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Voltage Stability Calculations in Power Transmission Lines: Indications and Allocations (IEEE 30 BUS SYSTEM)

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Abstract: **Power system is facing new challenges as the present system is subjected to severely stressed conditions. Voltage instability is a quite frequent phenomenon under such a situation rendering degradation of power system performance. In order to avoid system blackouts, power system is to be analyzed in view of voltage stability for a wide range of system conditions. In voltage stability analysis, the main objective is to identify the system maximum loadability limit and causes of voltage instability. Static voltage stability analysis with some approximations gives this information. Voltage stability problem is related to load dynamics and therefore different load characteristics are to be considered in the voltage stability analysis. This paper presents an efficient method for conducting line voltage stability analysis in power systems. This newly developed method is accurate, fast, simple, and theoretically proven for finding precise voltage collapse points and for determining voltage stability at each transmission line. Voltage stability margins can be easily calculated, providing an indication of how far the transmission line is from its severe load condition and allowing separate analysis if one transmission line is highly stressed. The proposed method was demonstrated on the IEEE 30-bus system and compared with existing methods to show its effectiveness and efficiency.**

Keywords: **voltage collapse, line voltage stability index, voltage stability analysis.**

1. INTRODUCTION

Recently, power systems have been operating close to stability limits because of deregulation and the complexity of constructing a new transmission lines causing violation of voltage limits. Operating power systems in such an environment initiates severe stability problems leading power systems as a whole to collapse. An inadequate supply of reactive powers also contributes to system voltage instability and eventually to electricity blackouts. Several blackout incidents have been recorded worldwide, including France in 1978, Sweden in 1983, in Japan in 1987 [1] and in the USA in 1996 [2]. More recently, in the summer of 2003, blackouts occurred in the USA, Italy and England [3].

Voltage collapse can be avoided. Maintaining system voltage profiles within an acceptable range in power system operations improves system security and reliability and prevents system collapse from happening. Operating beyond acceptable range limits leads to voltage instability and ultimately to voltage collapse. Power systems might be subjected to a sudden increase of reactive power demands causing a partial or total system breakdown. The extra reactive power demands must be met by the generator and reactive power compensator reserves to prevent such incidents.

Voltage stability, instability and collapse are well-defined in [4] and these issues have been the focus of a great deal of research recently. Dynamic analysis has been used to conduct voltage stability since voltage instability is a dynamic phenomenon. Nevertheless, static voltage stability analysis is widely used in voltage stability research, as static analysis is not overly complex, and requires low calculation time. Static analysis provides an accurate analysis method for handling mostly short disturbances while dynamic analysis is used to analyze heavy load disturbances.

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For the last two decades, several methods were developed to conduct static voltage stability analysis. Some methods have used Jacobian matrix to determine the exact values of voltage collapse [5-10] while others determine the bifurcation point to predict voltage stability margins [11]. Maximum load determination enables assessment of proximity to voltage collapse [12] while scalar indices (including line stability index (L_{mn}) [13],line stability factor, (*LQP)* [14], fast voltage stability index (*FVSI)* [14], and voltage collapse proximity index [14]) can be calculated as part of line voltage stability analysis.

Recently, several researchers have used voltage stability/instability analysis to predict voltage collapse; some developed new methods, while others improved existing methods or proposed hybrid methods. Arya and others [17], for example, developed a line voltage stability index used to devise a protective scheme against voltage collapse; the index halves at a collapse point and is easily implemented in a distant relay to give an alarm/tripping signal indicating the system has entered an insecure zone.

Although all the methods briefly described above can be used to carry out static voltage stability analysis, their scope is limited. Some methods are suitable only for specific applications, while others are too complex, consuming so much time running through their procedures that it may be too late to avoid voltage collapse events.

This paper presents a new method to calculate line voltage stability (in a line connected between nodes *k* and *m*) that points out how far the transmission line.

2. THE PROPOSED METHOD

Consider a simple line power system which can be extended to an n-line power system.

Vk ,Vm = sending and receiving voltages at system buses.

δk, δm. = sending and receiving voltages angle at system bus *k* and *m*

Pk, Pm = sending and receiving real powers at buses

Qk ,Qm =sending and receiving reactive powers at buses

Ykm = (G+jB) line a admittance between bus *k* and *m*

θ = line admittance angle

r+jx = line impedance between bus *k* and *m*

When bus *k* is taken as a reference bus,

the line current I_{Line} , is calculated by:

$$I_{Line} = (V_k - V_m)Y_{km} \quad (1)$$

The I_{Line} also can be determined by using the receiving apparent power at bus *m*, given as:

$$I_{Line} = \left(\frac{S_m}{V_m}\right) = \frac{P_m - jQ_m}{V_m \angle -\delta_m} \quad (2)$$

Rearranging equation (1) and (2) yields:

$$|V_m V_k Y_{km}| \angle (\theta - \delta_m) - |V_k|^2 . |Y_{bus}| \angle\theta \quad (3)$$

The real and imaginary parts can be separated from equation (3) as:

$$Re : P_m = |V_m V_k Y_{km}| \cos (\theta - \delta_m) - |V_k|^2 . |Y_{bus}| \cos\theta \quad (4)$$

$$Im : Q_m = -|V_m V_k Y_{km}| \sin (\theta - \delta_m) + |V_k|^2 . |Y_{bus}| \sin\theta \quad (5)$$

Substituting equation (4) into equation (3) to establish a relationship between V_k and Q_m yields:

$$|V_m V_k Y_{km}| \cos (\theta - \delta_m) - |V_k|^2 . |Y_{bus}| \cos\theta \;\; -jQ_m = |V_m V_k Y_{km}| \angle (\theta - \delta_m) - |V_k|^2 . |Y_{bus}| \angle\theta$$

$$|V_k|^2 - |V_m V_k| \frac{\sin\theta - \delta_m}{\sin\theta} + \frac{Q_m}{|Y_m| \sin\theta} = 0 \quad (6)$$

Since δm is very small, it is assumed to be zero seeking equation simplification, then the whole term of (sin(θ-δm)/sin(θ)) is eliminated and yields,

$$|V_k|^2 - |V_m V_k| + \frac{Q_m}{|Y_m| \sin\theta} = 0$$

Since B_{km}=Y_m.sin (θ), the new equation can be rewritten as

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$$|V_k|^2 - |V_m V_k| + \frac{Q_m}{B_{km}} = 0 \quad (7)$$

By taking the quadratic of V_m, the root of V_m is expressed as:

$$V_m = \frac{-|V_k| \pm \sqrt{|V_k|^2 - 4\frac{Q_m}{B_{km}}}}{2} \quad (8)$$

The V_m varies from zero to one indicating the real root limitation and can be used as voltage stability limits. The voltage real root must be greater than zero and lower than one, otherwise the voltage stability are compromised; this proves that the developed equation determines voltage stability at each line and predicts system voltage collapse, named as voltage reactive power index at line, VQI_{Line} , and expressed as

$$VQI_{Line} = 4\frac{Q_m}{B_{km}|V_k|^2} \leq 1.0 \quad (9)$$

Once the value of VQI_{Line} approaches unity, the voltage stability reaches stability limits. Voltage instability occurs when VQI_{Line} is beyond stability limits. VQI_{Line} determines how far the power system is from instability or collapse point.

3. LOAD FLOW SOLUTION

The load flow study is also known as power flow study, and it is an important tool involving numerical analysis applied to a power system. A power flow study uses simplified notation such as a one line diagram and per unit system, and determine all three forms of AC power (i.e. reactive ,real and apparent) rather than voltage and current. It analyses the power systems in normal steady state operation. There exist a number of software implementations of power flow.A single line bus diagram of IEEE 30 bus system is shown here, having different methods of studies including Gauss siedel and Newton Raphson.

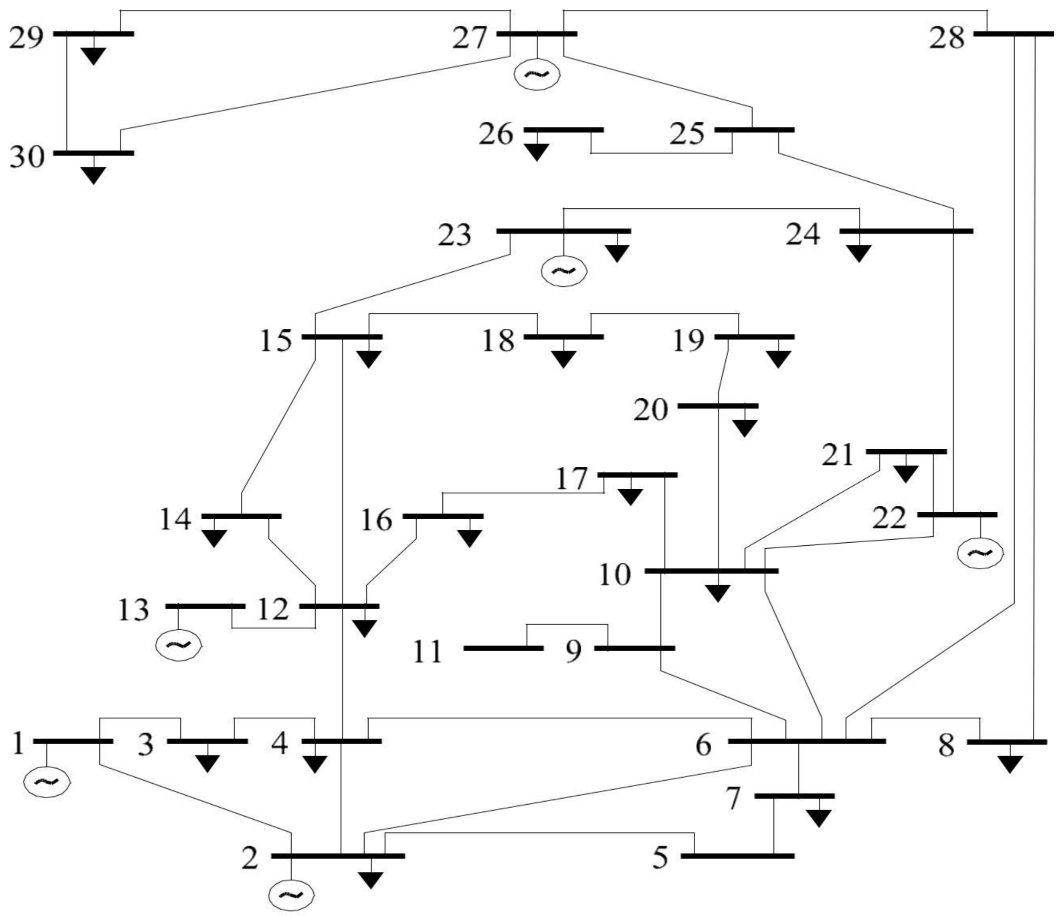

Figure 1: One line diagram of IEEE 30- Bus system.

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4. RESULTS AND DISCUSSIONS

This section demonstrates the implementation of The proposed method, VQI_{Line}, on IEEE (30-bus,41 lines) to conduct line voltage stability analysis. VQI_{Line} and line stability index, L_{mn} were compared to measure VQI_{Line}*'s* relative effectiveness and efficiency, as they share similar characteristics. Several loading scenarios were observed, in which loads were progressively increased until the power system collapsed.

Normal Load scenario on 30-bus system:

Table1 (in index) shows the performance of the proposed method on IEEE (30-bus, 41 lines) system. The proposed method was compared with L_{mn} to check its accuracy in a normal load condition. The comparison outcomes show VQI_{Line} had very similar voltage stability results at each individual line, recording 0.8474 and 0.9069 as the total summation of VQI_{Line} and L_{mn} respectively. There was a difference of only 0.0595 ***k*** load rate between the total summations of two methods confirming their similarity.

Load scenarios on power systems:

This section discusses the accuracy of VQI_{Line} when under gradual load increase to the point that the power system reaches collapse condition. In this application, loads as a whole were assumed to be constant although the load, in whole or in part, is considered dynamic. Loads were assumed to be constant and subject to gradual increases in steps of 0.01 units until the system voltage collapsed, where system voltage indications were easily determined and voltage collapse points were predicted.Two load scenarios were considered in this study. In the first scenario, the loads, active and reactive powers, were increased in the system at all buses simultaneously at identical rate ***k*** until the system voltage collapsed. In the second scenario, the loads were increased in the system at only one bus a second. For both load scenarios, the power factors were assumed to remain constant. Figures 2 to 4 show the performance of the proposed method, VQI_{Line}, versus L_{mn} on IEEE (30-bus, 41 lines) for two loading scenarios. Figure 2 illustrates the first loading scenario showing the similar results between the proposed method, $VQI_{Line,}$ and L_{mn} method.

Results show there are slight differences in terms of voltage collapse predictions among the three methods in critical *Lines* The overall results show that VQI_{Line} has similar voltage stability indications at each individual line along with very similar voltage stability margins and system voltage collapse points when compared to L_{mn} index. In system critical lines, both methods were compared to line receiving voltages, V_m at those particular lines to verify VQI_{Line} accuracy of voltage stability indications, margins and voltage collapse points. Results show VQI_{Line} has very close locations to voltage collapse points giving more accurate voltage collapse results. VQI_{Line} is designed to have a direct relationship between line sending voltages and line receiving reactive powers along with formula simplicity while L_{mn} is more complex. VQI_{Line} permits more efficient and faster stability analysis than L_{mn}, particularly when a power system is subjected to a sudden increase in reactive power demands. Lack of supply of reactive power demand results in voltage collapse causing a partial or total system breakdown.

Hence, the proposed index, VQI_{Line}, is superior to its predecessors in its accuracy, simplicity, speed of calculations and low computation time, indicating that it is a powerful tool for static voltage stability analysis. VQI_{Line} is accurate, fast and simple in terms of allocating voltage stability at each individual line and predicting precisely the point of system voltage collapse. Any system line can also be studied separately when the line is highly stressed.

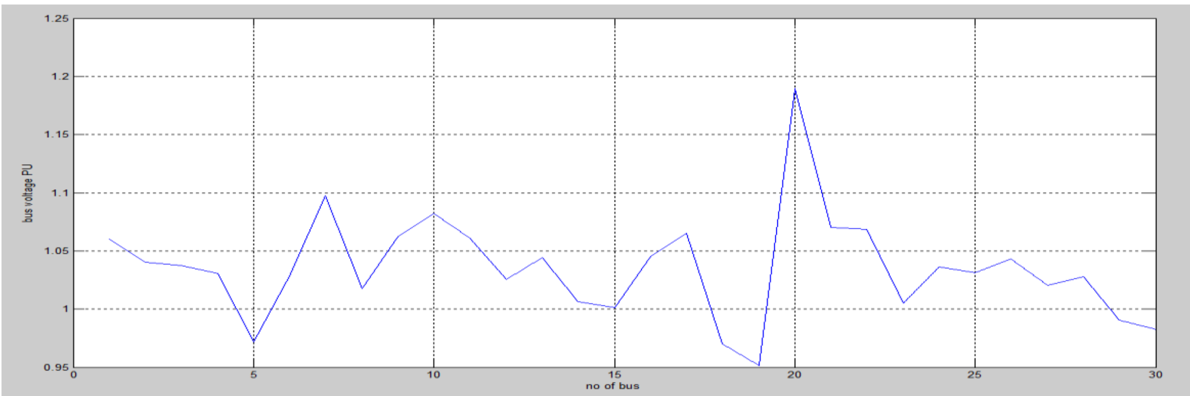

Figure 2: Bus voltage for IEEE 30 bus system

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5. CONCLUSION

This paper presented a new line voltage sability analysis which accurately calculates voltage stability analysis at each transmission line and precisely predicts voltage collapse on power systems. The proposed method, VQI_{Line}, indicates how far the transmission line is from a severe load condition or collapse point, permitting separate analysis if one transmission line is highly stressed. VQI_{Line} is designed to have a direct relationship between sending line voltages and line receiving reactive powers, permitting more effective stability analysis, particularly when a power system is subjected to a sudden increase in reactive power demands. VQI_{Line}*'s* accuracy in conducting line voltage stability analysis and its predictions of voltage collapse were tested, showing very similar voltage stability margins and the same system voltage collapse points when compared to existing methods. One line or more might collapse/outage early as a result of reactive power being inadequate to support the required demand. The results show VQI_{Line} is superior to its predecessors in its simplicity, speed of calculations, accuracy and low computation time, factors which are vital to the prevention of power system collapse. The results also show that voltage collapse events occur at faster rates when the loads at all buses are increasing. VQI_{Line} was demonstrated on the IEEE 30 -bus and compared with existing methods to show its effectiveness and efficiency.

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APPENDIX

LINE PARAMETERS OF THE IEEE 30-BUS SYSTEM

Table C3 Line Parameter of 30-Bus System

Line	From Bus	To Bus	*R* (p.u.)	*X* (p.u.)	Tap Ratio	Rating (p.u.)
1	1	2	0.0192	0.0575		0.300
2	1	3	0.0452	0.1852	0.9610	0.300
3	2	4	0.0570	0.1737	0.9560	0.300
4	3	4	0.0132	0.0379		0.300
5	2	5	0.0472	0.1983		0.300
6	2	6	0.0581	0.1763		0.300
7	4	6	0.0119	0.0414		0.300
8	5	7	0.0460	0.1160		0.300
9	6	7	0.0267	0.0820		0.300
10	6	8	0.0120	0.0420		0.300
11	6	9	0.0000	0.2080		0.300
12	6	10	0.0000	0.5560		0.300
13	9	11	0.0000	0.2080		0.300
14	9	10	0.0000	0.1100	0.9700	0.300
15	4	12	0.0000	0.2560	0.9650	0.650
16	12	13	0.0000	0.1400	0.9635	0.650
17	12	14	0.1231	0.2559		0.320
18	12	15	0.0662	0.1304		0.320
19	12	16	0.0945	0.1987		0.320
20	14	15	0.2210	0.1997		0.160
21	16	17	0.0824	0.1932		0.160
22	15	18	0.1070	0.2185		0.160
23	18	19	0.0639	0.1292	0.9590	0.160
24	19	20	0.0340	0.0680		0.320
25	10	20	0.0936	0.2090		0.320
26	10	17	0.0324	0.0845	0.9850	0.320
27	10	21	0.0348	0.0749		0.300
28	10	22	0.0727	0.1499		0.300
29	21	22	0.0116	0.0236		0.300
30	15	23	0.1000	0.2020		0.160
31	22	24	0.1150	0.1790		0.300
32	23	24	0.1320	0.2700	0.9655	0.160
33	24	25	0.1885	0.3292		0.300
34	25	26	0.2544	0.3800		0.300
35	25	27	0.1093	0.2087		0.300
36	28	27	0.0000	0.3960		0.300
37	27	29	0.2198	0.4153	0.9810	0.300
38	27	30	0.3202	0.6027		0.300
39	29	30	0.2399	0.4533		0.300
40	8	28	0.0636	0.2000	0.9530	0.300
41	6	28	0.0169	0.0599		0.300