Research on Grid State Vulnerability Assessment Method based on The Margin of Voltage Stability

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Abstract. The vulnerability of power system is always one of hot areas, which was concerned by many researchers in last several decades. In this paper, a state vulnerability assessment model and index based on the margin of voltage stability is introduced, namely comparing the margin of the actual operating voltage and the critical voltage to assess the state vulnerability of load nodes. And the effect of power sources access to the grid is also considered, which make the system of state vulnerability assessment to be more perfect to identify potential weaknesses of the grid. Combing the simulation results of IEEE-39 node system, it is verified the accuracy and superiority of the assessment model. In this way a theoretical reference is provided for the further study on reasonable planning power network and dispatching.

Introduction

In recent years, the fast development of new energy, including wind power development in China shows the characteristics of the large-scale centralized development, and through the extra-high voltage circuit to the load center, its application has received wide attention from all over the world. However, due to the randomness and intermittent, the safe operation of power grid has been brought a lot of uncertainty, which cause blackouts accidents occur frequently[1-9]. It is worthy of special attention for such load nodes. Vulnerability is one of the hot research topic of the smart grid. State vulnerability assess the power system vulnerability from the angle of the system running state. It not only can put forward reasonable and effective improvement measures for possible weaknesses in time, but also provide valuable data for safe and stable operation of power grid and early warning.

The main research aspects of state vulnerability, such as the energy function method and the assessment method based on probability and risk theory, are analyzed. The literature[10-14], from the angle of the energy function to assess state vulnerability, although a relatively small amount of calculation, but the model is simple and the result is not very accurate. The literature[15-21] define the probability model and risk index to quantitatively evaluate the vulnerability of power system, but the risk index of power system often changes with the running state, the risk assessment does not reflect the situation. These methods are mainly used in the power grid failure, should be further improved. Although the literature[22-26] based on the critical voltage index to assess the state vulnerability of load node, but doesn't take account into the condition of power access to the grid.

This paper proposes applied the assessment model and index based on the margin of voltage stability into the study of state vulnerability, namely comparing the margin of the actual operating voltage and the critical voltage to assess the state vulnerability of load nodes, this comprehensive vulnerability analysis model combines structural vulnerability with state vulnerability, Finally simulation results through IEEE 39-node system illustrate that the method is effective and practicable.

The Model of State Vulnerability

This paper introduced the concept of voltage stability margin, based on voltage stability margin index to analyze the state vulnerability of load nodes.

For each load node, the power system other than the load node can be equivalent to a voltage source and a impedance, the system is simplified into two nodes system[27]. And if a power sources access to the load node, the equivalent electrical network model after three node system as shown in figure 1.

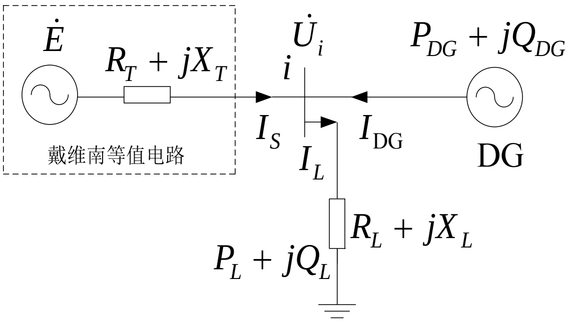

Figure1． The thevenin equivalent system of the load node access to a generator

In Figure 1, $\dot{E}$ is the potential of the thevenin equivalent, whose phase angle is 0. The impedance of the thevenin equivalent is $Z_T\angle\theta = R_T + jX_T$. The voltage amplitude and phase of lode node are respectively U_i 、 θ. The power load is $\dot{S}_L = P_L + jQ_L$. The active power and reactive power of the new power source access are respectively P_{DG} 、 Q_{DG}.

$$P_L + jQ_L = \dot{U}_L \frac{\dot{E}^* - \dot{U}_L^*}{R_s\text{-}jX_s} + \left(P_{DG} + jQ_{DG}\right). \tag{1}$$

Due to the stability critical point, the voltage have unique solution:

$$V_{C\_i} = \sqrt{E^2/2 - \left(P_L - P_{DG}\right)R_s - \left(Q_L - Q_{DG}\right)X_s}. \tag{2}$$

Therefore, define the state vulnerability index:

$$\omega_{ri} = \frac{1}{Y_i} = \frac{V_{C\_i}}{V_i - V_{C\_i}}. \tag{3}$$

Wherein，Y_i is margin of the actual operating voltage distance threshold about the node，V_i s the operating voltage of node i ,V_{C_i} is the critical voltage of load node.

In order to make the state vulnerability index is more clear, normalized state vulnerability indexes, as shown in the formula (4).

$$\overline{\omega}_{ri} = \frac{\omega_{ri} - \omega_{ri\_\min}}{\omega_{ri\_\max} - \omega_{ri\_\min}}. \tag{4}$$

Wherein, $\omega_{ri\_\max}$ 、 $\omega_{ri\_\min}$ represent the index of state vulnerability of node i after the normalization .By formula (4), $0 < \overline{\omega}_{ri} < 1$,when the $\omega_{ri} = \omega_{ri\_\max}$, $\overline{\omega}_{ri} = 1$, when the $\omega_{ri} = \omega_{ri\_\min}$, $\overline{\omega}_{ri} = 0$.

Concluded from formula (4), the greater state vulnerability index is, the weaker the load node is, the more unstable running state is. Conversely, indicating that the lower the importance of node in the grid topology is.

Numerical Examples

Choose the IEEE - 39 node system as exampleof analysis, the specific parametersin literature [28], as shown in figure 2.

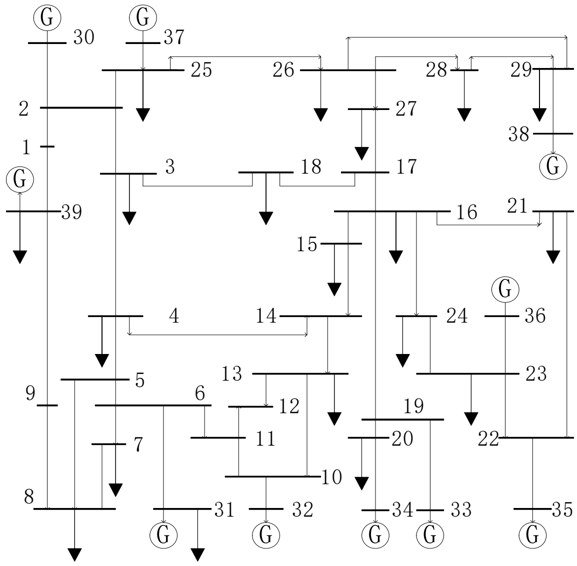

Fig.2. Diagram of IEEE-39 node power system

When a power source access to the load node 4, calculate the state vulnerability of the 17 load nodes in the IEEE39 node-power system respectively, sort the results in accordance with the method described in this paper in descending order, as shown in table 1.

Tab.1 The top six state vulnerability indexes sorting of load nodes when power source access

rank	Load node	ω_{ri}	$\tilde{\omega}_{ri}$
1	12	2.44260	1.00000
2	28	2.06213	0.84424
3	26	1.83497	0.75124
4	8	1.52476	0.62424
5	7	1.17164	0.43873
6	15	1.14366	0.42737

From the above table 1, it can be seen that the state vulnerability normalized of node 15 is 0.42737, far less than other nodes, whose operating condition is relatively stable. the state vulnerability normalized of node 12 and node 28 are respectively 1 and 0.84424, relatively large, represent the node is vulnerable.

In order to verify the practicability and validity of assessment method described in this paper, choose the target node and gradually increase its load power, then using the method of literature [22] to analyze the load capacity of load node by voltage change situation by recording the change of the load node voltage, as shown in figure 3. The results obtained are as shown in table 2.

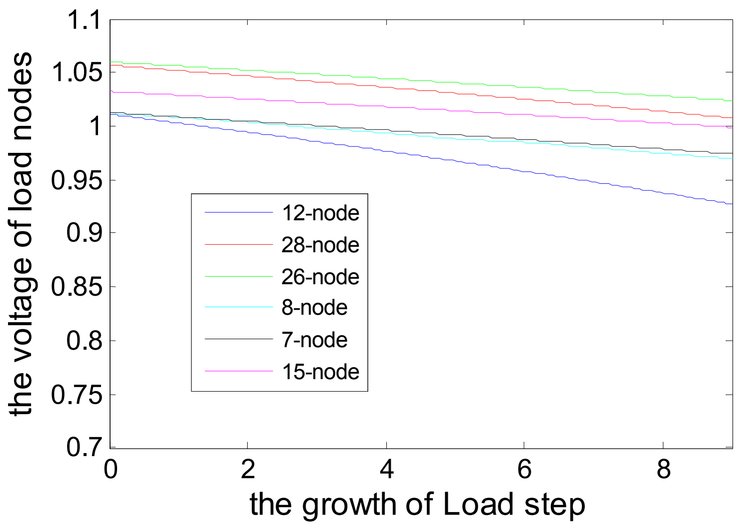

Fig.3 the voltage drop of lode nodes

Tab.2 The sort of voltage drop rate of load nodes based on the load growth

rank	Load node	ω_{ri}	$\tilde{\omega}_{ri}$
1	12	0.08305	1.00000
2	28	0.04644	0.55923
3	26	0.03395	0.40881
4	7	0.03818	0.45970
5	8	0.03768	0.45375
6	15	0.03245	0.39075

Among them the state vulnerability normalized of node 15 is 0.39075, relatively small, the state vulnerability normalized of node 12 is 1,which is the largest number of all indexes.

Compare table 1 and table 2, The sorting results are basically identical, which proves the accuracy of the method described in this article.

Conclusions

This paper put forward the state vulnerability assessment model and index based on the margin of voltage stability, which considers the effect of power sources access, and make the system of state vulnerability assessment to be more perfect to identify potential weaknesses of the grid. From the perspective of voltage stability to evaluation node resist the ability of the chain fault or disturbance. In the end by IEEE39 node system simulation, the rationality and effectiveness of this assessment model is verified.

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