On-line Estimation and Correction of Voltage Stability Index as Slack Nodes Failure

Jundong Duan
Department of Electrical Engineering and Automation of Henan Polytechnic University, Jiaozuo, China
Email: jundongd@hpu.edu.cn

Ju Xiong and Fan Zhou
Xinyang Power Supply Corporation of Henan Electric Power Corporation, Xinyang, China
and
Department of Electrical Engineering and Automation of Henan Polytechnic University, Jiaozuo, China
Email: {Xiong_ju, hpueducn}@sina.com

***Abstract*—Along with the widely application of the Wide—Area Measurement System in power system, voltage instability based on WAMS is becoming all increasingly important worldwide issue. By using the WAMS to collect the measured value of local voltage and current vector directly, we can realize the online estimate and instruction of the voltage stability degree of key node. Use this as a foundation, this paper analyses problems in the phase failure of slack node, puts forward that taking the voltage phase of the node, which has the nearest electrical distance from the slack node, as the reference phase; and according to the least square method based on historical data of WAMS two effective methods to correct and estimate the voltage andcurrent phasor of the key node, can also realize online correction and estimating of the voltage stability of the key node. The simulations show that this method is suitable for the surveillance of online static voltage stability of node and has certain feasibility.**

***Index Terms*—wide-area, measurement system, power system, communication interruption, voltage stability, electrical distance**

I. Introduction

Since the reform and opening up, with the high-speed development of national economy, the social demand for power is growing rapidly. The power system is more and more complicated, developing to the big unit, high voltage and long-distance transmission, to form the massive power grid. It is significant to improve economic benefit and protect the environment for rational utilization of natural resources, but it also brings some new safety operation problems to the power system. Especially since the 1970s, a series of power outage at home and abroad, which led to widespread and long time power outages and caused great economic losses and the disorder[1-2] of social life, are mostly due to the voltage fluctuation. So, adopting reasonable index of voltage stability is of great significance to monitor and forecast voltage stability.

Currently, most methods are to take some of the voltage stability index[3-5] to indicate the stability degree of the node voltage. As the load impedance modulus can be measured, impedance mode index has been used in the power system voltage stability analysis and online voltage stability surveillance to some degree. The key of this kind of problems is to calculate the equivalent impedance of the key nodes of the power grid side, it is difficult to get the measurement data of the whole grid simultaneously online in SCADA/EMS, and data refresh need a long time, so we can do analysis online only according to several typical operation mode and state of the system, which has some defects.

In the early 1990s, Scientists developed Phase Measurement Unit (PMU) based on Global Positioning System (GPS), this shows that technologies of synchronized phasor has been basically formed. And contribute to Wide Area Measurement System (WAMS) has been basically formed. With the development and applications of wide-area measurement technology, WAMS can real-time, on-line, accurately measuring and transmission the parameters of the power system coordinate in the same time coordinate, it has provided new data acquisition and measurement for the power system. The system realizes vector measurement, and the data refresh faster than SCADA/EMS, so it provides a good technology platform for estimating equivalent impedance of the key nodes of the grid side.

Reference [7,8] use the measured value of local voltage, current vector collected by WAMS to put forward a kind of index of voltage stability, which can judge the stability degree of the key nodes voltage online. The calculating for local voltage phase of this index uses the voltage phase of slack node as the reference phase, however Reference [1] analyzes from the perspective of scheduling and gets that the communication interrupt, out of getting correct data are one of the reasons of the further expansion of the accidents. On the basis of the above reasons, this paper further researches the phase failure problem of slack node, puts forward that taking the voltage phase of the node, which has the nearest electrical distance from the slack node, as the reference phase, and according to the least square method based on historical data of WAMS two effective methods to correct and estimate the voltage and current phasor of the

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key node, can also realize online correction and estimating of the voltage stability index.

II. Online Correction Method Of Key Node

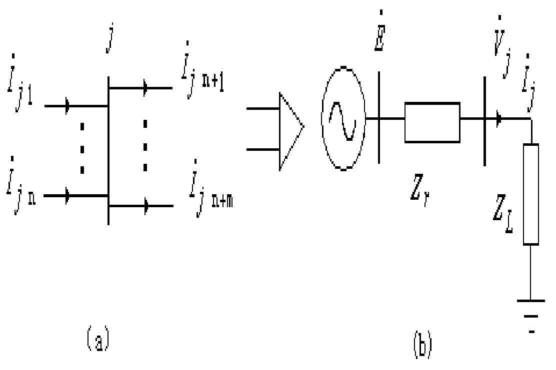

Figure.1 Thevenin Equivalent of Node *j*

Reference [8] analyzed the simplified model of node in Figure 1 (b), deduced and proved with some examples that using the wide-area measurement system (WAMS) can get equivalent impedance modulus of the power grid online:

we consider two cases

case 1：the equivalent impedance of the power grid side is constant

$$\frac{\Delta\dot{V}}{\Delta\dot{I}} = -(R_r + jX_r) = -Z_r \qquad (1)$$

case 2：the equivalent impedance of the power grid side is mutative

$$\frac{\Delta\dot{V}}{\Delta\dot{I}} = R_L + jX_L = Z_L \qquad (2)$$

At time t, set $\dot{V}_t$ as the measured value of voltage vector of key node, and set $\dot{I}_t$ as the corresponding measured value of load current vector. At time t-1, set $\dot{V}_{t-1}$ as the measured value of voltage vector of key node, and set $\dot{I}_{t-1}$ as the corresponding measured value of load current vector. From formula (1) we can get: if the voltage and current changes of key node are mainly due to the load change of the node, the equivalent impedance of the power grid side is :

$$Z_{r\cdot t} = -\frac{\dot{V}_t - \dot{V}_{t-1}}{\dot{I}_t - \dot{I}_{t-1}} \qquad (3)$$

The impedance modulus is:

$$|Z_{r\cdot t}| = \frac{|\dot{V}_t - \dot{V}_{t-1}|}{|\dot{I}_t - \dot{I}_{t-1}|} \qquad (4)$$

Use the ratio of load impedance modulus $|Z_{L\cdot t}|$ and equivalent impedance modulus of the power grid side $|Z_{r\cdot t}|$ as the index of the voltage stability degree of the node[7,8]. Namely

$$k = \frac{|Z_{L\cdot t}|}{|Z_{r\cdot t}|} = \left|\frac{\dot{V}_t}{\dot{I}_t}\right| / \left|\frac{\dot{V}_t - \dot{V}_{t-1}}{\dot{I}_t - \dot{I}_{t-1}}\right| \qquad (5)$$

The calculating for measured value of voltage vector in formula (3), (4), (5) uses the voltage phase of the slack node as the reference phase.

III. Estimation And Correction Of Online Voltage Stability Index Of The Key Nodesas Slack Nodes Phase Failures

As the power system become much more dependent on communication network, the reliability of information and communication system will be an important factor that impacts the stability of modern power system. A key communication equipment malfunctions will make the whole power system go dead, and lead to the lost of controllability and monitoring of the power system[10,11]. Due to the slack node is the reference node of the whole power grid, other nodes collect data from the slack node. If communication breaks down at the slack node, it will cause phase failure of slack node, we are also unable to utilize above method to realize online correction of the voltage stability of the key node. This paper proposes the following two methods to deal with this problem.

A On-line Correction of Voltage Stability Index of Key Node Based on Auxiliary Node

On the basis of the above reasons, this paper puts forward using voltage phase of auxiliary node to replace voltage phase of slack node as the reference phase, use voltage phase of auxiliary node to revise voltage phase of local node, the revised voltage phase of local node is described as follows:

At time t, set $\hat{V}_t$ as the correction of voltage vector of key node, and set $\hat{I}_t$ as the corresponding correction of load current vector. At time t-1, set $\hat{V}_{t-1}$ as the correction of voltage vector of key node, and set $\hat{I}_{t-1}$ as the corresponding correction of load current vector; If the voltage and current changes of key node are mainly due to the load change of node, the equivalent impedance of the key nodes of the power grid side is:

$$Z_{r\cdot t} = -\frac{\hat{V}_t - \hat{V}_{t-1}}{\hat{I}_t - \hat{I}_{t-1}} \qquad (6)$$

The impedance modulus is

$$|Z_{r\cdot t}| = \frac{|\hat{V}_t - \hat{V}_{t-1}|}{|\hat{I}_t - \hat{I}_{t-1}|} \qquad (7)$$

The reference phase of voltage phase in formula(6),(7)is not unique, the voltage phase angle of key node varies with the voltage phase change of different reference nodes.

We can get an correctional index of the voltage stability degree of key node by the formula (5). Namely:

$$k^* = \frac{|Z_{L\cdot t}|}{|Z_{r\cdot t}|} = |\frac{\hat{V}_t}{\hat{I}_t}| / |\frac{\hat{V}_t - \hat{V}_{t-1}}{\hat{I}_t - \hat{I}_{t-1}}| \quad (8)$$

Simplify the power system, view from the load node,equate the power system to three-node system, as shown in Figure 2:

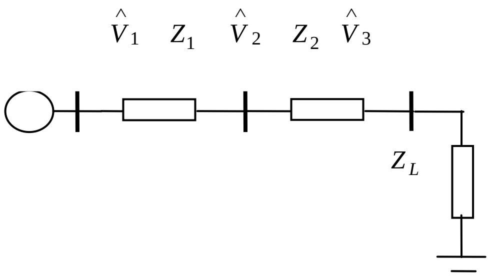

Figure. 2 Equivalent Three-node System

In Figure 2, $\hat{V}_1$ is the system equivalent potential (node 1 is the slack node), Z_1 and Z_2 are system equivalent impedance, $\hat{V}_2$ is the voltage of auxiliary node, $\hat{V}_3$ is the load voltage, Z_L is the load impedance.

Set node 3 as the key node, .voltage phase of slack node is the reference phase, from formula (5) we can get:

$$k = \frac{|Z_L|}{|Z_1 + Z_2|} \quad (9)$$

Set the voltage phase of auxiliary node as the reference phase, from formula (6) we can get:

$$k^* = \frac{|Z_L|}{|Z_2|} \quad (10)$$

From formula (7),(8) we has:

$$d = \frac{|Z_1 + Z_2|}{|Z_2|} \quad (11)$$

d represents the proximity degree of value k^* and value k , d is getting smaller when value k^* is more closer to value k . When Z_1 is kept to a minimum, value k^* is the closest to value k , the equivalent impedance from the slack node to the key node is the closest to the equivalent impedance from the auxiliary node to the key node at this time, namely, the electrical distance from this auxiliary node to the slack node is the closest. When communication interruption and phase failure of the slack node happen, we can use the voltage phase of the auxiliary node which has the nearest electrical distance from the slack node as the reference phase.

B On-line Estimation of Voltage Stability Index Based on the WAMS Historical Data

When the communication interrupt and phase failure of the slack node, Through the historical data by WAMS, it was found that dispatcher can fit a variation trend of the curve to the historical data, used the curve to predict future data.

Set (x_i, y_i) $(i = 1, 2, \ldots, n)$ as a group of measurement data. Now we could adopt some approximate expression $y = f(x)$ to reflect the relationship between variables x and y . Then we could used extrapolation to look for the approximate value of y_{n+1} when $x_i = x_{n+1}$.

Supposing selected known function $\varphi(x)$ approach $f(x)$. δ_i is defined as t the error of between $\varphi(x_i)$ and $f(x_i)$ .Namely,

$$\delta_i = \varphi(x_i) - f(x_i) \quad (i = 1, 2, \ldots, n) \quad (12)$$

The summation of quadratic of formula (12) error is

$$S = \sum_{i=1}^{n} \delta_i^2 = \sum_{i=1}^{n} [\varphi(x_i) - f(x_i)]^2 \quad (13)$$

When the above formula to minimum, the so-called least squares.

We could describe the general $y = f(x)$ by $(x_1, y_1), (x_2, y_2), \ldots (x_n, y_n)$ and polynomial of degree m

$$\varphi(x) = a_0 + a_1 x + a_2 x^2 + \ldots + a_m x^m \quad (14)$$

Where, m<n.

According to (13) we could get the coefficient of(14), that is, get the minimum of the function below.

$$S = \sum_{j=1}^{n} [f(x_j) - a_0 - a_1 a_j - \ldots - a_m x_j^m]^2 \quad (15)$$

Where, S is the function of $m+1$ arguments with $a_0, a_1, \ldots, a_m$.

We can respectively take the derivatives with respect to $a_0, a_1, \ldots, a_m$,and then let these derivatives be zero, then we can get $m+1$ equations.

$$-2\sum_{j=1}^{n} [f(x_j) - a_0 - a_1 a_j - \ldots - a_m x_j^m] x_j^k = 0 \quad (16)$$

Where, $(k = 0, 1, \ldots, m)$.

We can expansion above(14):

$$a_0 \sum_{j=1}^{n} x_j^k + a_1 \sum_{j=1}^{n} x_j^{k+1} + \ldots + a_m \sum_{j=1}^{n} x_j^{k+m} = \sum_{j=1}^{n} y_j x_j^k \quad (17)$$

Where, $(k = 0, 1, \ldots, m)$;

$$y_i = f(x_i)\ .;$$

Or simply：

$$s_k = \sum_{j=1}^{n} x_j^k \tag{18}$$

$$v_k = \sum_{j=1}^{n} y_j x_j^k \tag{19}$$

Then, we can expansion(17)：

$$\begin{bmatrix} s_0 & s_1 & \cdots & s_m \\ s_1 & s_2 & \cdots & s_{m+1} \\ \vdots & \vdots & \ddots & \vdots \\ s_m & s_{m+1} & \cdots & s_{2m} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_m \end{bmatrix} = \begin{bmatrix} v_0 \\ v_1 \\ \vdots \\ v_m \end{bmatrix} \tag{20}$$

Where, the coefficient matrix of (20) is a symmetric matrix. We can prove this matrix is nonsingular matrix. So the (20) has a unique solution.

When the communication of slack node is interrupted at time t. we can get N historical data of voltages and current of the key node by the WAMS. For example, voltage amplitude V_t , voltage phase δ_t , current amplitude I_t , current phase angle ψ_t $(t = 1, 2, ..., n)$ .Then we could get estimated voltage amplitude $\hat{V}_{t+1}$, voltage phase $\hat{\delta}_{t+1}$, current amplitude $\hat{I}_{t+1}$ and current angle $\hat{\varphi}_{t+1}$ at t+1 time by the least square method based on historical data of the key node.

Then according to (3),we can use the ratio of load impedance modulus $|Z_{L\cdot t}|$ and equivalent impedance modulus of the power grid side $|Z_{r\cdot t}|$ as the estimated index of the voltage stability degree of the node[7,8]. Namely

$$\hat{k} = \frac{|Z_{L\cdot t}|}{|Z_{r\cdot t}|} = \left|\frac{\hat{V}_{t+1}}{\hat{I}_{t+1}}\right| / \left|\frac{\hat{V}_{t+1} - V_t}{\hat{I}_{t+1} - I_t}\right| \tag{21}$$

According to the above methods, We can use the voltage phasor and current phasor as historical data at time t+1,then predict $\hat{k}$ of the key nodes at time t+2. According to the impedance mold criterion, it is known that when $\hat{k}$ is greater than 1, the system is stable, and when the $\hat{k}$ more closer 1, the margin of voltage stability is smaller and the node is more vulnerable.

IV. Simulations Analysis

A Simulation and Test of K Based on Auxiliary Node

Tab.1 uses the 8 generators 36 nodes of PSASP to simulate, choose node 16 as the research node, change the load of node 16, keep the power factor of node 16 and other nodes constant (power factor is 0.9), the slack node bears the increase of the load, keep the growing of the load until the computing become non–convergent.

TABLE I.
Results of Slack Node Bearing Load Growth

P_{16}	V_m	Slack Node k_1	Auxiliary Node k_{24}^*	Relative Error (%)	Auxiliary Node k_2^*	Relative Error (%)	Auxiliary Node k_{23}^*	Relative Error (%)	Auxiliay Node k_9^*	Relative Error (%)
4.5	0.9581									
5	0.9386	1.3322	1.4971	12.38	2.2111	65.97	2.3145	73.74	2.4228	81.86
5.5	0.915	1.2396	1.3814	11.44	1.9925	60.74	2.1199	71.01	2.2103	78.31
6	0.8838	1.1586	1.2767	10.19	1.7865	54.19	1.9429	67.69	2.0153	73.94
6.5	0.8252	1.0469	1.1215	7.13	1.5023	43.49	1.704	62.77	1.7521	67.36
6.55	0.8029	1.0788	1.1456	6.19	1.4466	34.09	1.7217	59.59	1.755	62.68

Tab.2 uses the 8 generators 36 nodes of PSASP to simulate, choose node 16 as the research node, change the load of node 16, keep the power factor of node 16 and other nodes constant (power factor is 0.9), the slack node and G3 bear the increase of the load according to a certain proportion, keep the growing of the load until the computing become non–convergent.

TABLE II.
RESULTS OF SLACK NODE AND G3 BEARING LOAD GROWTH ACCORDING TO A CERTAIN PROPORTION

P_{16}	V_m	Slack Node k_1	Auxiliary Node k^*_{24}	Relative Error (%)	Auxiliary Node k^*_2	Relative Error (%)	Auxiliary Node k^*_{23}	Relative Error (%)	Auxiliay Node k^*_9	Relative Error (%)
4.5	0.9581									
5	0.9386	1.3322	1.4971	12.38	2.2111	65.97	2.3145	73.74	2.4228	81.86
5.5	0.915	1.2396	1.3814	11.44	1.9925	60.74	2.1199	71.01	2.2103	78.31
6	0.8838	1.1586	1.2767	10.19	1.7865	54.19	1.9429	67.69	2.0153	73.94
6.5	0.8252	1.0469	1.1215	7.13	1.5023	43.49	1.704	62.77	1.7521	67.36
6.55	0.8029	1.0788	1.1456	6.19	1.4466	34.09	1.7217	59.59	1.755	62.68

In Table 1,2 and Fig.3,4, k_1 is obtained using the voltage phase of slack node as the reference phase; k^*_{24} is obtained using the voltage phase of node 24 as the reference phase; k^*_2 is obtained using the voltage phase of node 2 as the reference phase; k^*_{23} is obtained using the voltage phase of node 23 as the reference phase; k^*_9 is obtained using the voltage phase of node 9 as the reference phase.

The simulation shows the variation curves between value k and power increment when the load increase. The variation results of curves show that the change trends of value k choosing the voltage phase of slack node or other auxiliary nodes as the reference phase respectively are consistent. When the voltage reaches static stability limit and power increment reaches limit, the value k tends to one, which shows the voltage stability degree of the key node approximately in the current condition. When communication interruption and phase failure of the slack node happen, we can use the voltage phase of the auxiliary node which has the nearest electrical distance from the slack node as the reference phase. The value k^*_{24} is the closest to value k_1, so we can use the voltage phase of node 24 which has the nearest electrical distance from the slack node as the reference phase. And we can sort the auxiliary nodes which can replace the slack node by proximity degree between the value k^* and value k, the order from good to bad is: the node 24, the node 2, the node 23, the node 9.

B Simulation Test of Forecast of K Based on WAMS

This example is also using the Power System Analysis Software Package (PSASP) to simulation and test the accuracy of the predicted results in 8 generator and 36 nodes system. We simulated the test system, set node 16 as the research. node. And use 7 sampling data to calculate model parameter and conclude the prediction model and predict the next moment data by using curve fitting of least square method. PMU could constantly gather new data. When adding a new data, it uses the latest seven data to conclude the new model parameters and predict future data with the latest prediction model. We could set conventional continuous flow calculation via PSASP, gets voltage amplitude, voltage phase , voltage angle, and current amplitude, current phase and current angle of the node 16 as the data from the PMU.

In the following tables, V_{16} , δ_{16} are the voltage amplitude and calculation value of voltage phase angle of node 16;. I_{16} , ψ_{16} are the current amplitude and calculation value of current phase angle of node 16; $\hat{V}_{16}$, $\hat{\delta}_{16}$ are the voltage amplitude and predictand of voltage phase angle. $\hat{I}_{16}$, $\hat{\psi}_{16}$ are the current amplitude and predictand of current phase angle.

Tab 3 describes that load power factor of node 16 keeps $\cos\phi$ =0.9 (lag), and load power of other nodes is constant, changes load power of 16 node. We could get the voltage amplitude and voltage phase angle , current amplitude and current phase angle. of node 16 by PSASP. Set the slack node as reference node.

TABLE III.
CALCULATION OF VOLTAGE,CURRENT PHASE COS ϕ =0.9(LAGGED)

Time	P_{16}	V_{16}	δ_{16}	I_{16}	ψ_{16}
1	1.0	1.0456	-11.314	1.8598	-37.9812
2	1.5	1.036	-14.541	2.1117	-41.3716
3	2.0	1.0261	-17.878	2.3702	-44.8571
4	2.5	1.0151	-21.352	2.6366	-48.4720
5	3.0	1.0030	-24.996	2.9123	-52.2557
6	3.5	0.9897	-28.855	3.1995	-56.2589
7	4.0	0.9749	-32.995	3.5008	-60.5527

Tab 4 describes that load power factor of node 16 keeps cos ϕ =0.9 (lag), and load power of other nodes is constant,. Compare computed value of the voltage amplitude and voltage phase angle of node 16 by PSASP with prediction of the voltage amplitude and voltage phase angle of node 16. According to seven data in tab 3, we could get the predicted value at time 8 with predicted method of this paper. Calculating step by step until calculation un-convergence.

TABLE IV.
COMPARISON CALCULATION AND PREDICTION OF VOLTAGE PHASE COS ϕ =0.9 (LAGGED)

Time	P_{16}	V_{16}	$\hat{V}_{16}$	Relative Error (%)	δ_{16}	$\hat{\delta}_{16}$	Relative Error (%)
8	4.5	0.9581	0.9586	-0.05	-37.5111	-37.4254	0.23
9	5.0	0.9386	0.9405	-0.20	-42.573	-42.2037	0.87
10	5.5	0.915	0.9205	-0.60	-48.482	-47.3684	2.29
11	6.0	0.8838	0.8985	-1.66	-56.007	-52.9611	5.44
12	6.5	0.8252	0.8742	-5.94	-69.636	-59.0231	15.24
13	.6.55	0.8029	0.8716	-8.56	-74.759	-59.6568	20.2

Tab 5 describes that load power factor of node 16 keeps cos ϕ =0.9 (lag), and load power of other nodes is constant,. Compare computed value of the current amplitude and current phase angle of node 16 by PSASP with prediction of the current amplitude and current phase angle of node 16.

TABLE V.
COMPARISON CURRENT PHASE OF CALCULATION AND PREDICTION COS ϕ =0.9 (LAGGED)

Time	P_{16}	I_{16}	$\hat{I}_{16}$	Relative Error (%)	ψ_{16}	$\hat{\psi}_{16}$	Relative Error (%)
8	4.5	4.0318	3.8169	5.33	-63.6657	-65.1542	-2.34
9	5.0	4.1666	4.1503	0.30	-70.5260	-70.1260	0.57
10	5.5	4.5507	4.5026	1.06	-76.7086	-75.5131	1.56
11	6.0	5.0051	4.8758	2.58	-84.6321	-81.3630	3.86
12	6.5	5.7080	5.2717	7.64	-99.2098	-87.7233	11.58
13	.6.55	5.9246	5.3126	10.33	-104.7866	-88.3893	15.65

Tab 6 describes that load power factor of node 16 keeps cos ϕ =0.9 (lag), and load power of other nodes is constant. According to the corresponding the predicted value of voltage and current, we could set $\hat{Z}_{r16}$ as the equivalent modulus of impedance of node 16 and set $\hat{Z}_{L16}$ as load modulus of impedance,so,we could get $\hat{k}$ by (19).

TABLE VI.
RESULTS OF COS ϕ =0.9 (LAGGED)

P_{16}	$\hat{Z}_{r16}$	$\hat{Z}_{L16}$	$\hat{k}$
4.5			
5.0	0.1692	0.2266	1.3394
5.5	0.1603	0.2044	1.2755
6.0	0.1507	0.1843	1.2227
6.5	0.1408	0.1658	1.1781
6.55	0.1353	0.1641	1.2121

From the above table we can see, voltage amplitude, phase angle, current amplitude, phase angle, practical calculation value and predicted value basically are consistent with very small relative error. Among them, due to smaller fluctuation, the prediction results of voltage amplitude and current amplitude are accurate but voltage and current phase angle relatively poor. Overall, the proposed algorithm can estimate the voltage stability index of a key node by using voltage and current phasor predictions. When the voltage is close to the collapse point, the index is close to 1. We can see the change trend and simulation is consistent, which can be used as a scheduling personnel in determining the degree of voltage stability index.

V CONCLUSION

Theoretical analysis and simulation results show that when the slack node communication interrupts and leads to slack node phase fail, use the method this paper brings up that using auxiliary node to replace slack node and collect the key nodes based on the WAMS historical data. And combining with least squares curve fitting calibration method we respectively correct and estimate online voltage stability index of the current key nodes. These two kinds of processing techniques can correctly reflect the voltage stability state of key nodes and the tendency is consistent, which can effectively solve the problem that slack node communication fault brings slack node voltage phase failure and provide a kind of effective treatment method for scheduling personnel with certain feasibility and practical significance.

REFERENCES

[1] Liu Yongqi, XIE Kai. “Analysis on Blackout of interconnected North America Power Grid occurred on Aug.14, 2003, from the viewpoint of power system dispatching,” *Power System Technology*, 2003, 28(8):10-15.

[2] Hu Xuehao, “Rethinking and enlightenment of large scope blackout in interconnected North America Power Grid,”. *Power System Technology*, 2003,27(9):2-6.

[3] Taylor C W, *Power System Voltage Stability*, NewYork:McGraw-Hill,Inc,1994.

[4] Zhou Shuangxi, Zhu Lingzhi, Guo Xijiu, et al. *Power System Voltage Stability and Its Control*, Beijing:, China Electric Power Press, 2004.

[5] Lu Baochun, Wang Chengshan, Guo Zhizhong, et al. “Judgement of Static Voltage stability in Power System,”. *Journal of Harbin Institute of Technology*, 2002, 34(2):225-227, 231.

[6] Liu Zhuo, “Voltage Stability Evaluation Based on Node Load Impedance Analysis,”. *Proceedings of the CSEE*, 1999, 19(11): 64-68.

[7] Duan Jundong, Sun Yankai, Yin Xiugang, “Voltage Stability’s Online Prediction Using WAMS,”.*High Voltage Engineering*, 2009, 35(7):1748-1752.

[8] Duan Jundong, Guo Zhizhong, “Research of on-line assessment of voltage stability,”.*Proceedings of the CSEE*,2005, 25(25): 199-202.

[9] Duan Jundong, Guo Zhizhong, “A New Method for on-line Determination of the Capability Curves of Voltage Stability,”.*Proceedings of the CSEE*, 2006, 26(04): 113-118.

[10] Xing Ningzhe, Yan Haifeng, “Research on the reliability of electric power telecommunication system,”. *Telecommunications for Electric Power System*, 2007, 28(176): 26-30, 38.

[11] .Su Bo, Qi Miaomiao, “A Method of Reliability Evaluation for Power Communication Network,”. *Telecommunications for Electric Power System*, 2010, 31(215): 5-8, 14.

[12] Duan Jundong, Liang Jian, “The Influence of Various Loads to Node Voltage in Power System,” *Intelligent System Design and Engineering Application(ISDEA)*, 2010 International Conference on Digital Object Identifier: 10.1109/ISDEA. 2010.412 , Publication Year: 2010 , Page(s): 669-672

[13] .Duan Jundong, Zhu Shanshan, “The Effect of OLTC on Static Voltage Stability Limit,” *Power and EnergyEngineering Conference (APPEEC)*, 2011 Asia-

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Jundong Duan (Mengzhou, Henan, China, 1969) received the B.E. degree from Zhengzhou University at Zhengzhou, Henan, China, in 1992, the M.S. degree from Wuhan University, Wuhan, Hubei, China, in 2002, and the Ph.D. degree from Harbin Institute of Technology, Harbin, China, in 2006, all in electrical power system and automation.

He is a associate professor at the Electrical Engineering and automation Department of Henan Polytechnic University, Jiaozuo, Henan, China. He undertakes Ph.D Foundation of the university. His published articles: Duan Jundong, Guo Zhizhong, "A New Method for on-line Determination of the Capability Curves of Voltage Stability,".*Proceedings of the CSEE*, 2006, 26(04): 113-118;
Duan Jundong, Guo Zhizhong, "Research of on-line assessment of voltage stability,".*Proceedings of the CSEE*,2005, 25(25): 199-202.; and Duan Jundong, Sun Yankai, Yin Xiugang, "Voltage Stability's Online Prediction Using WAMS,".*High Voltage Engineering*, 2009, 35(7):1748-1752.
His main interests are power system operating, analyzing and controlling

Dr. Duan is the member of CHINESE SOCIETY FOR ELECTRICAL ENGINEERING (CSEE). He acquired the accessit of Coal Science and Technology Society In 2009.

Ju Xiong (Xinxian, Henan, China, 1970) received the B.E. degree in power system and automation from Zhengzhou University at Zhengzhou, Henan, China, in 1992.

He has been the deputy director and director of electric dispatching office of Xinyang Power Supply Corporation of Henan Electric Power Corporation. Now, he is the chairman of Production Technology Department of Xinyang Power Supply Corporation of Henan Electric Power Corporation. His published articles: Xin Li, Ju Xiong, Quan Dong, Dayong LU, "Summary of relay scheme which trips bus-tie," *Power System Protection and Control* 2010,38(22):243-246. His main interests are power system dispatching and relaying, automated management. His current research interest is power system operating and technique management of equipment.

Mr. Xiong is a Senior Engineer and the member of HENAN SOCIETY FOR ELECTRICAL ENGINEERING. He is the C-level technical expert of He undertaken the technology project: "Faultlocation of Fiber-optic Cable Based on GPS", and acquired the third prize of science and technology progress prize of Henan province and the first prize of science and technology progress prize of Xinyang city.

Fan Zhou (Shayang, Hubei, China, 1987) received his the B.E. degree in electrical engineering and the automation from Henan Polytechnic University, Jiaozuo, Henan, China, in 2009. His main interests are power system operating, analyzing and controlling.