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Voltage Stability Proximity Index Determined by LES Algorithm

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Abstract**—**In this paper, we propose an easily computable proximity index for predicting voltage collapse of a load bus using only measured values of the bus voltage and power; Using these measurements a polynomial of fourth order is obtained by using LES estimation algorithms. The sum of the absolute values of the polynomial coefficient gives an idea of the critical bus. We demonstrate the applicability of our proposed method on 6 bus test system. The results obtained verify its applicability, as well as its accuracy and the simplicity. From this indicator, it is allowed to predict the voltage instability or the proximity of a collapse. Results obtained by the PV curve are compared with corresponding values by QV curves and are observed to be in close agreement.

Keywords**—**least square method, Voltage Collapse, Voltage Stability, PV curve

I. Introduction

VOLTAGE stability is an important factor, which needs to be taken into consideration during the planning and operation of electrical power systems in order to avoid voltage collapse and subsequently partial or full system blackout. From the voltage stability analysis point of view, system operators need to know not only the severity of their system, but also the mechanisms that cause voltage instability.

The ability to maintain voltage stability depends on appropriate and accurate analysis of various operating conditions. A fast method is required in order to perform this kind of assessment efficiently for operating conditions online. There are many types of voltage indices counted as voltage stability limits, such as sensitivity index[1], singular value index[2], load proximity index[3][4],impedance index[5], line stability index[6].These indices have various considerations during its foundation. There is still a need to develop an analytical tool capable of assessing voltage stability proximity accurately and identifying voltage–weak points/areas susceptible to voltage instability for the purpose of online application. Voltage collapse proximity indicators are usually considered as useful measures of the closeness of the power system to the collapse point. For a particular operating point, the value of the indicator provides information of each bus voltage and proximity to the voltage collapse limits. However, as the operating condition of a power system continuously changes, it is difficult to use these methods to provide real time information due to the significant computational requirements of such methods.

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LES estimation algorithms have been successfully applied in security assessment and have the potential to estimate the voltage collapse proximity indicator of a power system without solving the governing power system equations. This paper proposes a method to find the most vulnerable bus for voltage collapse in a system. Usually the load flow solution a set of voltage and loads at a particular bus is obtained and a fourth order polynomial is formed for the relation of load voltage and load bus at each bus. The sum of the magnitudes of the coefficients gives a good measure to find the critical bus.

II. Voltage Stability Analysis

A. PV analysis

When considering voltage stability, the relationship between transmitted P and receiving end V is of interest. The process of voltage stability analysis involves the transfer of P from one region of a system to another, and monitoring the effects to the system voltages V. This type of analysis is commonly referred to as a P-V study [7]. The P-V curves, real power- voltage curve, are used to determine the MW distance from the operating point to the critical voltage. A typical P-V curve is shown in Fig.1. Consider a single, constant power load connected through a transmission line to an infinite-bus. Let us consider the solution to the power-flow equations, where P, the real power of the load, is taken as a parameter that is slowly varied, and V is the voltage of the load bus. The three regions shown in Figure .1 are related to the parameter P. In the first region, the power flow has two distinct solutions for each choice of P; one is the desired stable voltage and the other is the unstable voltage. As P is increased, the system enters the second region, where the two solutions intersect to form one solution for P, which is the maximum. If P is further increased, the power-flow equations fail to have a solution. This process can be viewed as a bifurcation of the power-flow problem.

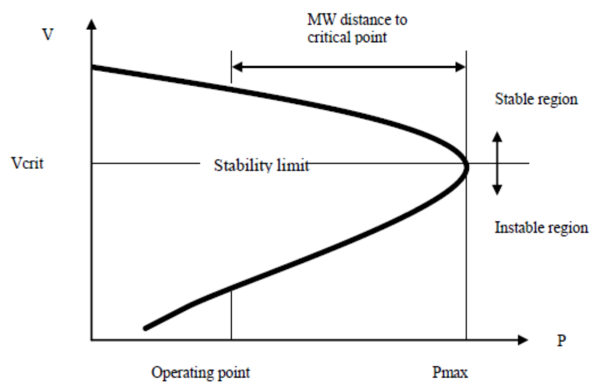

Fig. 1 PV curve

B. QV analysis

In Figure.2, the Q axis shows the reactive power that needs to be added or removed from the bus to maintain a given voltage at a given load. The reactive power margin is the Mvar distance from the operating point to the bottom of the curve. The curve can be used as an index for voltage instability. Near the nose of a Q-V curve, sensitivities get very large and then reverse sign. Also, it can be seen that the curve shows two possible values of voltage for the same value of power. The power system operated at lower voltage value would require very high current to produce the power. That is why the bottom portion of the curve is classified as an unstable region; the system cannot be operated, in steady state, in this region. The top portion of the curve represents the stability region while the bottom portion from the stability limit indicates the unstable operating region. It is preferred to keep the operating point far from the stability limit[7].

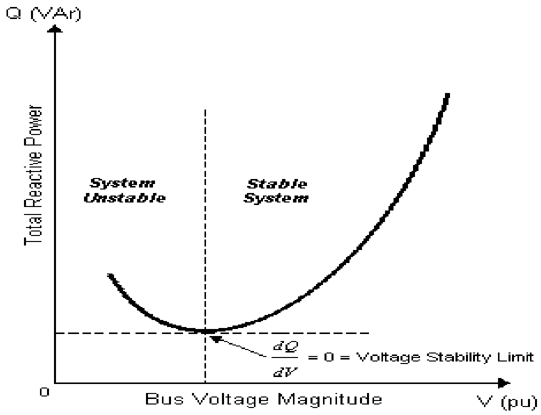

Fig. 2 QV curve

III. Proposed Methodology

Initially the voltage is determined using power flow at base case loading conditions, and then the load is gradually increased at that bus in steps and at each step the load flow solution is carried out. The voltages at that load bus corresponding to each load flow solution are calculated. By using these set of voltages and loads a fourth order polynomial which results in the relation between the voltage and load at that load bus is estimated by using Least squares method [8].
Similar analysis is carried out for each and every load bus in the test system. The sum of the absolute values of the coefficients of the fourth order polynomial of each load bus is calculated. The bus whose sum of the coefficients is less is termed to be weak bus or critical bus.
All results obtained for voltages and loads at a particular load bus can be expressed by relationship (1).

$$V_i = k_1 + k_2.P_i + k_3.P_i^2 + k_4.P_i^3 + k_5.P_i^4 \quad (1)$$

V_i: The load voltage magnitude

P_i: The load bus

k_i: The regression coefficients estimated using lest square algorithm

We tested our method on 6-bus system .This system has 2 generator buses, 4 load buses. Initially power flow studies are carried on system with Newton Raphson method. We increased the load at load buses gradually, only in one bus at a time in 8 steps, from the base case until its maximum allowable load, keeping the load at the other bus fixed at base load. At each step the load voltages and corresponding load buses are arranged in vector. Using the LES algorithm, a fourth order polynomial is assumed for the load voltage as a function of the load bus. Similar analysis is carried out for each and every load bus in the test system. The sum of the absolute values of the coefficients of the fourth order polynomial of each load bus is calculated. The bus whose sum of the coefficients is less is termed to be weak bus or critical bus.

IV. Algorithm

The 6-bus data [7] is considered for the above test system in that bus-1 is the slack bus, bus-3 is the PV bus and the other are PQ bus. For drawing PV curve for 2,4,5 and 6 bus, we Gradually increase the load in steps until the load flow diverges.

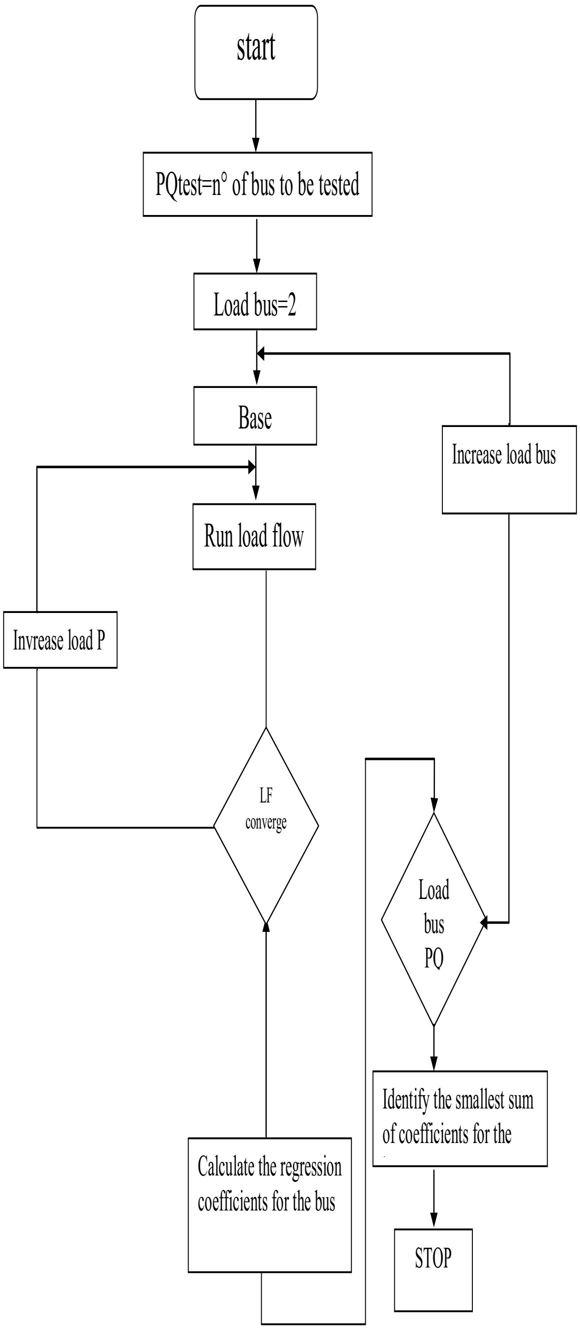

Fig. 3 Flow chart computation latest bus

V. Results and Discussion

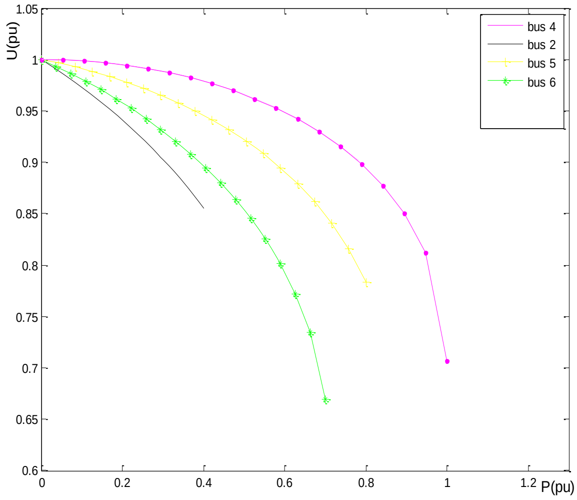

Fig. 4 PV Curves of 6-bus test system

The PV curves are generated for each individual load buses in order to analyze the operating voltage and collapse voltage for all the load buses.

The analysis was performed at base case load conditions. The nose of the PV curve represents the voltage stability limit. Table. I gives the numerical values of the operating voltage and collapse voltage

TABLE I
Operating and Collapse Voltages of 6-bus system

n° bus	Operating Voltage (pu)	Collapse Voltage (pu)
2	0.961	0.707
4	1.018	0.794
5	1.017	0.793
6	0.904	0.706

The sum of the absolute values of the coefficients of the fourth order polynomial of each load bus is calculated. The bus whose sum of the coefficients is less is termed to be weak bus or critical bus.

TABLE II
THE REGRESSION COEFFICIENTS FOR THE BUSES

k_i	Bus 2	Bus 4	Bus 5	Bus 6
k_1	-5.147	-1.453	-1.350	-1.542
k_2	12.485	3.8082	3.720	2.028
k_3	-11.153	-3.807	-3.807	-1.131
k_4	4.026	1.543	1.496	0.089
k_5	0.498	0.810	0.802	0.988

The sum of the absolute is carried out for all the load buses in the test system. Table III shows the corresponding sum of the coefficients against the bus number

TABLE III
SUM OF THE COEFFICIENTS AGAINST THE BUS NUMBER

n° bus	Sum of coefficients PV
2	-3.32
4	0.9
5	0.86
6	0.42

The weakest bus corresponds to bus 2 for the least sum of the absolute values of the coefficients. Results obtained by the proposed method are compared with the corresponding values obtained by QV curves.

The effect of reactive power characteristics of the devices at loads is more apparent in a QV curve. Voltage stability depends on how the deviations in Q and P affect the voltages at the load buses.

This curve shows the limit of voltage stability in the places where derivative dQ/dV is zero.

Using measurements of voltage and power, QV curve can be plotted using a same algorithm as PV curve and a polynomial of fourth order is obtained by using LES estimation algorithms. The sum of the absolute values of the polynomial coefficient gives an idea of the critical bus, this result was approved in [9]. Case studies are done on a 6 bus test system.

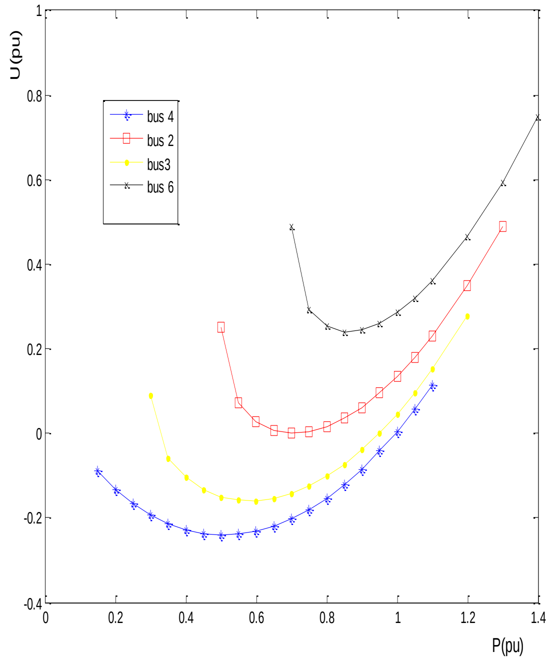

Fig. 5 QV Curves of 6-bus test system

TABLE IV
SUM OF THE COEFFICIENTS AGAINST THE BUS NUMBER

n° bus	Sum of coeffiacients QV
2	7.46
4	9.96
5	8.15
6	9.42

TABLE V
COMPARISON ANALYSIS

Rank	Type d'analyse	
	PV analysis	QV analysis
1	2	2
2	6	5
3	5	6
4	4	4

VI. Conclusion

This paper proposes a simple method to determining a voltage stability proximity index based on the polynomial estimation from voltage and load buses. The slack buses can correctly determine with PV curve as it has been determined by calculating the regression curve QV. The developed system was tested using 6 bus system and the results shows there is a good concordance between the PV curves and the QV. With local measurements for the voltage, load buses and proposed method the slack bus can be correctly determined.

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