CPF METHOD FOR STATIC VOLTAGE STABILITY ANALYSIS USING PSAT

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Abstract: This study has been undertaken to investigate the determinants of stock returns in Karachi Stock Exchange (KSE) using two assets pricing models the classical Capital Asset Pricing Model and Arbitrage Pricing Theory model. Voltage Stability is the ability of a Power system to maintain an acceptable power throughout all the buses in the power system under normal condition and after experiencing a perturbation in the power network. A power system undergoes voltage collapse if the post disturbance equilibrium voltages near loads are below acceptable limits. Voltage collapse may be total or partial. The jacobian matrix becomes singular at the voltage stability limit. As a result conventional load flow algorithms may have convergence problems at the operating conditions near the stability limit. The continuation power flow analysis overcomes the problem by reformulating the load flow equations so that they remain well conditioned at all possible loading conditions. A salient feature of the so-called continuation power flow is that it remains well-conditioned at and around the critical point. The continuation method of power flow analysis is robust and flexible and suited for solving load flow problems with convergence difficulties. The static voltage stability analysis using continuation power flow method has been carried out on IEEE 6-Bus Test System using MATLAB and PSAT software's and results are presented.

***Index Terms* – Voltage stability, Continuation power flow, Power system.**

I. INTRODUCTION

In recent years, the increase in peak load demand and power transfers between utilities has elevated concerns about system voltage security. Voltage collapse has been deemed responsible for several major disturbances [1] and significant research efforts are under way in an effort to further understand voltage phenomena [2]. A large portion of this research is concentrated on the steady state aspects of voltage stability. Indeed, numerous authors have proposed voltage stability indexes based upon some type of power flow analysis [3-8]. A particular difficulty being encountered in such research is that the Jacobian of a Newton-Raphson power flow becomes singular at the steady state voltage stability limit. In fact, this stability limit, also called the critical point, is often defined as the point where the power flow Jacobian is singular. *As* a consequence, attempts at power flow solutions near the critical point are prone to divergence and error. For this reason, double precision computation and anti-divergence algorithms such as the one found in [8] have been used in attempts to overcome the numerical instability. This paper demonstrates how singularity in the Jacobian *can* be avoided by slightly reformulating the power flow equations and applying a locally parameterized continuation technique. During the resulting "continuation power flow", the reformulated set of equations remains well-conditioned *so* that divergence and error due to a singular Jacobian are not encountered. *As* a result, single precision computations can be used to obtain power flow solutions at and near the critical point.

II. CONTINUATION POWER FLOW

III. The continuation power flow analysis uses an iterative process involving predictor and corrective steps as shown in fig. From a known initial solution (A), a tangent predictor is used to estimate the solution (B) for a specified pattern of load increase. The corrector step then determine the exact solution(C) using a conventional power flow analysis with the system with the system load assumed to be fixed. The voltages for further increase in load are then predicted based on new tangent predictor. If the new estimated load(D) is now beyond the maximum load on the exact solution, a corrector step with loads fixed would not converge; therefore a corrector step at the monitored bus is applied to find the exact solution(E).As the voltage stability limit is reached ,to determine the exact minimum load the size of load increase has to be reduced gradually during the successive Predictor steps.

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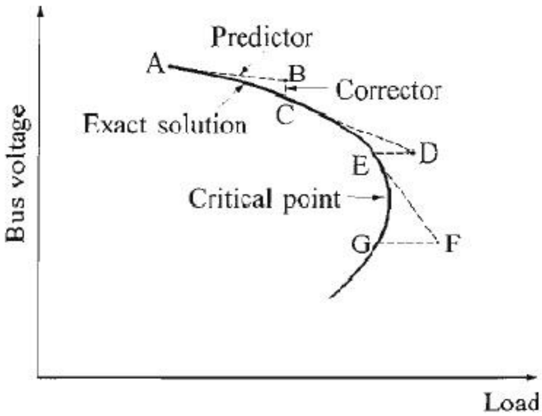

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Figure 1: Continuation Power Flow analysis

III.MATHEMATICAL FORMULATION

The basic equations are similar to those of standard power flow analysis expect that the increase in load is added as a parameter. The reformulated power flow equations with provision for increasing in generation as the load is increased may be expressed as

$$F(\theta,V) = \lambda K \quad (1)$$

Where λ is the load parameter
θ is the Vector of bus voltage angles
V is the vector of Bus voltage magnitudes
K is the vector representing percent load change at each bus.
The above set of nonlinear equations is solved by specifying a value for λ such that

$$0 \leq \lambda \leq \lambda critical$$

Where λ =0 represents the base load conditions, and $\lambda = \lambda_{critical}$ represents the critical load.
Equation (1) may be represented as

$$F(\theta, V, \lambda) = 0 \quad (2)$$

Predictor Step:
In the predictor step, a linear approximation is used to estimate the next solution for a change in one of the state variable (θ, V, λ)
Taking the derivatives of the both side of equation (2) with the state variable corresponding to the initial solution will result in the following set of linear equation:

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

Or

$$\begin{bmatrix} F_\theta & F_V & F_\lambda \end{bmatrix} \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix} = 0 \quad (3)$$

Since the insertion of () in the power-flow equation added an unknown variable, one more equation is needed to solve the equation. This is satisfied by setting one of the components of the tangent vector to +1 or -1. This component is referred to as the continuation parameter. Equation (3) now becomes

$$\begin{bmatrix} F_\theta & F_V & F_\lambda \\ & e_K & \\ & & \end{bmatrix} \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix} = \begin{bmatrix} 0 \\ \pm 1 \end{bmatrix} \qquad (4)$$

Where e_k is a row vector with all elements equal to zero except for the k^{th} element (corresponding to the continuation parameter) being equal to 1.

Initially, the load parameter (λ) is chosen as the continuation parameter and the corresponding component of the tangent vector is set to +1. During the subsequent predictor steps, for reasons given later, the continuation parameter is chosen to be the state variable that has the greatest rate of change near the given solution, and the sign of its slope determines the sings of the corresponding component of the tangent vector. As the maximum load is approached, a voltage will typically be the parameter with the largest change. Once the tangent vector found, the prediction for the next solution is given by

$$\begin{bmatrix} \theta \\ V \\ \lambda \end{bmatrix} = \begin{bmatrix} \theta_0 \\ V_0 \\ \lambda_0 \end{bmatrix} + \sigma \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix} \qquad (5)$$

Where the subscript "σ" identifies the values of the state variable at the beginning of the predictor step. The step size sigma is chosen so that a power-flow solution exists with the specified continuation parameter. If for a given step size a solution cannot be found in the corrector step, the step size is reduced and the corrector step is repeated until a successful is obtained.

Corrector step:

In the corrector step, the original set of equation $F(\theta,V,\lambda)=0$ is augmented by one equation that specifies the sate variable selected as the continuation parameter. Thus the new set of equation is

$$\begin{bmatrix} F(\theta,V,\lambda) \\ x_{k-\eta} \end{bmatrix} = [0] \qquad (6)$$

In the above, x_k is the state variable selected as the continuation parameter and (η) is equal to the predicted value of x_k .This set of equations can be solved using a slightly modified Newton-Raphson power flow method. This introduction of the additional equation specifying x_k makes the Jacobian non-singular at the critical operating point. The continuation power-flow analysis can be continued beyond the critical point and thus obtain solution corresponding to the lower portion of the *V-P* curve. The tangent component of λ (i.e. dλ) is positive for the upper portion of *V*-P curve, is zero at the critical point, and is negative beyond the critical point. Thus the sign of dλ will indicate whether or not the critical point has been reached. If the continuation parameter is the load increase, the corrector will be a vertical line (for example, segment BC in Figure 1) on the *V-P* plane. If, on the other hand a voltage magnitude is is the continuation parameter, the corrector will be a horizontal line (for example, segment DE).

3.1 Selection of continuation parameter

The selection of appropriate continuation parameter is particularly important for the corrector steps. A poor choice of the parameter can cause the solution to diverge. For example, the use of load parameter λ as the continuation parameter in the region of critical point can cause the solution to diverge if the estimate exceeds the maximum load. On the other hand, when the voltage magnitude is used as the continuation parameter the solution may diverge if large steps in voltage change are used. A good practice is to choose the continuation parameter as the state variable that has the greatest rate of change the given solution.

3.2 Sensitivity information

In the continuation power-flow analysis, the elements of the tangent vector represent differential changes in the state variable in response to a differential change in the system load. Therefore, the *dV* elements in a given tangent vector are useful in identifying "weak buss", that is buss which is experiences large voltage variations in response to a change in a load.

IV. RESULTS AND DISCUSSION

PSAT is power system analysis software, which has many features including power flow and continuation power flow and optimal power flow. Our test system is IEEE 6 bus system. Simulated diagram of system with 6bus is drawn in PSAT software in Figure2.

Case 1: Power Flow Analysis

The power flow is done in a PSAT and the results are tabulated in table1 shows the base case real power and reactive power

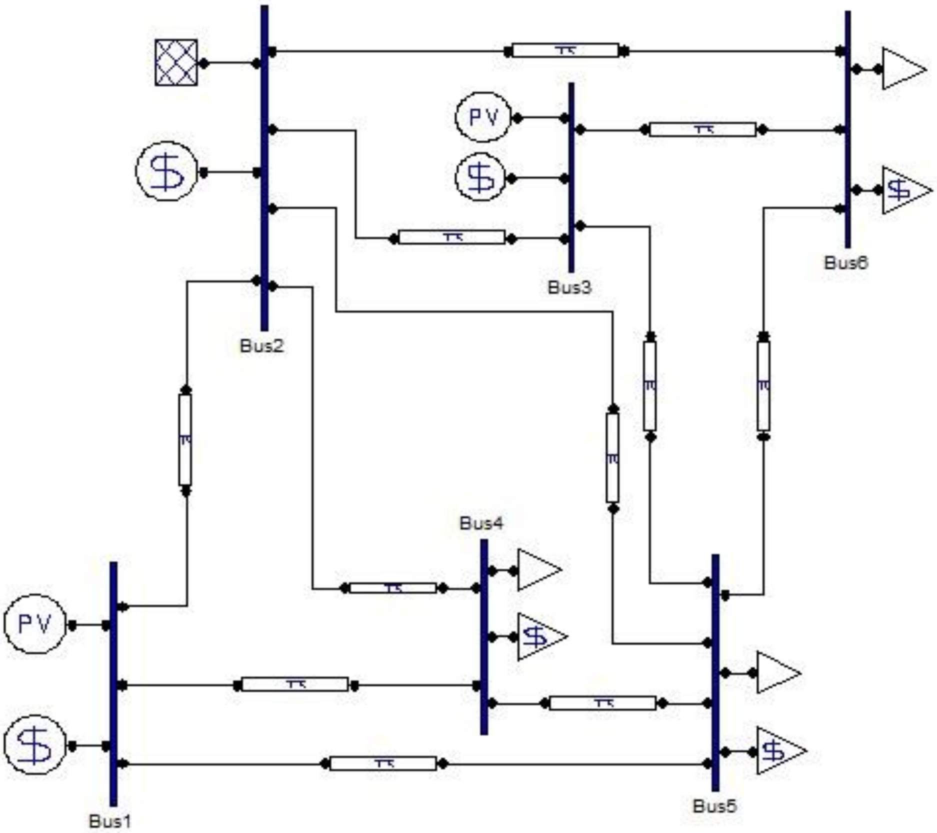

Figure2: IEEE 6 Bus Test System

Table 1: power flow of IEEE-6 Bus Test System

Bus No	Voltage magnitude	Voltage Angle(rad)	Real power(P.U)	Reactive power(P.U)
1	1.05	0.02534	0.9	0.31409
2	1.05	0	1.3988	0.65025
3	1.05	-0.03529	0.6	0.70318
4	0.98592	-0.04064	-0.9	-0.6
5	0.96854	-0.07261	-1	-0.7
6	0.99121	-0.0735	-0.9	-0.6

Case2: Continuation power Flow Analysis

Continuation Power Flow is done in PSAT software and the maximum loading parameter λ_{max}=11.1607. From table2 it is clear that buses 4, 5 &6 has lowest voltages due to high loading. The loading margin for buses 4, 5&6 is shown in figure.

Table 2: Continuation Power Flow of IEEE-6 Bus Test System

Bus No	Voltage magnitude	Voltage Angle(rad)	Real Power(P.U)	Reactive Power(P.U)
1	1.05	0.09706	3.1322	3.1664
2	1.05	0	5.451	5.6278
3	1.05	-0.04602	2.8322	2.8176
4	0.53596	-0.28286	-3.6902	-2.4601
5	0.73347	-0.21	-2.1161	-1.4813
6	0.83564	-0.24411	-3.1322	-1.344

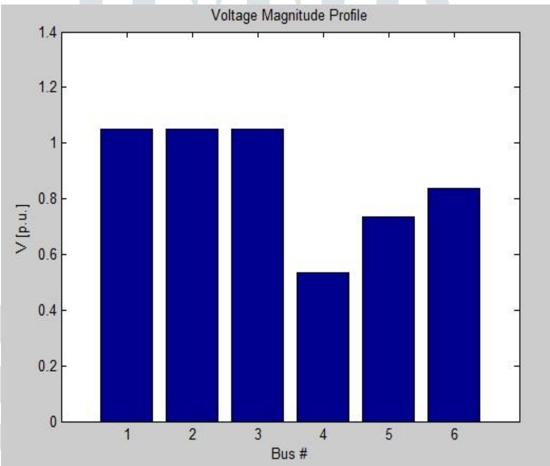

Figure 3: Voltage Profiles at different buses

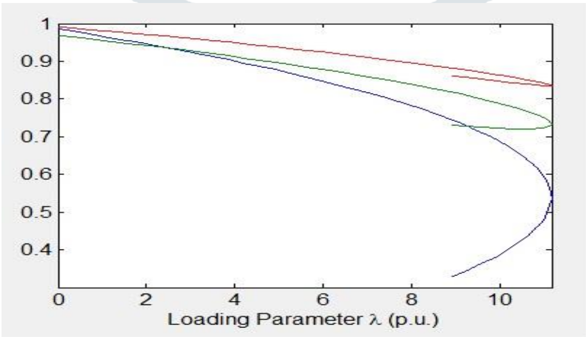

Figure4: V- λ curves for buses 4, 5 &6

V.CONCULUSION

In this paper to analyze the Static Voltage stability the continuation power flow method is applied based on PSAT software. The proposed method gives solution beyond the critical point.

In each case divergence was not a problem as it would have been in a conventional Newton-Raphson power flow. The simulation PSAT software runs the continuation power flow in seconds .PSAT software is also best for analyzing Optimal Power flow problem, Multi-objective Voltage stability problems

VI. ACKNOWLEDGMENT

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