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

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Abstract: **Voltage collapse has been recognized as a series threat in power system stability and operation. Fast and accurate indications and allocations of voltage stability in power systems are a challenging task to accomplish. Voltage violations and undesirable line outages might be inevitable when power systems operated close to its transmission capacity limits. Unexpected load increases or insufficient reactive power supply may contribute to partial or total voltage collapse threatening system security. The ability to draw a clear and complete picture of system voltage stability with accurate indications and precise voltage collapse allocations allow operators to take the necessary action to prevent such incidents. A successful avoidance of such system collapse is based on method's accuracy, speed of indication, and very low computation time. 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.**

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

1. INTRODUCTION

The growth of power systems have been witnessed worldwide by engineers, utilities and customers. As energy demands is increasing rapidly, power system is expanding to accommodate the rapid load growths by constructing new power plants, transmission lines, substations, and control devices. The shape of electric power industry also has been changed and persistently pressured by government agencies, large industries, and investors to privatize, restructure, and deregulate [1].

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. Most of the large power system blackouts, which occurred worldwide over the last twenty years, which are caused by heavily stressed systems with large amount of real and reactive power demand and low voltage condition. When the voltages at power system buses are low, the losses will also to be increased. This study is devoted to develop a technique for improving the voltage and eliminate voltage instability in a power system.

As a result, several blackouts directly related to voltage collapse have been occurred costing lots of million dollars, and still a threat to power system stability and security. Some well-known incidents of blackout recorded in Germany in 2006 and Russia in 2005[2], in Greece 2004, Italy in 2003[2] and in the same year, blackouts occurred in USA and Canada[3], Sweden-East Denmark[2], London, UK[4] and Croatia and Bosnia Herzegovina[5].

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Voltage collapse is most likely to occur when a power system is operated near its capacity limits. Some electric utilities are forced at such level due to the difficulty of constructing a new transmission line because of the new regulations and policy, or to reduce their operational costs and maximize their profits, but doing so raises risks that make it challenge for operators to contain or control. Operating within operational design limits makes power system more protected and secure, yet operating beyond those limits can lead to the absence of generator synchronism, transmission outages or might result in partial or total system voltage collapse. Hence, maintaining voltage stability in power networks plays a significant role in preventing voltage collapse.

Voltage collapse can be avoided by 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 has been studied using two main approaches: static and dynamic analysis, where voltage instability as fact is considered as dynamic phenomenon. Although the dynamic analysis is preferable by most utilities, the static voltage stability approach is commonly used in research and on-line applications providing an insight into stability problems with high speed analysis.

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 [6-7] while others determine the bifurcation point to predict voltage stability margins [8], maximum load determination enables assessment of proximity to voltage collapse [9] while scalar indices (including line stability index (*Lmn)* [10], line stability factor, (*LQP)* [11], fast voltage stability index (*FVSI)*, and voltage collapse proximity index 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.

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 is from its outage condition or collapse point. The proposed index is simple and accurate in conducting rapid voltage stability analysis, providing the reduced calculation time needed to prevent voltage collapse. The proposed method can be easily used in on-line applications, allowing operators to take action to prevent such incidents.

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:

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

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

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

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Rearranging equation (1) and (2) yields:

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

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

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

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

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

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

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

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 $B_{km} = Y_m . \sin(\theta)$, the new equation can be rewritten as

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

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

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

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

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

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. REVIEW ON LINE STABILITY INDEX, L_{mn}

This section briefly discusses line stability index, L_{mn} [12] which will be used as base method for comparison purpose with the proposed method, VQI_{Line}. L_{mn} is a line power index used to calculate line voltage stability. This index detects the stress condition of power system lines and decides which areas are weak and exposed to voltage collapse, providing online system stability prediction.

$$S_m = \frac{|V_k|.|V_m|}{Z} \angle (\theta - \delta_k + \delta_m) - \frac{|V_m|^2}{Z} \angle\theta \quad \textbf{(10)}$$

$$S_k = \frac{|V_k|^2}{Z} \angle\theta - \frac{|V_k|.|V_m|}{Z} \angle (\theta - \delta_k + \delta_m) \quad \textbf{(11)}$$

The real and imaginary parts can be separated from equation (10) as:

$$P_m = \frac{|V_k|.|V_m|}{Z} \cos(\theta - \delta_k + \delta_m) - \frac{|V_m|^2}{Z} \cos\theta \quad \textbf{(12)}$$

$$Q_m = \frac{|V_k|.|V_m|}{Z} \sin(\theta - \delta_k + \delta_m) - \frac{|V_m|^2}{Z} \sin\theta \quad \textbf{(13)}$$

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Let's δ=δ_k-δ_m and V_m is given as

$$V_m = \frac{V_k(\theta-\delta) \pm \sqrt{b(V_k.\sin(\theta-\delta))^2 - 4XQ_m}}{2sin\theta} \quad (14)$$

The root of the real receiving voltage varies from zero to one indicating the real root limitation expressed as

$$\begin{cases} (V_k.\sin(\theta-\delta))^2 - 4XQ_m \leq 0 \\ \frac{4XQ_m}{(V_k.\sin(\theta-\delta))^2} L_m \leq 1 \end{cases} \quad (15)$$

Once the value of L_{mn} exceeds one, the system reaches its voltage collapse point.

4. CONCLUSIONS

This paper presented a new line voltage stability 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

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