A steady-state voltage stability analysis method based on equivalent of grid parameters

Xin Li[1,2], *Panfeng Guo*[1,*] *Youping Fan*[2]

[1] *Three Gorges University, YiChang 443000, China*

[2] *Wuhan University, Wuhan 430072, China*

**E-mail: lxgpf@foxmail.com*

Abstract: A voltage stability analysis method based on the value of grid parameters is presented in this paper. The algorithm uses local synchronized phasor measurement to identify real-time online parameters in situ. After identifying the two-node equivalent system and static load model, it can estimate voltage stability in real time according to a node voltage stability index. The method is the local two bus equivalent system n-shaped branch model identification based on reactive power characteristics and the variation of load parameters can better reflect the line. Finally, combined with the simulation results of the new England 39-bus system, we compare the different equivalent system models and load models. The results show that the proposed method can provide more accurate voltage stability estimation index, and verify the feasibility of the method.

Keywords: Voltage stability; Parameter identification; Stable indicators; Least squares method

1. INTRODUCTION

Voltage stability has become an important research area of power system.The study of voltage stability is mainly studied on voltage stability mechanism, voltage stability modeling, voltage stability index and voltage collapse prevention and control.And voltage collapse is with the steady growth of load and system voltage is falling and eventually lead to a sudden irreversible mass of collapse, thus can effectively predict the system when the voltage collapse is of great significance to the stable operation of power system.

Voltage collapse is generally classified as static stability of power system.The traditional method is to judge the voltage stability of the current system by judging the distance from the point of collapse point of the system.The commonly used static determination methods mainly include the sensitivity analysis method [1], the trend analysis [2], the singularity of the trend Jacobi matrix [3], and the multiresolution of the trend [4].However, most of these methods fail to consider the load characteristics, which lead to the disadvantages of large deviation and low calculation accuracy.

The synchronous phase measurement technology based on phase-measurement unit (PMU) can realize the on-line synchronous measurement of the operation state of the wide-area network, and provides new ideas and methods for online voltage stability estimation.Literature [5] synchronous measurement is put forward a kind of voltage stability analysis method, this method synchronous measurement of the direct use of various load branch direct identification of local load equivalent branch model, thus the corresponding voltage stability index is calculated.However, there are two defects in this method: firstly, the equivalent method adopts the simple impedance branch model and ignores the influence of the support on the ground capacitance. Practice show that the level of voltage in the grid, 35 kv and below branch charging power is small, can be regarded as reactive load, and in 110 kv and above power grid voltage level, charging capacitor reactive power could be produced is greater than the reactance of reactive power losses, the branch is equal to the reactive power [6]-[10]. Therefore, simply the simple circuit impedance model can not fully reflect the reactive power characteristics of the branch.

Based on the above analysis, this paper proposes a more precise local synchronized phasor measurement based on the real-time voltage stability analysis method, the method of equivalent load branch adopts consider charging capacitor Π type circuit, because each local equivalent system parameters is less, the voltage stability index calculation is very simple, can make the voltage stability analysis to meet the real-time requirements.

2. PARAMETER IDENTIFICATION BASED ON π MODEL CIRCUIT

Assume that each load node voltage phasor and branch current phasor can be measured simultaneously, because of the need to consider the branch charging capacitor reactive power characteristic, need of the parameter identification of π type circuit accordingly. As shown in figure 1，

The electric potential and impedance of the external equivalent system and the charging capacitance will change with the change of the operating state of the system. The electric potential, impedance and capacitance parameters of the external equivalent system can be estimated in real time by using the least square method of the recursive least square method according to the bus voltage and the associated branch current measured at the load node.

$$I_k = I_{eq,k} - j\frac{B_k}{2}V_k \qquad (1)$$

I_k is k moment load bus injection current, V_k is k moment load bus voltage and $I_{eq,K}$ is external system impedance branch current, B_k is charging capacitor equivalent branch admittance, E_k is external system equivalence potential, Z_k is equivalent branch impedance.

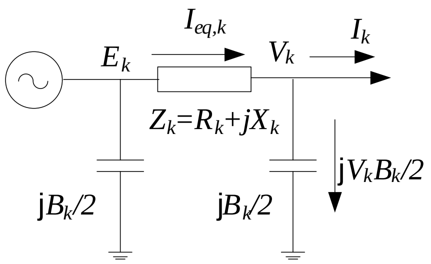

Figure 1. Equivalent branch model with capacitance

When the current phase in equation (1) and the load node voltage are in rectangular coordinates, the real part and the imaginary part can be expanded respectively:

$$\begin{aligned} I_{R,k} &= I_{eqR,k} - \frac{B_k}{2}V_{I,k} \\ I_{I,k} &= I_{eqI,k} + \frac{B_k}{2}V_{R,k} \end{aligned} \qquad (2)$$

The linear observable equation of eq.(2) is obtained as follows.

$$y_k = x_k\theta_k + e_k \qquad (3)$$

$$\begin{aligned} y_k &= [I_{R,k} \quad I_{I,k}]^T \\ x_k &= \begin{bmatrix} 1 & 0 & -\frac{V_{I,k}}{2} \\ 0 & 1 & \frac{V_{R,k}}{2} \end{bmatrix} \\ \theta_k &= [I_{eqR,k} \quad I_{eqI,k} \quad B_k]^T \end{aligned} \qquad (4)$$

According to fig.1, a similar observation equation can be established to directly identify the potential of the equivalent branch and the equivalent system.In order to express the convenience, the observation equation for equivalent support impedance and equivalent system electric potential identification is shown in equation (5) and (6).

$$y_k^* = x_k^*\theta_k^* - e_k^* \qquad (5)$$

$$\begin{aligned} y_k^* &= [V_{R,k} \quad V_{I,k}]^T \\ x_k^* &= \begin{bmatrix} 1 & 0 & I_{eqR,k} & I_{eqI,k} \\ 0 & 1 & I_{eqI,k} & I_{eqR,k} \end{bmatrix} \\ \theta_k^* &= [E_{R,k} \quad E_{I,k} \quad R_k \quad X_k]^T \end{aligned} \qquad (6)$$

To sum up, the parameters identification process of the equivalent branch model considering the influence of charging capacitance is as follows:

(1) for each load node, we directly identify $I_{eqR,0}$、$I_{eqI,0}$ and B_0 as the initial values of $I_{eqR,\mathrm{k}}$、$I_{eqI,\mathrm{k}}$ and B_k according to a set of voltage and current phasors measured from PMU (the number of measurements is two times larger than the number of identified parameters) and the observation equation (6.4).

(2) the recursive least square method is used to identify the $I_{eqR,\mathrm{k}}$、$I_{eqI,\mathrm{k}}$ and B_k in real time.

(3) when the number of data $I_{eqR,\mathrm{k}}$ and $I_{eqI,\mathrm{k}}$ are two times larger than that in the observation eq.(5), we can select the parameters of the observation eq.(5) as the initial value of the identification.

(4) $I_{eqR,\mathrm{k}}$ and $I_{eqI,\mathrm{k}}$, which are recursively recursion at every moment, use the recursive least square method to identify the Ek and Zk of each time.

3. VOLTAGE STABILITY INDEX BASED ON LOCAL EQUIVALENT SYSTEM

Firstly, as shown in figure 2，the two node systems are simplified after the equivalence of this paper. The simplified backside only has the impedance, and the simplified load is only the constant power load,which is shown as follows:

$$\begin{aligned} E_{eq,k} &= (Z_{L,k} - j\frac{4}{B_k})\frac{E_k - I_{L,k}Z_k}{Z_k + (Z_{L,k} - j\frac{4}{B_k})} \\ Z_{eq,k} &= \frac{Z_k(Z_{L,k} - j\frac{4}{B_k})}{Z_k + (Z_{L,k} - j\frac{4}{B_k})} \end{aligned} \qquad (7)$$

In the case of maximum power, the equivalent impedance $Z_{eq,k}$, the voltage on the k landing ΔV_k equals the voltage V_k of the load node. Define the voltage stability indicator of load node and the voltage stability index of the whole system as follows:

$$VSI_k = \max_{i\in e}\{\frac{\Delta V_{ik}}{V_{ik}}\} \qquad (8)$$

The subscript k represents the k moment, subscript i represents the load node. When VSI_k=1, the voltage level of the k moment system reaches the stability limit

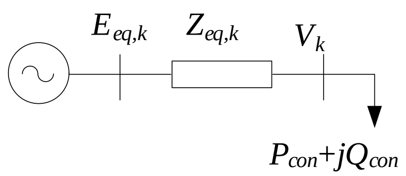

Figure 2. the simplized equivalent circuit

4. CASE STUDY

Based on the new England 39-bus system, simulation calculation was carried out by PSS/E. In different load growth rate for each load node voltage phasor and current phasor, and if the voltage and current phasor measurements of these are configured to load the value of PMU, the equivalent circuit model by each pi load node recursive least squares method step by step in each period and the corresponding accurate load model.

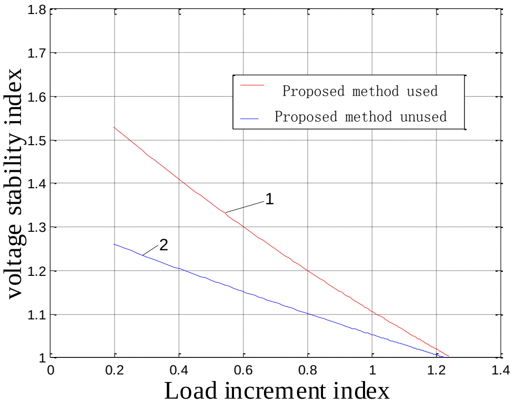

Figure3.Comparisons of different equivalent branch models

Based on the external load bus8 equivalent system and real-time parameter identification of ZIP model as an example, figure 3 is when the load with constant power model, the external equivalent system were used to compare changes, simple model and considering the branch impedance PI equivalent circuit of capacitor charging load node 8 voltage stability index with load increasing can be seen when a branch, consider charging capacitance, voltage stability index node 8 has a high voltage stability margin, and the simple impedance branch model is conservative, which is consistent with the actual analysis.

It can be seen from Figure 4, the load of node 8, with the increase of the load power, the proportion coefficient of various load of static load model is changing, the constant current load change is small, and the proportion coefficient change of constant impedance and constant power load is large, this indicates that the load model for real-time identification it is an effective way to ensure the accurate load model.

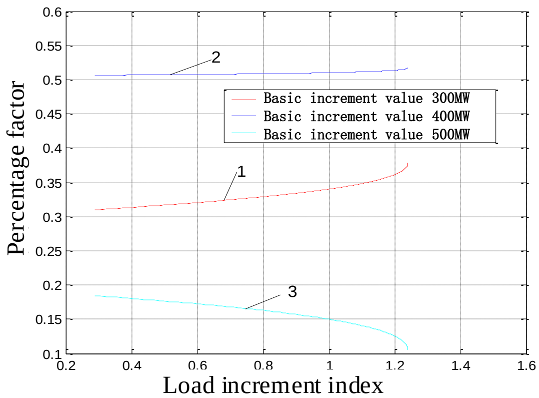

Figure4. Changes of different load component percents of ZIP model

In figure 5, the external system adopts π type equivalent branch, and the load model with two fixed ratio coefficient and through real-time identification using the time-varying proportion coefficient model, through the different curve shows a fixed proportion coefficient model to a certain extent, will affect the accuracy of voltage stability index.

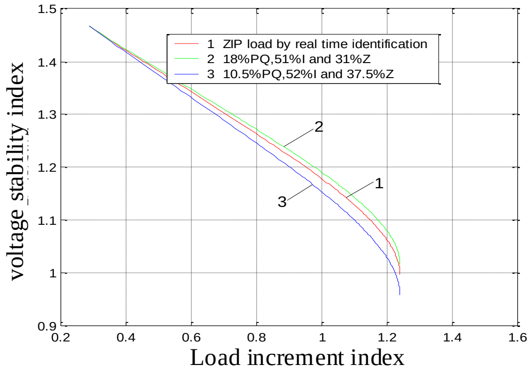

Figure5.Comparisons of VSLBI of different load models

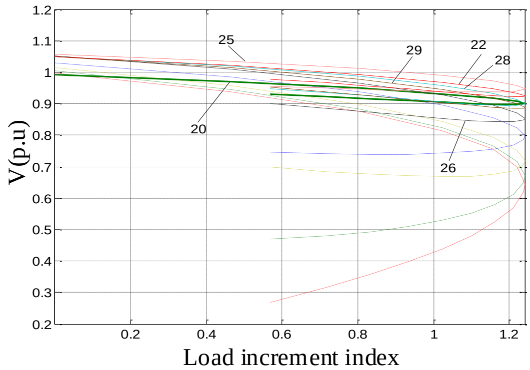

Figure 6. V- curves of load buses

Figure 6 lists all changes in load load node V - curve (for the purposes of V - curve, according to figure 6.8 just now closer to the curve of the critical voltage levels for labeling, and only list the curve of the part has higher stability margin), which represents the growth of the load process.Can be seen in figure 6.8, when λ =1.0, node voltage of 20 closer to its corresponding critical voltage levels, prone to voltage collapse, the results are consistent with actual situation, and shows that the voltage stability index is a good way to reaction system voltage stability

5. CONCLUSION

The development of synchronous phasor measurement technology can provide a more effective and accurate analysis method for the voltage stability analysis of power system based on local measurement. Firstly, using the load node synchronous measurement on-line identification of static load model and external equivalent system charging capacitance effect and time-varying consideration, then based on voltage stability index. The simulation results show that the capacitance and the load branch changes will be predicted on voltage stability and accuracy to a certain extent, and methods this paper can provide a voltage stability index is more reliable, can be more effective in voltage stability real-time monitoring system.

REFERENCES

[1] Hui. Jiang, Kun. Wang, Yihui. Wang, Min. Gao and Yan. Zhang, "Energy big data: A survey," IEEE Access, vol. 4, no. , pp. 3844-3861, 2016

[2] X. Ancheng et al., "On-line voltage stability index based on the voltage equation of transmission lines," in IET Generation, Transmission & Distribution, vol. 10, no. 14, pp. 3441-3448, 11 4 2016

[3] A. B. Almeida, E. V. De Lorenci, R. C. Leme, A. C. Zambroni De Souza, B. I. Lima Lopes and K. Lo, "Probabilistic voltage stability assessment considering renewable sources with the help of the PV and QV curves," in IET Renewable Power Generation, vol. 7, no. 5, pp. 521-530, Sept. 2013

[4] Xiao-Ping Zhang, Ping Ju and E. Handschin, "Continuation Three-Phase Power Flow: A Tool for Voltage Stability Analysis of Unbalanced Three-Phase Power Systems," in IEEE Transactions on Power Systems, vol. 20, no. 3, pp. 1320-1329, Aug. 2005.

[5] K. H. Youssef, "A New Method for Online Sensitivity-Based Distributed Voltage Control and Short Circuit Analysis of Unbalanced Distribution Feeders," in IEEE Transactions on Smart Grid, vol. 6, no. 3, pp. 1253-1260, May 2015.

[6] D. H. A. Lee, "Voltage Stability Assessment Using Equivalent Nodal Analysis," in IEEE Transactions on Power Systems, vol. 31, no. 1, pp. 454-463, Jan. 2016.

[7] J. M. Lim and C. L. DeMarco, "SVD-Based Voltage Stability Assessment From Phasor Measurement Unit Data," in IEEE Transactions on Power Systems, vol. 31, no. 4, pp. 2557-2565, July 2016.

[8] H. Y. Su and C. W. Liu, "Estimating the Voltage Stability Margin Using PMU Measurements," in IEEE Transactions on Power Systems, vol. 31, no. 4, pp. 3221-3229, July 2016.

[9] A. Sajid, H. Abbas and K. Saleem, "Cloud-Assisted IoT-Based SCADA Systems Security: A Review of the State of the Art and Future Challenges," IEEE Access, vol. 4, no. , pp. 1375-1384, 2016.

[10] T. Guo and J. V. Milanović, "Probabilistic Framework for Assessing the Accuracy of Data Mining Tool for Online Prediction of Transient Stability," in IEEE Transactions on Power Systems, vol. 29, no. 1, pp. 377-385, Jan. 2014.