Prediction of voltage stability in power System by using CPF Method

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ABSTRACT

A method for the online testing and estimation of power system stability is proposed. This paper deals with the voltage stability by using P –V curve method. P –V curve can be drawn by obtaining the various load flow data. For the load flow analysis we adopted continuous power flow analysis method on IEEE standard 30 bus system. Continuous power flow analysis starting from the initial starting point and reaches to the maximum loading point. P –V curve has been plotted for different contingency conditions in this paper. A power system analysis tool is used to run continuation power flow. The Jacobian matrix of power flow equations becomes singular at the voltage stability limit. Continuation power flow overcomes this problem. Continuation power flow finds successive load flow solutions according to a load scenario. Power system voltage stability is analyzed for pre contingency and post contingency condition by using load ability margin concept.

Keywords- *Voltage stability, continuation power flow, predictor –corrector step, P –V curve maximum loading point.*

1. INTRODUCTION

Power System Voltage Stability At any point of time, a power system operating condition should be stable, meeting various operational criteria, and it should also be secure in the event of any credible contingency. Present day power systems are being operated closer to their stability limits due to economic and environmental constraints. Maintaining a stable and secure operation of a power system is therefore a very important and challenging issue. It is one of the major sources of power system insecurity. Voltage instability phenomena are the ones in which the receiving end voltage decreases well below its normal value and does not come back even after setting restoring mechanisms such as VAR compensators, or continues to oscillate for lack of damping against the disturbances. Voltage collapse is the process by which the voltage falls to a low, unacceptable value as a result of an avalanche of events accompanying voltage instability. Once associated with weak systems and long lines, voltage problems are now also a source of concern in highly developed networks as a result of heavier loading. The main factors causing voltage instability in a power system are now well explored and understood. Simulation results on test power systems are presented to illustrate the problem of voltage stability and the conventional methods to analyze the problem. Limitations of conventional methods of voltage stability analysis are pointed out and the scope of the use of continuous power flow method is a better alternative is discussed.

2. CONTINUATION POWER FLOW METHOD

2.1. The Predictor-Corrector Continuation Method.

The Jacobian matrix of power flow equations becomes singular at the voltage stability limit. Continuation power flow overcomes this problem. Continuation power flow finds successive load flow solutions according to a load scenario. It consists of prediction and correction steps. From a known base solution, a tangent predictor is used so as to estimate next solution for a specified pattern of load increase. The corrector step then determines the exact solution using Newton-Raphson technique employed by a conventional power flow. After that a new prediction is made for a specified increase in load based upon the new tangent vector. Then corrector step is applied. This process goes until critical point is reached. The critical point is the point where the tangent vector is zero. The illustration of predictor-corrector scheme is depicted in Fig.1.

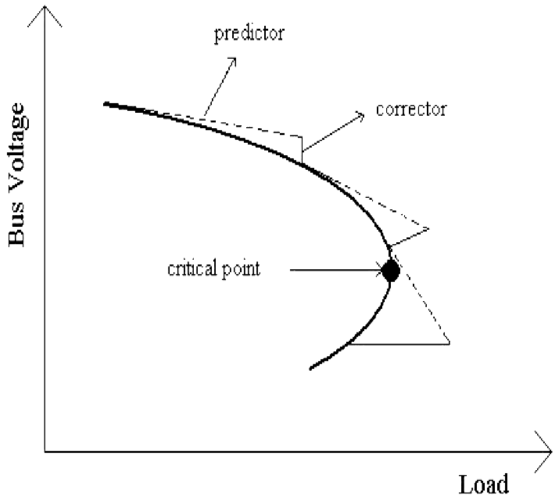

Fig.1. An illustration of predictor-corrector continuation.

In continuation load flow, first power flow equations are Reformulated by inserting a load parameter into these equations (7).

2.2 Mathematical reformulation & analysis of voltage stability:

The most common methods used in voltage stability analysis are continuation power flow, point of collapse, minimum singular value and optimization methods. In this study, continuation power flow method, widely used in voltage stability analysis, is utilized in order to analyze voltage stability of power systems. Voltage stability can be analyzed by using bifurcation theory.

2.2.1. Bifurcation Theory:

Bifurcation theory is used to describe changes in the qualitative structures of the phase portrait when certain system parameters change. Local bifurcations can be studied by analyzing the vector differential equations near the bifurcation equilibrium points. Voltage collapse in power systems can be predicted by identifying parameter values that lead to saddle-node bifurcations. In order to present the characteristic of bifurcation, Equation (1) is considered.

$$f(x, \lambda) = \dot{x} = \lambda - x^2 \qquad \text{….(1)}$$

In differential Equation (1), x is the state variable and λ is a parameter. There is a point called equilibrium point where $f(x_o, \lambda_o) = 0$. For this value of λ the linearization of f(x, λ) is singular. In differential Equation (1), x is the state variable and λ is a parameter. There is a point

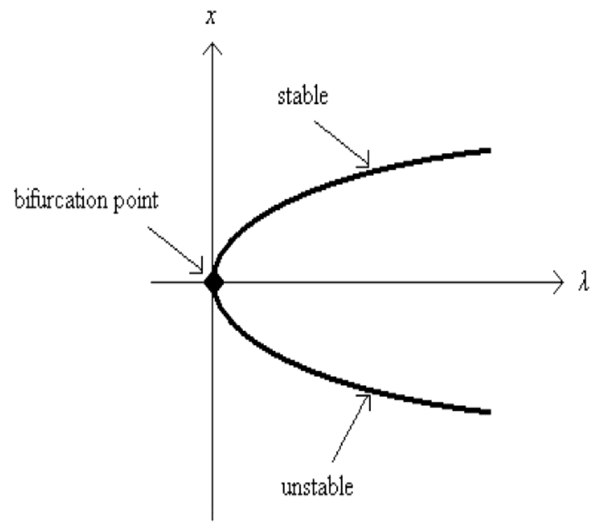

Fig.2. Bifurcation diagram for f(x, λ).

called equilibrium point where $f(x_o, \lambda_o) = 0$. For this value of λ the linearization of f(x, λ) is singular. Fig.1. is

obtained for f(x, λ), as λ changes. When λ =0 there is a saddle node point. For λ <0, there is no equilibrium whereas for λ >0 there are two equilibrium points as stable and unstable points.

The shape of the diagram shown in Fig.1. is quite similar to the bus voltage versus load parameter curves that are obtained in the following discussion. Injected powers can be written for the i^{th} bus of an n-bus system as follows:

$$Pi = \sum_{k=1}^{n} |Vi|\,|Vk|\; Gik\; cos\theta ik + Bik\; sin\theta ik$$

$$Qi = \sum_{k=1}^{n} |Vi|\,|Vk|\; Gik\; sin\theta ik - Bik\; cos\theta ik \qquad \text{…. (2)}$$

$$P_i = P_{Gi} - P_{Di}, \qquad Q_i = Q_{Gi} - Q_{Di} \qquad \text{…..(3)}$$

Where, the subscripts 'G' and 'D' denote generation and load demand respectively on the related bus. In order to simulate a load change, a load parameter 'λ' is inserted into demand powers 'P_{Di}' and 'Q_{Di}'.

$$P_{Di} = P_{Dio} + \lambda(P_{\Delta base})$$

$$Q_{Di} = Q_{Dio} + \lambda(Q_{\Delta base}) \qquad \text{….. (4)}$$

'P_{Dio}' and 'Q_{Dio}' are original load demands on i^{th} bus whereas 'P_b' base and 'Q_b' base are given quantities of powers chosen to scale 'λ' appropriately. After substituting new demand powers in Equation (4) to Equation (3), new set of equations can be represented as:

$$F(\theta, V, \lambda) = 0 \qquad \text{….(5)}$$

Where, 'θ' denotes the vector of bus voltage angles and 'V' denotes the vector of bus voltage magnitudes. The base solution for λ =0 is found via a power flow. Then, the continuation and parameterization processes are applied.

2.2.2. Prediction Step

In this step, a linear approximation is used by taking an appropriately sized step in a direction tangent to the solution path. Therefore, the derivative of both sides of Equation (5) is taken.

$$F_\theta\, d\theta + F_V dV + F_\lambda d\lambda = 0$$

$$\begin{bmatrix} F\theta & FV & F\lambda \end{bmatrix} \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix} = 0 \qquad \text{…..(6)}$$

In order to solve Equation (6), one more equation is needed since an unknown variable 'λ' is added to load flow equations. This can be satisfied by setting one of the tangent vector components to +1 or -1 which is also called continuation parameter. Setting one of the tangent vector components +1 or -1 imposes a non-zero value on the tangent vector and makes Jacobian nonsingular at the critical point. As a result Equation (6) becomes:

$$\begin{bmatrix} F\theta & FV & F\lambda \\ & ek & \end{bmatrix} \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix} = \begin{bmatrix} 0 \\ \pm 1 \end{bmatrix} \qquad \text{….(7)}$$

Where 'ek' is the appropriate row vector with all elements equal to zero except the k^{th} element equals 1. At first step W is chosen as the continuation parameter. As the process continues, the state variable with the greatest rate of change is selected as continuation parameter due to nature of parameterization. By solving Equation (7), the tangent vector can be found. Then, the prediction can be made as follows:

$$\begin{bmatrix} \theta \\ V \\ \lambda \end{bmatrix}^{P+1} = \begin{bmatrix} \theta \\ V \\ \lambda \end{bmatrix}^{P} + \sigma \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix} \qquad \text{….(8)}$$

Where the subscript "p+1" denotes the next predicted solution. The step size 'σ' is chosen so that the predicted solution is within the radius of convergence of the corrector. If it is not satisfied, a smaller step size is chosen.

2.2.3. Correction Step

In correction step, the predicted solution is corrected by using local parameterization. The original set of equation is increased by one equation that specifies the value of state variable chosen and it results in:

$$\begin{bmatrix} F(\theta, V, \lambda) \\ \varkappa k - \eta \end{bmatrix} = [0] \qquad \text{….(9)}$$

Where '$\varkappa$k' is the state variable chosen as continuation parameter and 'η' is the predicted value of this state variable. Equation (9) can be solved by using a slightly modified Newton-Raphson power flow method.

3. PARAMETERIZATION

Selection of continuation parameter is important in continuation power flow. Continuation parameter is the state variable with the greatest rate of change. Initially, 'λ' is selected as continuation parameter since at first steps there are small changes in bus voltages and angles due to light load. When the load increases after a few steps the solution approaches the critical point and the rate of change of bus voltages and angles increase. Therefore, selection of continuation parameter is checked after each corrector step. The variable with the largest change is chosen as continuation parameter. If the parameter is increasing +1 is used, if it is decreasing -1 is used in the tangent vector in Equation (7).

3.1. Determination of critical point.

The continuation power flow is stopped when critical point is reached as it is seen in the flow chart. 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.

3.2. Continuation Method without Parameterization.

Although parameterization is necessary to guarantee the non-singularity of Jacobian matrix in power flow equations, the continuation equations of the corrector step can be shown nonsingular at the collapse point. In this method, continuation power flow is applied without changing continuation parameter. Load parameter 'λ' is selected as continuation parameter in all prediction and correction steps. The non-singularity of Jacobian in this method can be obtained by reducing step size 'σ' as the solution approaches to critical point. In this study, continuation power flow method without parameterization is utilized so as to analyze the voltage stability of systems since it gives satisfactory results. The procedure of the method is shown systematically as in Fig.3. in the form of flow chart.

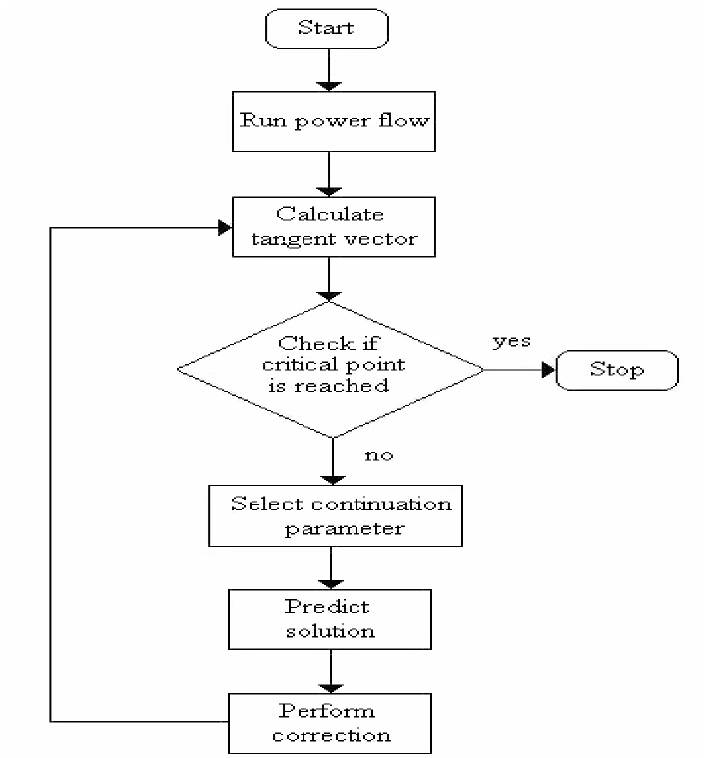

Fig.3. Flow chart for predictor corrector method.

3.3. Loadability Margin Index

The most basic and widely accepted index is loading margin. The loading margin is straightforward and easily understood. It can be applicable to any type of power system model static as well as dynamic. In case of contingency the loadability margin is reduced to lower value. Voltage stability margin is defined as distance with respect to the bifurcation parameter, from the current operating point to voltage collapse point. The system is said to be voltage secure if this margin is reasonably high. In this paper this voltage stability margin is referred to as maximum loadability margin.

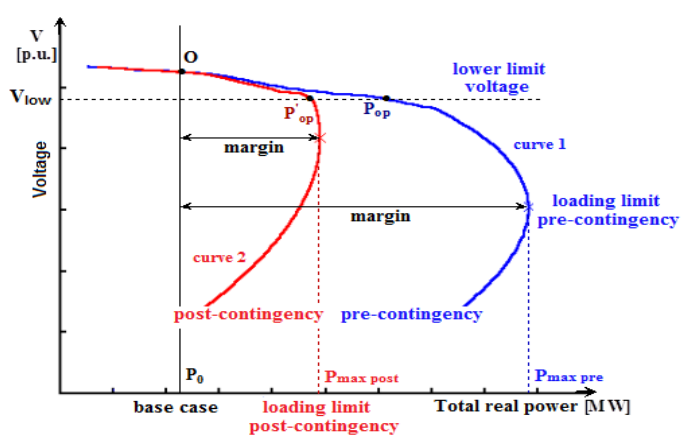

Fig.4. P-V Curve for Pre-contingency and Post-contingency case.

4. CONTINUATION POWER FLOW TO IEEE-30 BUS SYSTEM

Here continuation power flow method is applied to following sample systems using Matlab based power system analysis tools.IEEE-30 bus system consists of 6 generators, 41 transmission lines, 21 loads, 7 Inter Ties and 3 Areas. IEEE-30 bus test system shown in Fig.5. The continuation power flow is run with two different conditions.

1) Without any outage condition(pre contingency case).
2) With outage condition(post contingency case).

CPF results are shown in Table I and II and P-V curve of the system with and without outage is shown in Fig.6 and Fig.7.Continuation power flow is run up to bifurcation point, that means when maximum loading point reaches power flow will stop.

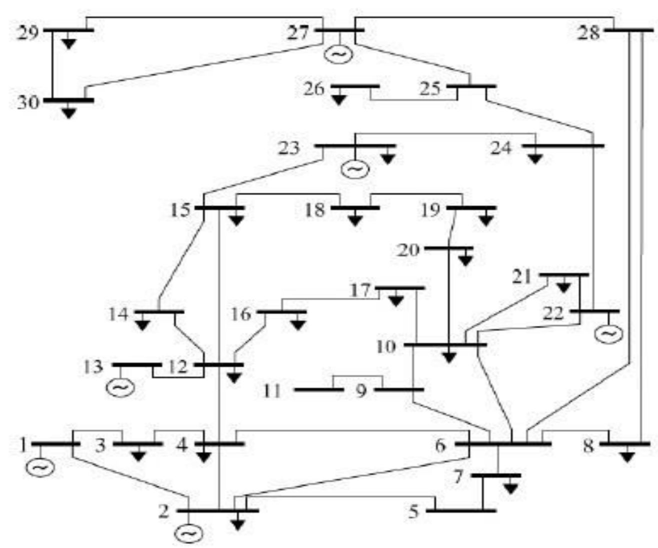

Fig.5.IEEE standard 30 bus system

5. SIMULATION RESULT AND DISCUSSION

The P-V curve has been drawn for two cases:-

Case1:- while considering 30 buses, 6 generators, 6 committed generators, 41 transmission line , 21 loads , 7 inter-ties , 3 areas. For this case all the load flow analysis parameters are calculated and listed in Table I. The P-V curve under this condition is shown in fig.6.

TABLE 1: BUS DATA

Bus	Voltage		Generation		Load	
#	Mag(pu)	Ang(deg)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	1	0.000*	352.16	-15.71	-	-
2	1	-9.676	60.97	707.41	21.7	12.7
3	0.873	-10.019	-	-	2.4	1.2
4	0.851	-12.427	-	-	7.6	1.6
5	0.125	-67.147	-	-	94.2	19
6	0.785	-15.438	-	-	-	-
7	0.488	-22.597	-	-	22.8	10.9
8	0.772	-16.212	-	-	30	30
9	0.889	-15.99	-	-	-	-
10	0.944	-16.231	-	-	5.8	2
11	0.889	-15.99	-	-	-	-
12	0.95	-13.312	-	-	11.2	7.5
13	1	-10.188	37	36.45	-	-
14	0.947	-14.382	-	-	6.2	1.6
15	0.955	-14.762	-	-	8.2	2.5
16	0.939	-14.901	-	-	3.5	1.8
17	0.937	-16.092	-	-	9	5.8
18	0.937	-16.111	-	-	3.2	0.9
19	0.931	-16.698	-	-	9.5	3.4
20	0.933	-16.646	-	-	2.2	0.7
21	0.984	-17.148	-	-	17.5	11.2
22	1	-17.304	21.59	112.27	-	-
23	1	-14.986	19.2	20.68	3.2	1.6
24	0.989	-16.29	-	-	8.7	6.7
25	0.99	-15.236	-	-	-	-
26	0.972	-15.685	-	-	3.5	2.3
27	1	-14.305	26.91	52.47	-	-
28	0.806	-15.919	-	-	-	-
29	0.98	-15.605	-	-	2.4	0.9
30	0.968	-16.518	-	-	10.6	1.9
		Total:	**517.83**	**913.58**	**283.4**	**126.2**

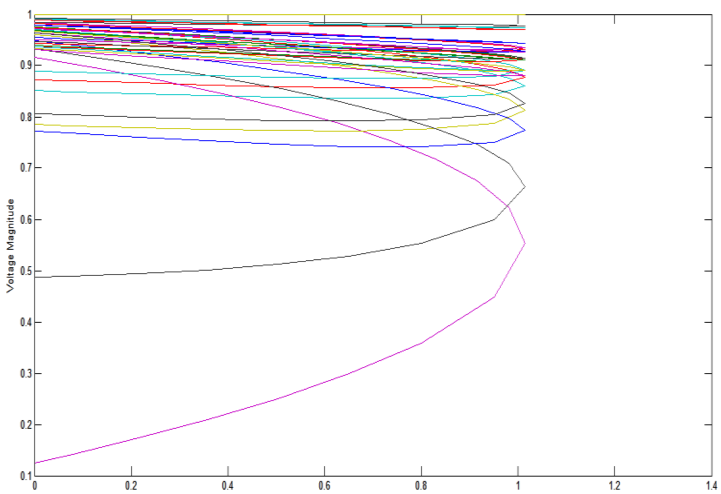

Fig.6. P-V Curve without outage condition (pre contingency)

Case 2:- Considering outage condition i.e. while branch 10th and 2nd generator are in outage due to some fault condition. The load flow analysis data sheet is shown in Table II. The related P-V curve is shown in fig.7.

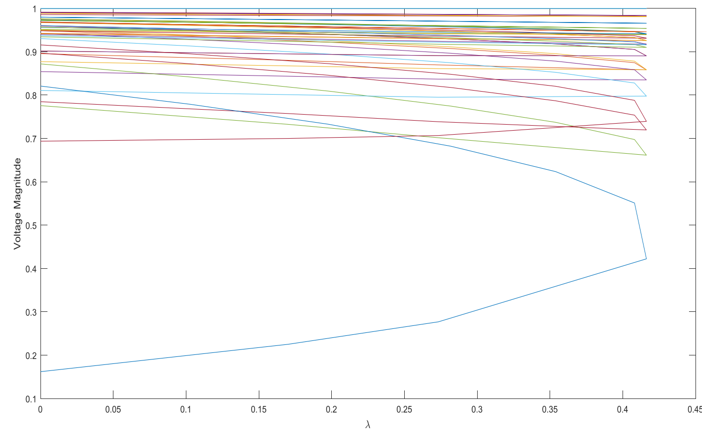

Fig.7. P-V Curve with outage condition (post contingency)

CONCLUSION

Voltage stability margin can be found easily by CPF as we can observe from the above result. P-V curve and maximum loading point can access. From the curve obtained and found loadability margin variation for pre contingency and post contingency condition which clearly indicates that how loadability margin shifts toward origin during outage and the collapse point variation can be easily observed.

Only collapse point is not enough for voltage stability assessment. From loadability margin weakest bus can identify. The Weakest bus identification is done by without excessive calculation. Placement of reactive power sources such as Fact devices, capacitor bank is known to us. This CPF method is more accurate and simple for Voltage stability analysis.

TABLE II: BUS DATA

Bus	Voltage		Generator		Load	
#	Mag(pu)	Ang(deg)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	1	0.000*	255.49	166.73	-	-
2	0.896	-5.585	-	-	21.7	12.7
3	0.877	-7.13	-	-	2.4	1.2
4	0.854	-8.827	-	-	7.6	1.6
5	0.776	-16.661	-	-	94.2	19
6	0.811	-10.935	-	-	-	-
7	0.785	-13.994	-	-	22.8	10.9
8	0.162	-34.545	-	-	30	30
9	0.902	-11.685	-	-	-	-
10	0.949	-12.02	-	-	5.8	2
11	0.902	-11.685	-	-	-	-
12	0.952	-9.356	-	-	11.2	7.5
13	1	-6.236	37	35.59	-	-
14	0.948	-10.387	-	-	6.2	1.6
15	0.956	-10.729	-	-	8.2	2.5
16	0.942	-10.839	-	-	3.5	1.8
17	0.942	-11.924	-	-	9	5.8
18	0.94	-12.015	-	-	3.2	0.9
19	0.934	-12.561	-	-	9.5	3.4
20	0.937	-12.49	-	-	2.2	0.7
21	0.986	-12.851	-	-	17.5	11.2
22	1	-12.979	21.59	102.44	-	-
23	1	-10.869	19.2	20.02	3.2	1.6
24	0.989	-12.115	-	-	8.7	6.7
25	0.99	-11.258	-	-	-	-
26	0.972	-11.707	-	-	3.5	2.3
27	1	-10.447	26.91	81.02	-	-
28	0.694	-12.58	-	-	-	-
29	0.98	-11.747	-	-	2.4	0.9
30	0.968	-12.66	-	-	10.6	1.9
		Total:	360.19	405.8	283.4	126.2

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