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# Voltage stability analysis through reactive power reserve and voltage sensitivity factor

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**Abstract** Today's modern power systems are being operated near maximum loading point so a voltage stability criterion is required more attention. This Paper presents voltage stability assessment with generator reactive power constraint. Here Reactive power reserve margin has been computed through P-V curve and V-Q curve. This margin shows measurement of system closeness to maximum loading point. Voltage sensitivity factor is calculated to identify weakest bus. Continuation power flow has been used to obtain P-V curve of power system and repeated Newton-Raphson power flow to obtain V-Q curve. A power system analysis tool is used to run continuation power flow and matlab programming for V-Q curve.

**Keywords** Voltage stability, Reactive Power Reserve (RPR), Continuation Power Flow, Maximum Loading Point, Bus Voltage Sensitivity Factor, Weakest Bus. Voltage Control Area

## Introduction

Now a days restructuring of the power system is rapidly growing because of heavy load demand along with economical and environmental constrains. As power system is operated near security limit with restricted transmission network, management of power systems is not easy, Voltage instability become serious problem concern to operation of secure power system. Generally voltage stability is defined as the ability of a power system to maintain steady voltages at all the buses in the system after being subjected to a disturbance from a given initial operating condition. It depends on the ability to maintain/restore equilibrium between load demand and power supply from the power system [1]. Definition of power system stability with different flavor has been given by Lyapunov and input/output approaches. While the disturbance leading to voltage collapse may be initiated by a variety of causes, the main causes is the inherent weakness in the power system has been proven [2]. Many voltage stability indices based on the eigenvalue analysis or singular value decomposition of the system power flow Jacobian matrix for detecting weak area and load ability of power system has been used [3], [4].The prominent methods in voltage stability analysis are those that find system load margin, especially when system contingency is considered. P-V curve and Q-V curve are most considerable method to find active power margin and reactive power reserve margin [5]. Network configurations and load distributions can also reflect using P-V curve. The linear approach between the generator reactive power reserves and voltage stability margin is related to the system PV curves versus nodal VQ curves. Using this relationship, a systematic and practical method for determining the online voltage stability margin has been proposed [6]. In most of the research work the voltage stability has been considered as static phenomenon, is due to slow variation of voltage over a long time observed in most of the incident until it reaches to the maximum loading point and then it decreases rapidly to the voltage collapse. Static voltage stability has been analysized by using bifurcation theory. Saddle node bifurcation has been used for static voltage stability analysis [7]. One-parameter and two-parameter bifurcation analysis is indicated [8]. It was proposed to monitor reactive margins on voltage zones in order to assess the voltage profile quality [9]. A voltage zone is defined as a group of "tightly coupled" generator buses, together with the union of the sets of load buses that they mutually support.

Two methods for determining the "effective" reactive reserve of a specific voltage area have been outlined [10]. The first method relies on VQ curves determined at one bus or for one area. The reserve has taken as the sum of individual reserves of the generators under limit at the minimum of the curve. It is thus an image, on the generation side, of a particular load power margin. The second method computed an effective power reserve as the weighted sum of individual reserves; the weights were based on sensitivities of generator reactive outputs to reactive loads. Index for evaluation of Reactive power reserve with respect to contingency has been proposed [11].

This paper is concentrated on the steady state aspects of voltage stability. System maximum loading point is obtained to indicate proximity to voltage instability. Generator which has reactive power reserve at voltage collapse is found and weakest bus of the system at different contingencies is also found through P-V curve which has obtained through continuation power flow for New England 39 bus system. Weakest bus of the system during different contingencies is found by calculating voltage sensitivity factor and V-Q curve. Voltage control area of the system is also determined by V-Q curve.

## P-V curve through continuation power flow

The general principle behind the continuation power flow is very simple. It employs a predictor-corrector scheme to find a solution path. Here locally parameterized continuation technique is adopted. It includes load parameter, step length for load parameter and state variable. Here all steps are referred from the reference [12].

A parameterization is a mathematical means of identifying each solution on the branch, a kind of measure along the branch. To find successive load flow solution using continuation power flow, the load flow equation is reformulated by inserting load parameter λ. So, locally parameterization technique can apply. Local parameterization allows not only the added load parameter, but also the state variables to be used as continuation parameters. In correction process, the predicted solution is corrected by using local parameterization. The continuation power flow is stopped when critical point is reached. Critical point is the point where the loading has maximum value. After this point it starts to decrease. The tangent component of λ is zero at the critical point and negative beyond this point. Therefore, the sign of dλ shows whether the critical point is reached or not.

V-Q curve Method: V-Q curve method is one most popular way to investigate voltage instability problems in power systems. Load reactive reserve margin of each bus can be found from this V-Q curve. Here for base or outage case, power flow is simulated with a series of voltage magnitudes scheduled at a selected important bus. The selected bus has changed to a fictitious PV bus, equivalent to applying a fictitious synchronous condenser or SVC at the bus. The voltage magnitude scheduled is an independent (x) variable. The reactive power injection is a dependent (y) variable. (Q –V curves, similar to PV curves are also possible where reactive power at one or many busses are independent variables, and voltages at many buses are dependent variables.) A curve of bus voltage versus synchronous condenser output is thereby generated. The operating point is at zero Mvar output of the fictitious synchronous condenser unless reactive power compensation is available or planned for the bus. The V-Q curve computation has been automated in many power flow programs. Here the analysis is applied to all PQ buses.

The most important information to be obtained from this curve is the reactive margin from the base case operating point to the curve minima. This reactive reserve margin generally indicates how much further the loading on the bus can be increased before its loading limit is exceeded and voltage collapse occurs. The reactive power margin (RPM) is the MVAR distance between the operating point and the nose point of the V-Q curve. The critical point or nose point of the characteristics corresponds to the voltage where dQ/dV becomes zero. If the minimum point of the V-Q curve is above the horizontal axis, the system is reactive power deficient. Additional reactive power sources are needed to prevent a voltage collapse. Buses having V-Q curves below the horizontal axis have a positive reactive power margin. It may be still be reactive power deficient, depending on the desired margin. Here P-V curves and V-Q curves of all PQ buses of New England39 bus sample system are obtained by simulating continuation power flow and V-Q method.

## Results and Discussion

**New England 39** bus system consists of one slack bus generator plus 9 generators, 46 transmission lines and 30 loads. In this system bus no.31 is slack bus and bus no. 30, 32 to bus no. 39 are PV buses, and bus no. 1 to 29 are PQ buses.

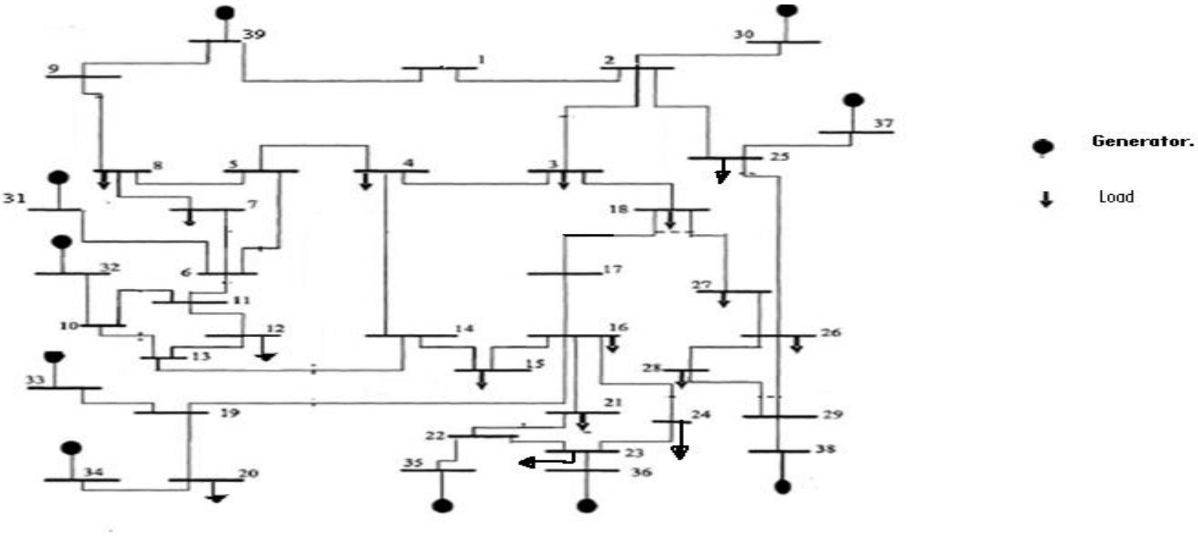

**Figure 1**: Line diagram of New England 39 bus system

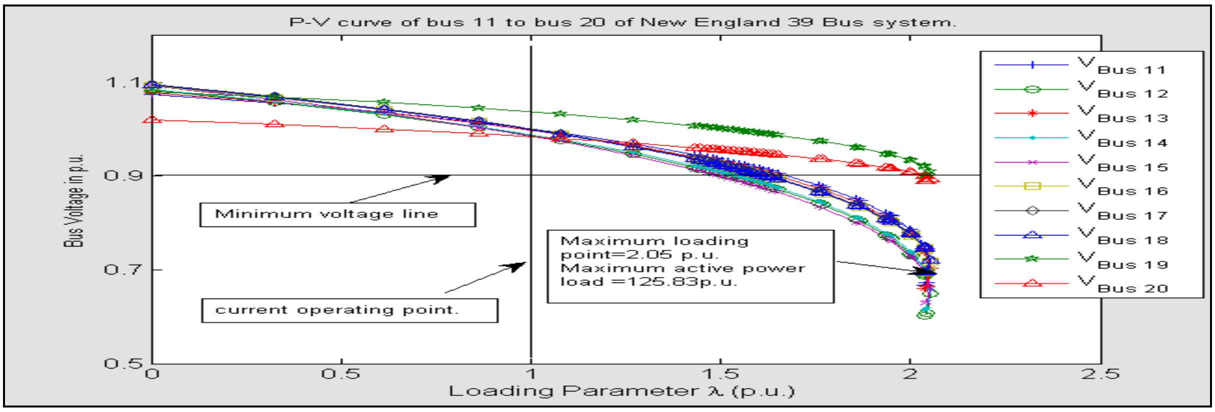

**Figure 2:** P-V curve of bus 11to 20 of New England 39 bus system

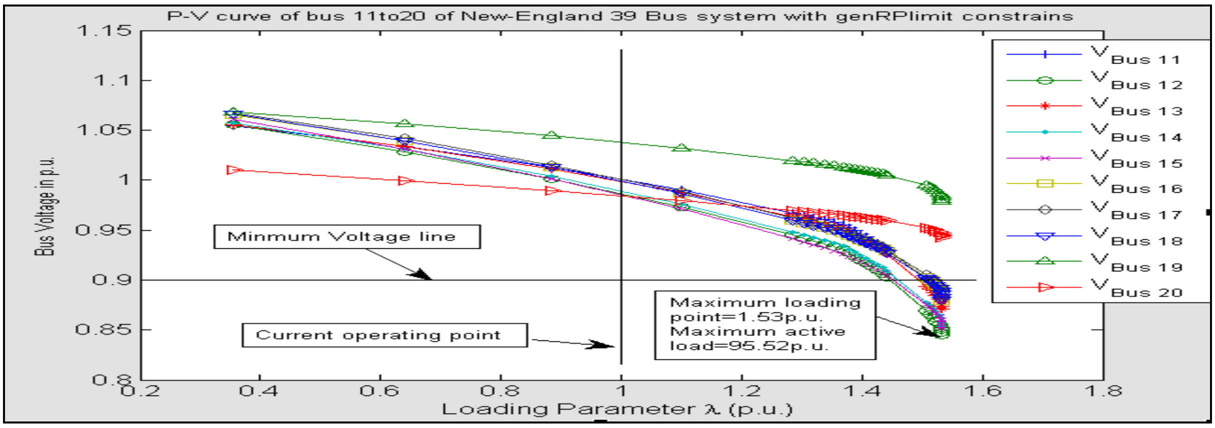

**Figure 3:** P-V curve of bus 11to 20 of New England 39 bus system with reactive power constraint

The continuation power flow is run with two different conditions. 1) Without considering any Generator reactive power (RP) limits. 2) With considering Generator maximum reactive power limits. CPF results for both the conditions are shown in Table I and P-V curve of all PQ buses of the system with and without maximum reactive power limit constrains obtained .Here P-V curve of Bus No. 11 to 20 is shown in “Figure 2,”and “Figure 3,”Continuation power flow is run up to bifurcation point, that means when maximum loading point reaches power flow will stop. Here distributed slack bus is used so all transmission losses distributed among all buses. At base case, loading point lambda is taken 1 and load increasing at each bus proposional to base load. In case of **New England 39** bus systems. Bus no.1,2,5,6,9,10,11,13,14,16,17,19,22 have no load, so after applying continuation power flow, load at these buses have zero value, but with increasing system load these buses approaches voltage collapse point. When reactive power constraint is not considered, voltages at PV buses are not affected. Maximum reactive power is supplied by slack bus generato , then generator at bus 32. When Reactive power constraint is considered, all the generators reaches its max reactive power limit “$Q_{max}$” at different loading point except Gen no.34, 37 and 39 as shown in “Figure.4”. It means these three generators still have reactive power reserve (RPR) and participating at collapse point and voltage at PV buses reduced with increased system load. Active power generation of each generator is also proposional to its base load generation. The power factor at each bus remains as same as base load condition. As shown in “Figure. 2.” and also from the result Table I, it can see that maximum loading point is 2.049 i.e. maximum active power transferred has125.83 p.u value, when maximum reactive power limit constraint is not considered. When maximum reactive power limit constraint is considered maximum loading point of the system is reduced to 1.54 or maximum active power load transferred is 95.52p.u. as shown in “Figure 3.”

When “Figure 2” and “Figure 3” has been examined, reduction in bus voltage is not same for each bus. Bus which has greatest reduction in voltage is the weakest bus of the system. It is decided by bus voltage sensitivity factor. This is same as finding the bus with the greatest ratio $|dV_i/dP_{total}|$value. The ratio $|dV_i/dP_{total}|$ has been taken as bus voltage sensitivity factor where $dP_{total}$ and $dV_i$ are respectively total active load change and per unit voltage change in $i^{th}$ bus in the system. Since the denominators in this ratio are the same for all buses, the differential change in bus voltages has been taken as voltage stability sensitivity factor. Table II shows voltage sensitivity factor at different contingencies

It can see that for different contingency cases rank of weakest bus is different. It means voltage stability factor indicates without stressing individual bus; by increasing system load proposional to its base load, individual performance of the bus is known.VSF with bold font indicates weakest bus of the system at particular contingency case. We can arrange all buses in descending order according to VSF value we can come to know about rank of all buses for all conditions. Bus no.12 is weakest bus in base case. In contingency case a,b,c bus no. 4 is weakest bus and contingency case e bus no.15 is weakest bus.

Here V-Q curves of PQ buses of New England 39 bus System has been obtained at current operating point. It is shown in ”Figure 5” to “Figure 7” Load reactive power reserve is computed for all the buses. If we observe these curves, it is seen that among all 29 PQ buses bus no. 12 has least reactive power reserve margin and it is weakest bus of the system same as CPF result. The New England 39 bus system is divided in different control area by identical V-Q curves as shown in Table III. Link between area and buses has been also checked by Algorithm given by R. A. Schlueter [11]. When different contingencies cases have been considered, V-Q curves are also obtained at different contingencies. Reactive power reserve margin is computed by taking Mvar distance between operating point and nose point. Table IV shows RPR at base case and at different contingency cases. It is observed that all buses are affected due to contingency, i.e. RPR at each bus is reduced. Rank of weakest bus has been found though RPR value in ascending order. Results have been obtained by RPR for weakest bus of the system which is different from CPF result. But for contingency case E and base case same result is found.

**Table 1:** Continuation Power Flow Result

| Bus No. | CPF result (without Gen. RP limit constraint). | | | | | | CPF result (with Gen. RP limit constraint). | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V | phase | P gen | Q gen | P load | Q load | V | Phase | P gen | Q gen | P load | Q load |
| | [p.u] | [rad] | [p.u] | [p.u] | [p.u] | [p.u] | [p.u] | [rad] | [p.u] | [p.u] | [p.u] | [p.u] |
| 1 | 0.98422 | -1.6533 | 0 | 0 | 0 | 0 | 1.0119 | -0.42566 | 0 | 0 | 0 | 0 |
| 2 | 0.89706 | -0.7727 | 0 | 0 | 0 | 0 | 0.964 | -0.35734 | 0 | 0 | 0 | 0 |
| 3 | 0.73579 | -0.91653 | 0 | 0 | 6.5976 | 2.4997 | 0.88747 | -0.44321 | 0 | 0 | 4.9591 | 1.8697 |
| 4 | 0.62649 | -0.91769 | 0 | 0 | 10.2447 | 3.77 | 0.84013 | -0.44669 | 0 | 0 | 7.7005 | 2.8199 |
| 5 | 0.63895 | -0.75518 | 0 | 0 | 0 | 0 | 0.8782 | -0.38279 | 0 | 0 | 0 | 0 |
| 6 | 0.65215 | -0.68381 | 0 | 0 | 0 | 0 | 0.88318 | -0.3537 | 0 | 0 | 0 | 0 |
| 7 | 0.61507 | -0.88705 | 0 | 0 | 4.7904 | 1.7211 | 0.86643 | -0.43421 | 0 | 0 | 3.6808 | 1.2873 |
| 8 | 0.61829 | -0.93708 | 0 | 0 | 10.6954 | 3.6061 | 0.86698 | -0.45377 | 0 | 0 | 8.0394 | 2.6973 |
| 9 | 0.87034 | -0.93852 | 0 | 0 | 0 | 0 | 0.97282 | -0.46079 | 0 | 0 | 0 | 0 |
| 10 | 0.71322 | -0.53839 | 0 | 0 | 0 | 0 | 0.88435 | -0.28318 | 0 | 0 | 0 | 0 |
| 11 | 0.68653 | -0.5858 | 0 | 0 | 0 | 0 | 0.88108 | -0.30757 | 0 | 0 | 0 | 0 |
| 12 | 0.62763 | -0.59852 | 0 | 0 | 0.17416 | 1.8031 | 0.84731 | -0.31196 | 0 | 0 | 0.13091 | 1.3487 |
| 13 | 0.68745 | -0.60029 | 0 | 0 | 0 | 0 | 0.87335 | -0.31162 | 0 | 0 | 0 | 0 |
| 14 | 0.65295 | -0.76144 | 0 | 0 | 0 | 0 | 0.85681 | -0.38095 | 0 | 0 | 0 | 0 |
| 15 | 0.65961 | -0.87353 | 0 | 0 | 6.5566 | 3.1349 | 0.85418 | -0.42458 | 0 | 0 | 4.9283 | 2.3448 |
| 16 | 0.71814 | -0.79325 | 0 | 0 | 6.7492 | 2.7107 | 0.88271 | -0.38435 | 0 | 0 | 5.0731 | 2.0276 |
| 17 | 0.72406 | -0.86391 | 0 | 0 | 0 | 0 | 0.8857 | -0.38435 | 0 | 0 | 0 | 0 |
| 18 | 0.72232 | -0.91498 | 0 | 0 | 3.2373 | 0.61468 | 0.88315 | -0.44304 | 0 | 0 | 2.4334 | 0.4598 |
| 19 | 0.91062 | -0.55364 | 0 | 0 | 0 | 0 | 0.98087 | -0.24863 | 0 | 0 | 0 | 0 |
| 20 | 0.89419 | -0.62555 | 0 | 0 | 13.9328 | 2.1104 | 0.94423 | -0.29652 | 0 | 0 | 10.4727 | 1.5785 |
| 21 | 0.75636 | -0.63555 | 0 | 0 | 5.6141 | 2.3563 | 0.89728 | -0.30433 | 0 | 0 | 4.2199 | 1.7624 |
| 22 | 0.87944 | -0.38432 | 0 | 0 | 0 | 0 | 0.95313 | -0.15975 | 0 | 0 | 0 | 0 |
| 23 | 0.85996 | -0.39411 | 0 | 0 | 5.0711 | 1.7334 | 0.94842 | -0.16691 | 0 | 0 | 3.8118 | 1.2965 |
| 24 | 0.71367 | -0.78746 | 0 | 0 | 6.323 | 1.8891 | 0.88017 | 0.38119 | 0 | 0 | 4.7928 | 1.4130 |
| 25 | 0.9225 | -0.71766 | 0 | 0 | 4.5896 | 0.9671 | 0.9845 | -0.32526 | 0 | 0 | 3.5598 | 0.7234 |
| 26 | 0.79912 | -0.77311 | 0 | 0 | 2.848 | 0.9630 | 0.9245 | -0.36341 | 0 | 0 | 2.1303 | 0.7203 |
| 27 | 0.74084 | -0.89145 | 0 | 0 | 5.7575 | 1.5469 | 0.89372 | -0.42913 | 0 | 0 | 4.3277 | 1.1571 |
| 28 | 0.83996 | -0.58341 | 0 | 0 | 4.2208 | 0.5655 | 0.93495 | -0.25298 | 0 | 0 | 3.2571 | 0.42298 |
| 29 | 0.87706 | -0.44211 | 0 | 0 | 5.8087 | 2.6001 | 0.94811 | -0.16482 | 0 | 0 | 4.91912 | 1.94480 |
| 30 | 1.0475 | -0.67757 | 4.811 | 10.2015 | 0 | 0 | 1.0067 | -0.2894 | 3.5509 | 3.8 | 0 | 0 |
| 31 | 0.982 | 0 | 15.1244 | 20.0148 | 0 | 0 | 0.982 | 0 | 11.2301 | 8.1581 | 0 | 0 |
| 32 | 0.9831 | -0.12447 | 13.1779 | 18.3265 | 0 | 0 | 0.90836 | -0.02109 | 9.7264 | 5 | 0 | 0 |
| 33 | 0.9972 | -0.34697 | 12.8013 | 10.9044 | 0 | 0 | 0.9858 | -0.10353 | 9.4485 | 5 | 0 | 0 |
| 34 | 1.0123 | -0.42702 | 10.2076 | 7.5596 | 0 | 0 | 1.0123 | -0.15713 | 7.5341 | 4.4567 | 0 | 0 |
| 35 | 1.0493 | -0.17345 | 13.1779 | 15.4322 | 0 | 0 | 1.0049 | -0.01035 | 9.7264 | 6 | 0 | 0 |
| 36 | 1.0635 | -0.0571 | 11.2953 | 9.6421 | 0 | 0 | 1.057 | 0.05871 | 8.3369 | 5 | 0 | 0 |
| 37 | 1.0278 | -0.44596 | 10.877 | 6.843 | 0 | 0 | 1.0278 | -0.13763 | 8.0281 | 3.5213 | 0 | 0 |
| 38 | 1.0265 | -0.16203 | 16.943 | 11.5156 | 0 | 0 | 1.0148 | 0.03018 | 12.5053 | 5 | 0 | 0 |
| 39 | 1.0265 | -0.9345 | 20.9172 | 12.37 | 22.6202 | 5.1223 | 1.0265 | -0.46248 | 16.834 | 5.6939 | 17.0828 | 3.8314 |
| Total | | | 129.33 | 122.8097 | 125.83 | 39.7145 | | | 96.9207 | 51.63 | 95.5195 | 29.705 |

Each contingency causes same effect in particular voltage control area. When contingency occurs in particular control area, it would be effect on RPR of buses belongs to that area. It can be seen that at time of contingency of line outage between bus no.15 and bus no.16- Case e, bus No. 15 is weakest bus of system and most of control areas are affected. As shown in Table IV. When line outage between bus no. 3and 4- Case a contingency, Area B and G are more affected, While contingency case b of line outage between bus no. 4and 5, 14-15case (c) and bus no.15-16 (case-e) Area B, D and G are more affected. It is shown in table V by different font.

**Table 2:** Voltage Sensitivity Factor of PQ Buses at Different Contingencies Cases

| Bus No. | Voltage sensitivity factor (VSF) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Base case (without RP Limit) | Base case (with RP Limit) | Line Outage (3-4) Case a | Line Outage (4-5) Case b | Line Outage (4-14) Case c | Line Outage (14-15) Case d | Line Outage (15-16) Case e |
| 1 | 0.0361 | 0.0347 | 0.0277 | 0.0354 | 0.0372 | 0.0323 | 0.0391 |
| 2 | 0.0887 | 0.0862 | 0.0675 | 0.0913 | 0.0926 | 0.081 | 0.0942 |
| 3 | 0.1697 | 0.1454 | 0.1159 | 0.1572 | 0.1553 | 0.1395 | 0.1644 |
| 4 | 0.2187 | 0.1737 | **0.2121** | **0.1991** | **0.1903** | 0.1678 | 0.2361 |
| 5 | 0.2087 | 0.1579 | 0.1870 | 0.1403 | 0.1708 | 0.1531 | 0.2123 |
| 6 | 0.2015 | 0.1522 | 0.1797 | 0.1377 | 0.1637 | 0.1475 | 0.2059 |
| 7 | 0.2196 | 0.1641 | 0.1916 | 0.1490 | 0.1753 | 0.1596 | 0.2159 |
| 8 | 0.2180 | 0.1632 | 0.1903 | 0.1482 | 0.1749 | 0.1588 | 0.2137 |
| 9 | 0.0899 | 0.0673 | 0.0785 | 0.0617 | 0.0722 | 0.0657 | 0.0881 |
| 10 | 0.1724 | 0.1490 | 0.1783 | 0.1485 | 0.1542 | 0.1428 | 0.2212 |
| 11 | 0.1853 | 0.1524 | 0.1812 | 0.1470 | 0.1602 | 0.1467 | 0.2187 |
| 12 | **0.2275** | **0.1802** | 0.2107 | 0.1798 | 0.1857 | **0.1737** | 0.2561 |
| 13 | 0.1864 | 0.1572 | 0.1862 | 0.1619 | 0.1599 | 0.1504 | 0.2360 |
| 14 | 0.2064 | 0.1686 | 0.1961 | 0.1836 | 0.1664 | 0.1606 | 0.2619 |
| 15 | 0.2078 | 0.1743 | 0.1791 | 0.1813 | 0.1756 | 0.1717 | **0.3399** |
| 16 | 0.1802 | 0.1542 | 0.1490 | 0.1578 | 0.1568 | 0.1492 | 0.1223 |
| 17 | 0.1788 | 0.1532 | 0.1403 | 0.1582 | 0.1583 | 0.1473 | 0.1382 |
| 18 | 0.1788 | 0.1531 | 0.1338 | 0.1608 | 0.1603 | 0.1471 | 0.1517 |
| 19 | 0.0820 | 0.0744 | 0.0701 | 0.0752 | 0.0754 | 0.0707 | 0.0569 |
| 20 | 0.0610 | 0.0556 | 0.0532 | 0.0559 | 0.0562 | 0.0535 | 0.0457 |
| 21 | 0.1609 | 0.1437 | 0.1370 | 0.1446 | 0.1454 | 0.1373 | 0.1084 |
| 22 | 0.0986 | 0.1004 | 0.0929 | 0.0993 | 0.1013 | 0.0934 | 0.0654 |
| 23 | 0.1075 | 0.1021 | 0.0947 | 0.1009 | 0.1029 | 0.0949 | 0.0721 |
| 24 | 0.1824 | 0.1562 | 0.1505 | 0.1589 | 0.1585 | 0.1506 | 0.1235 |
| 25 | 0.0757 | 0.0710 | 0.0571 | 0.0740 | 0.0746 | 0.0674 | 0.0715 |
| 26 | 0.1437 | 0.1268 | 0.1121 | 0.1263 | 0.1301 | 0.1194 | 0.1147 |
| 27 | 0.1726 | 0.1497 | 0.1354 | 0.1516 | 0.1537 | 0.1429 | 0.1354 |
| 28 | 0.1142 | 0.1052 | 0.0902 | 0.0986 | 0.1073 | 0.0940 | 0.0904 |

**Table 3:** Voltage Control Area

| **Area** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** |
|---|---|---|---|---|---|---|---|---|
| PQ Bus No. | 1,9 | 4,5,6<br>7,8,10<br>11,13,14 | 19,20 | 15,16,17,<br>18,21,22,<br>23,24, | 26,<br>27 | 28,<br>29 | 2,3<br>25 | 12 |

**Table 4:** Reactive Power Reserve Margin at Differentcontingencies Cases

| Bus No. | Reactive power reserve margin through V-Q Curve | | | | | |
|---|---|---|---|---|---|---|
| | Base Case | Line Outage (3-4) a Mvar | Line Outage (4-5) b Mvar | Line outage (4-14) c Mvar | Line outage (14-15) d Mvar | Line Outage (15-16)-e Mvar |
| 1 | 1479 | 1475 | 1477 | 1475 | 1481 | 1471 |
| 2 | 3061 | 2866 | 2931 | 3017 | 3056 | 2054 |
| 3 | 2014 | 1596 | 1761 | 1909 | 1992 | 1967 |
| 4 | 1862 | **1319** | **1292** | 1424 | 1655 | 1495 |
| 5 | 1825 | 1562 | 1484 | 1690 | 1648 | 1519 |
| 6 | 1946 | 1629 | 1668 | 1835 | 1751 | 1618 |
| **7** | **1463** | **1316** | **1324** | **1434** | **1399** | **1329** |
| 8 | 1597 | 1420 | 1415 | 1531 | 1498 | 1430 |
| 9 | 1377 | 1329 | 1335 | 1359 | 1350 | 1333 |
| 10 | 2056 | 1799 | 1990 | 2000 | 1789 | 1582 |
| 11 | 1898 | 1647 | 1819 | 1863 | 1680 | 1527 |
| **12** | **758.5** | **712.8** | **749.8** | **749.2** | **717.6** | **682.5** |
| 13 | 1802 | 1577 | 1718 | 1693 | 1526 | 1310 |
| 14 | 1708 | 1475 | 1477 | **1475** | **1481** | **1471** |
| 15 | 1644 | 1627 | 1555 | 1580 | **1149** | **559** |
| 16 | 2407 | 2403 | *2285* | 2378 | *2003* | 2172 |
| 17 | 1854 | 1802 | *1747* | 1843 | *1741* | 1784 |
| 18 | 1626 | *1506* | *1503* | 1602 | *1579* | 1599 |
| 19 | 2844 | 2840 | 2810 | 2833 | 2741 | 2801 |
| 20 | 2160 | 2154 | 2148 | 2154 | 2132 | 2151 |
| 21 | 1771 | 1772 | 1735 | 1765 | 1651 | 1713 |
| 22 | 2716 | 2712 | 2682 | 2705 | 2605 | 2661 |
| 23 | 2298 | 2296 | 2266 | 2292 | 2210 | 2255 |
| 24 | 1748 | 1746 | 1692 | 1733 | 1561 | 1644 |
| 25 | 2570 | 2506 | 2508 | 2552 | 2547 | 2566 |
| 26 | 1467 | 1453 | 1439 | 1468 | 1443 | 1470 |
| 27 | **1338** | **1316** | **1289** | **1333** | **1297** | **1325** |
| 28 | **1080** | **1079** | **1072** | **1077** | **1076** | **1080** |

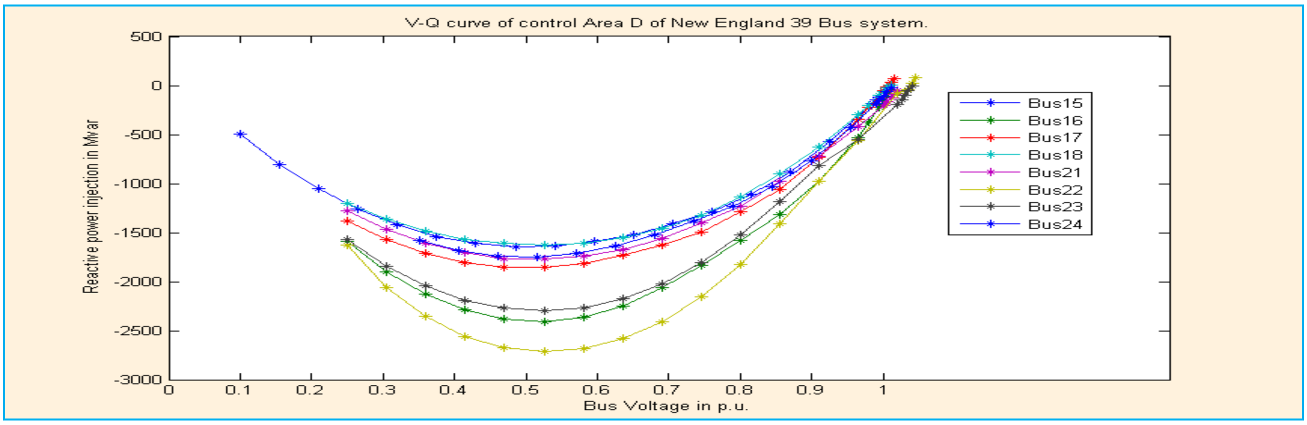

**Figure 5:** V-Q curve of control area 'D' of New England 39 bus system

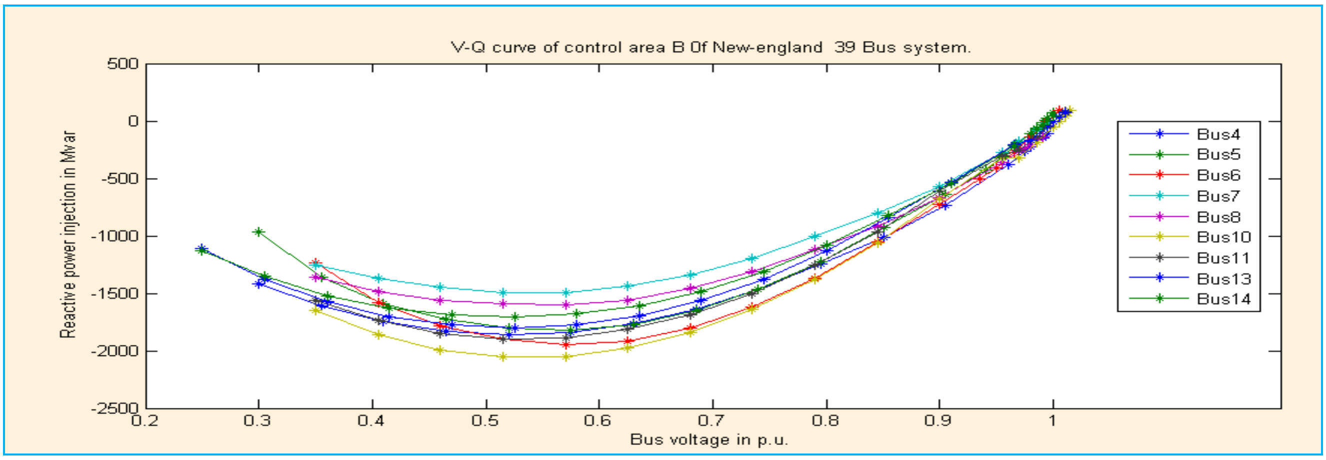

**Figure 6:** V-Q curve of control area 'B' of New England 39 bus system

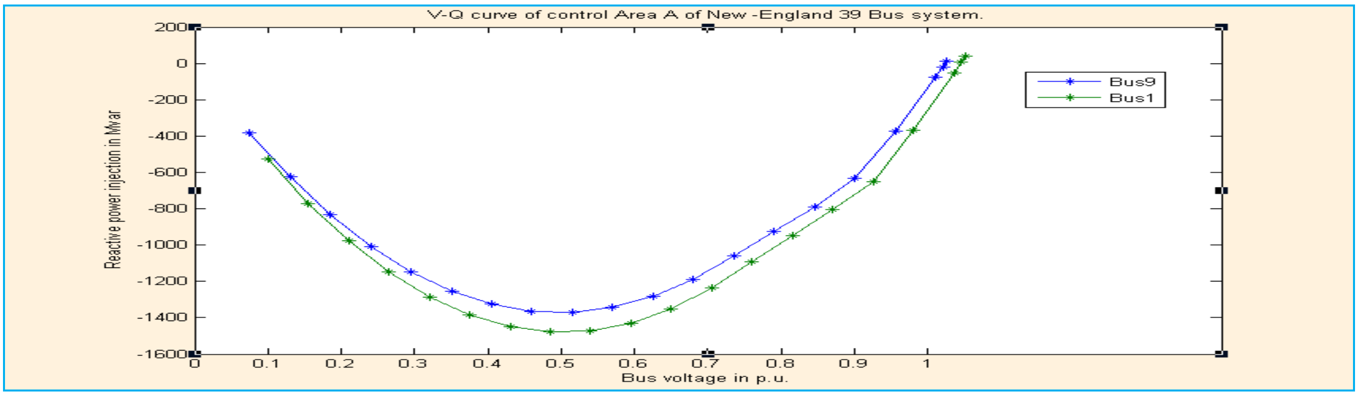

**Figure 7:** V-Q curve of control area 'D' of New England 39 bus system

## Conclusion

Above all results show that voltage stability margin i.e. reactive power reserve margin and maximum loading point can be found easily by V-Q curve and P-V curve through CPF. Maximum loading point has been accessed. Placement of reactive power sources such as Fact devices, capacitor bank can easily found. It means the Weakest bus identification can be done by without excessive calculation. Here both methods give same result for weakest bus. It is found from both methods that bus no 12 is the weakest bus among all PQ buses. At base case buses under one voltage control area have been easily determined by V-Q curve. The CPF method is more accurate and simple for Voltage stability analysis. Individually load reactive power reserve has been found through V-Q curve at base case and different contingency cases.By determining reactive power reserve using V-Q curve at different contingency, most severe contingency is identified. Severe contingency found is case e.

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