0.8	0.44	0.2	0.482	0
3	0.6	0.475	0.2	0.581	0

Table 1: Results of contours on 2 bus system as per plot in fig. 2

These results give the maximum power transfer capability of the system for various amounts of reactive power at the load. In table 1, for maintaining V=0.8 pu at load bus 2 , the maximum reactive power loading is to be restricted to 0.44 pu when the active power load is 0.2 pu. Also, the maximum active power load is 0.482 pu with no reactive power loading for V=0.8 pu. Table 2 also gives the maximum reactive and active power load at the load bus 2 for different voltage values. It is seen from both the tables and fig. 2 and 3 that as the reactive power loading on bus 2 increases, the voltage on that bus decreases.

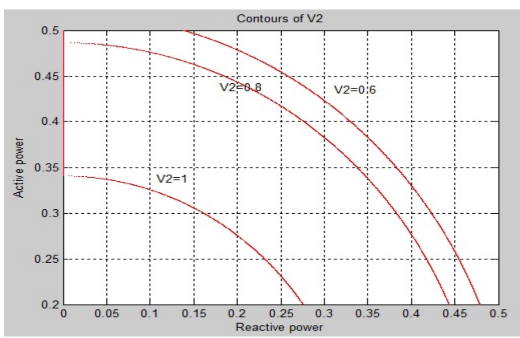

Figure. 2: Contours of voltage in P-Q plane

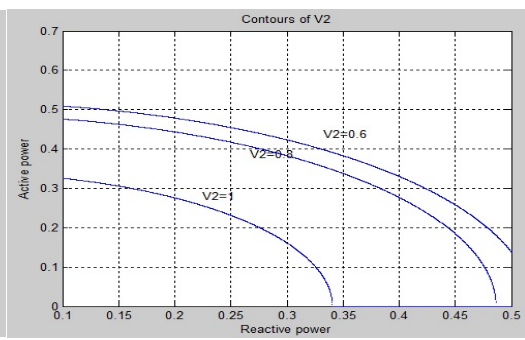

Figure 3: Contours of voltage in P-Q plane

Sr. No.	V(pu)	Qmax (pu)	Corr. P (pu)	Pmax (pu)	Corr. Q (pu)
1	1.0	0.339	0.01	0.321	0.1
2	0.8	0.472	0.01	0.483	0.1
3	0.6	0.525	0.01	0.515	0.1

Table 2: Results of contours on 2 bus system as per plot in fig. 3

Tables 3 and 4 indicate the quantities that can be taken as variables and target functions respectively in the contour evaluation program.

Sr. No	Variable
1	Node voltage magnitude
2	Injected active power
3	Injected reactive power
4	Shunt Conductance
5	Shunt Susceptance
6	Voltage angle of one node relative to another

Table 3: Variable parameters for contour plotting

Sr. No.	Target function
1	Node voltage magnitude
2	Injected active power
3	Injected reactive power
4	Voltage angle of one node relative to another
5	Total system power loss

Table 4 : Target functions for contour plotting

The contour evaluation program is also implemented on IEEE 14 bus system shown in fig. 4 using MATLAB programming. Voltage contours have been plotted first without taking generator reactive power limits into consideration and then taking into consideration, the generator reactive power limits.

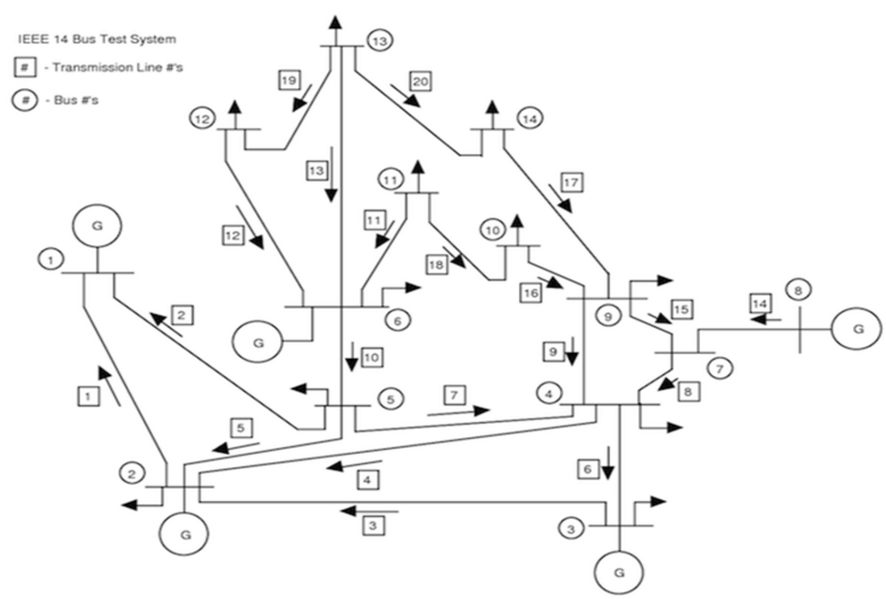

Figure 4: IEEE 14 bus system

The voltage contour on bus 9 for base case load is shown in fig. 5 for both the above mentioned cases. Fig. 6 shows the voltage contours on bus 14 at base load for the same two cases

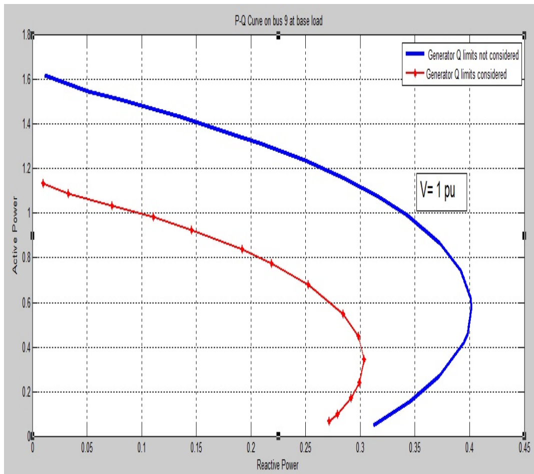

Figure 5: P-Q Curve on bus 9 for base load condition

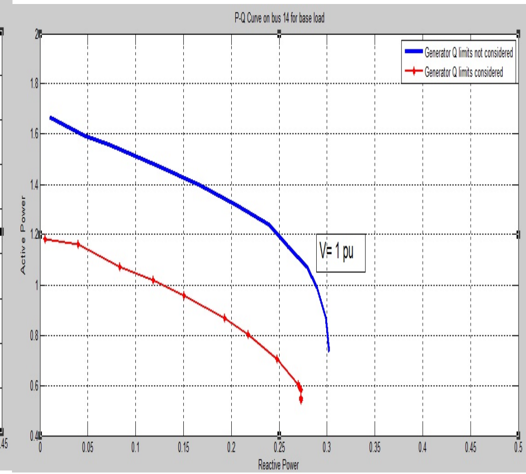

Figure 6: P-Q Curve on bus 14 for base load condition

When the generator reactive power limits are taken into consideration, the maximum reactive power loading on the buses 9 and 14 for V=1 pu are shown in table 5.

Sr. No.	Generator Reactive Power Limits not considered			
	Case	Bus No.	Max Q load(pu)	Remarks
1	Base load	9	0.4018	Close to Gen. bus.
2		14	0.3011	Far from Gen. bus

Table 5 : Maximum Q loading on buses 9 & 14 for V=1 pu

When the generator reactive power limits are taken into consideration, the maximum reactive power loading on the said buses reduces for V=1 pu as in table 6.

Sr. No.	Generator Reactive Power Limits considered			
	Case	Bus No.	Max Q load(pu)	Remarks
1	Base load	9	0.3036	Close to Gen. bus.
2		14	0.2712	Far from Gen. bus

Table 6: Maximum Q Loading on buses 9 & 14 for V=1 pu

Some contingent conditions have also been considered. The line (9-14) between buses 9 and 14 is removed from operation. and the P-Q curve has been plotted. We get different contours of P-Q at constant V as depicted in the fig. 7 where impact of the line removal on bus 14 is shown.

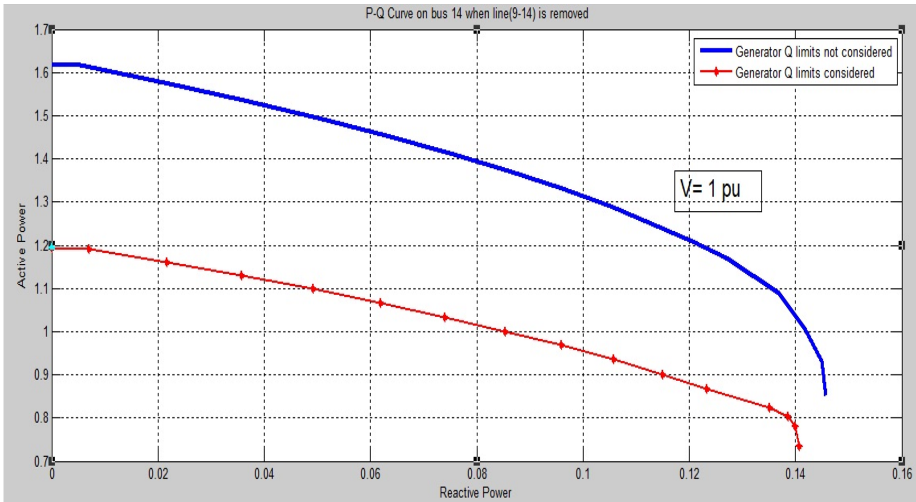

Figure 7: P-Q Curve on bus 14 when line (9-14) removed

Figure 8 shows the impact of removal of line 9-14 on the performance of bus 9. P-Q curve is plotted on bus 9 for V= 1 pu.

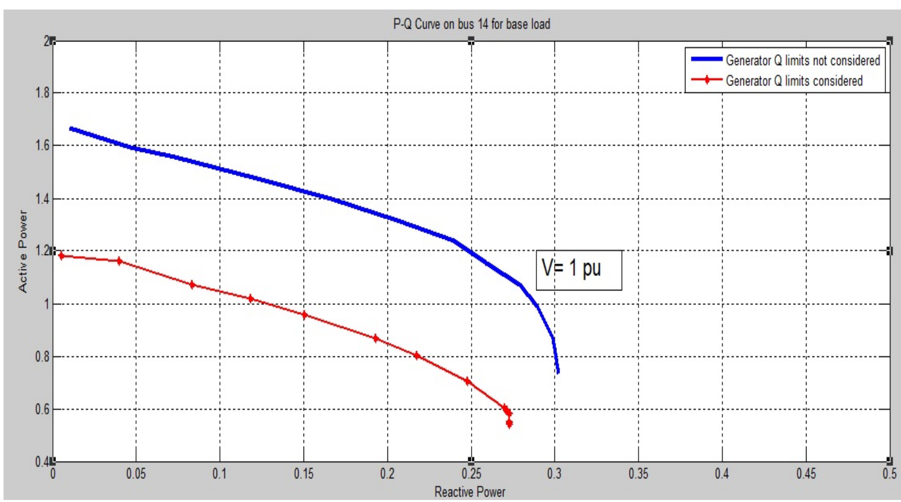

Figure.8: P-Q Curve on bus 9 when line (9-14) removed

Sr. No.	Generator Reactive Power Limits not considered (V=1 pu)			
	Case	Bus No.	Max Q load(pu)	Remarks
1	Line (9-14) removed	9	0.292	Close to Gen. bus.
2		14	0.147	Far from Gen. bus

Table 7: Results of P-Q Curve on buses 9 & 14 when line (9-14) removed

The maximum reactive power loading on bus 9 when the line (9-14) is removed for some maintenance purpose is 0.292 pu as shown in table 7. The removal of the line causes the voltage on the bus to drop. To keep the voltage constant at 1 pu, the reactive load on the bus needs to be reduced by 0.1098 pu. Similarly, we can find the amount by which the reactive power loading on bus 14 needs to be modified for maintaining V=1 pu on this bus.

A case of reactive power load increase has also been considered as the reactive power loading has the worst effect on the voltage stability limit. The reactive power load on buses 5,9,12 and 14 is increased by 10 %. The contours of P-Q at V = 1 pu have been plotted as shown in the fig. 9.

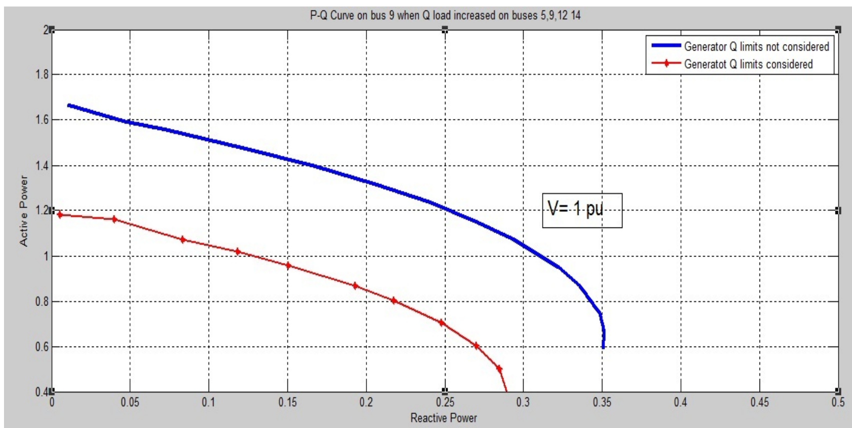

Figure 9: P-Q Curve on bus 9 when Q load on buses 5,9,12,14 increased by 10%

The maximum reactive power loading on bus 9 when the reactive power load on buses 5,9,12 and 14 is increased by 10 % is 0.3504 pu for V=1 pu. The increase in the load will cause voltage on bus 9 to drop. To maintain it at 1 pu, the reactive power loading on the bus needs to be reduced by 0.0514 pu.

Sr. No	Generator Reactive Power Limits not considered (V=1 pu)		
	Case	Bus No.	Max Q load(pu)
1	Q load increased by 10% on buses 5,9,12 & 14	9	0.3504

Table-8: Result of P-Q Curve on bus 9 under contingent condition

4. Discussion

From the graphical representations, we can see how the active and reactive power loading are related to keep the bus voltage magnitude constant. Details of the maximum active power and the maximum reactive power that can be increased without facing the threat of voltage decline can be obtained. The quantum of reactive power that needs to be modified on a given bus to keep the voltage constant on that bus can be obtained from the P-Q curve at one stroke. If such contours are plotted beforehand in any power system for various contingent conditions, decision can be made about the placement of reactive power sources in the system. Also, idea about the amount by which the reactive power loading needs to be modified on a bus for maintaining constant bus voltage can be obtained.

5. Conclusion

The contour evaluation program can be used to find the relationship between P and Q at the load bus for various operating conditions for a particular bus voltage. For a given operating point, the maximum active and reactive power load on a given bus can be found under normal, faulty and various contingent conditions.

6. References

[1] C.W.Taylor, Power System Voltage Stability, New York: McGraw Hill, 1994.
[2] Marisea Crow-Computational methods for electric power systems, CRC Press.
[3] M.H.Haque-Determination of steady state voltage stability limit using P-Q curve, IEEE Power Engineering Review, pp 71-72, April 2002.
[4] V.Ajjarapu-Computational techniques for voltage stability, assessment and control-Springer Publication.
[5] G.B.price-A generalized circle diagram approach for global analysis of transmission system performance-, IEEE Transaction on Power apparatus and systems, Vol-11, pp-2881-2890, 1984.
[6] Ian Hiskens, Robert Davy, Exploring the Power flow solution space boundary, IEEE Transaction on Power Systems, Vol-16, no. 3, 2001.
[7] V. Ajjarapu, C.Christy-The continuation power flow: A tool for steady state voltage stability
analysis- IEEE Transaction on power system, Vol.7, pp. 416- 423, 1992.
[8] M. Sobierajski, K. Wilkosz, J.Bertsch and M.Fulezyk, Using bus impedance and bus P-Q curve for voltage stability control, IEEE Power Sysems, pp 79-84, 2001.