Energy and Power Engineering, 2013, 5, 902-905
doi:10.4236/epe.2013.54B173 Published Online July 2013 (http://www.scirp.org/journal/epe)

The Research of Transmission Network Planning Based on System's Self-organized Criticality

Zheng-yu Shu, Chang-hong Deng, Wen-tao Huang, Yi-xuan Weng
Wuhan University, Hubei, Wuhan, China
Email: Shuzhengyu@126.com

Received March, 2013

ABSTRACT

This paper presents a new line importance degree evaluation index for the propagation of cascading failures, which is used to quantify transmission lines for cascade spread. And propose an improved capital matching model, according to the results of the evaluation, to enhanced robustness of the power system. The simulation results proved that in the case of the same system, the new model can inhibit cascade spread, reduce the probability of large-scale blackouts.

Keywords: Transmission Line Assessment, Self-organized Criticality, Cascade, Load Distribution

1. Introduction

The power system is a typical extended dissipative system, such a system will evolve to reach self-organized criticality[1], its important feature is the scale of the fault occurs in the system and the corresponding probability distribution follows the power law characteristic. This phenomenon also been verified in many domestic and international large-scale grid statistics [2-5].

In response to this phenomenon, the researchers analyzed, according to the cascading failures model, the self-organized critical characteristics in the power grid. The results show, for the power system, in addition to the network topology, the load rate factor of the system for grid characteristics of self-organized criticality is particularly important. Reference [6, 7], respectively, for the system average load rate and load rate heterogeneity characteristics analysis, where in [6] proposed the concept of a uniform load distribution, assuming that the active power flow of each line of the system and the corresponding transmission limit into a uniform rate. And pointed out that the higher the rate of the average load of the system, the closer to self-organized criticality, the higher the chance of large-scale cascade. In contrast, if the load rate is lower, the system occurs cascade chance also lower. Reference [7], which based on entropy theory, analysis the relationship between load rate heterogeneity and the self-organized criticality of the power grid. The simulation results prove, the distribution of the entropy has an important impact on the scale of the cumulative probability of blackouts, with the trend of an increase in entropy, the power grid from non-self- organized critical state transition to self-organized criticality.

The above studies have indicated that the system load rate will directly affect the power system cascade probability and its scale. However, in reality, the capital of transmission lines as well as transmission limit of lines, can not raise unlimited. Therefore, how to plan the grid investment makes the system's load rate distribution optimal are the main issues that need to be addressed. In view of this, we propose a new evaluation index to quantify the importance of transmission lines, and based on the assessment results to optimize investment, In order to improve the robustness of grids, reduce the probability of large-scale failure.

2. SOC-PF Model of Self-organized Criticality

In this paper, we use SOC-PF model for system's self-organized criticality simulation [7]. Its Concrete steps as described below:

1) Loading the parameters for flow calculation and the transmission limit of each line.

2) Increase the load of a node randomly and recalculate the power flow of the grid.

3) Checking whether there is flow of lines over the transmission limit (the capital of the line), and if so, go to step 4; otherwise return to step 2.

4) Cut off the line which is beyond transmission limit, and determine whether there is disconnected from the neighboring lines of hidden faults caused.

5) If the system has been cut into two or more silos, first processing Islands problem. If no silos problem, judged whether the load is cut, if there is go to step 6, and if not, to modify the network topology, the process

returns to step 2.

6) Statistics the loss load of blackouts, the end.

3. Match Model Based on Spread Betweenness

3.1. Spread Betweenness

Evaluate the importance of the transmission lines from the direction of the network topology is complex network theory's application hot spots in the power system. Mainly from a static perspective of the components for the overall performance of the system, recognize the weak links in the grid. This identification results similar to the static N-1 calibration of the power system. However, the cascading failure of the power network is a dynamic process. When the flow of the grid has changed, such static assessments can not be fully reactive the degree of importance of a bus or line[8-11]. So we propose a new assessment index to quantify transmission line's impor- tance from cascade spread angle. The formula of cascade spread betweenness (hereinafter referred to as spread be- tweenness) is as follow:

$$L^G(e_{ij}) = \sum_{e_{mn}\in G'} \left|\Delta L_{ij}(e_{mn})\right| \tag{4}$$

In formula (4), $L^G(e_{ij})$ is spread betweenness of transmission line e_{ij}, its value equal the sum of the generated-load in the other branches when e_{ij} has been cut from the system. $\Delta L_{ij}(e_{mn})$ is the generated-load on transmission line e_{mn}, when e_{ij} has been cut from the system, its formula as below equation(5):

$$\Delta L_{ij}(e_{mn}) = y_{mn}(X_{mn} Z_{ij} X_{ij}^T) \tag{5}$$

In this formula, y_{mn} is the admittance of transmission line e_{mn}, Z_{ij} is impedance matrix of the system after e_{mn} has been cut off. X_{ij} is a N-dimensional column vector, that the I-th Element equals 1 and the J-th Element equals -1. X_{ij} could be described as follow:

$$X_{ij} = \begin{bmatrix} 0 & \cdots & 1 & \cdots & -1 & \cdots & 0 \end{bmatrix} \tag{6}$$

The physical meaning of $\Delta L_{ij}(e_{mn})$ is the electric current generated by e_{ij}'s fault, when unit current injected from node i and flow out from node j. $L^G(e_{ij})$ is sum of all the generated-current caused by e_{ij}'s fault.

3.2. Improved Match Model

Seen by the physical meaning of the spread betweenness, the more disturbances transfer to the grid as if the higher spread betweenness line failed. So, in the fault spread process, we should try to avoid higher spread betweenness transmission lines arise overload fault[12-15]. Therefore, in this paper, we propose a new capital match model in order to optimize the redundancy capacity configuration. Improved capital match model can be expressed as:

$$F_{ij}'^{\max} = \left(1+\alpha\frac{L^G(e_{ij})}{L^G_{avg}(e_{ij})}\right)F_{ij,0} \tag{7}$$

$F_{ij}'^{\max}$ and $F_{ij,0}$, respectively, are the transmission limit as well as steady-state flow of transmission line e_{ij}. α is the tolerate coefficient for the system, that represent the capital redundancy of the transmission lines in the system. $L^G_{avg}(e_{ij})$ is the average value of spread betweenness of transmission lines in the system :

$$L^G_{avg}(e_{ij}) = \frac{1}{m}\sum_{e_{ij}\in G} L^G(e_{ij}) \tag{8}$$

4. Simulation

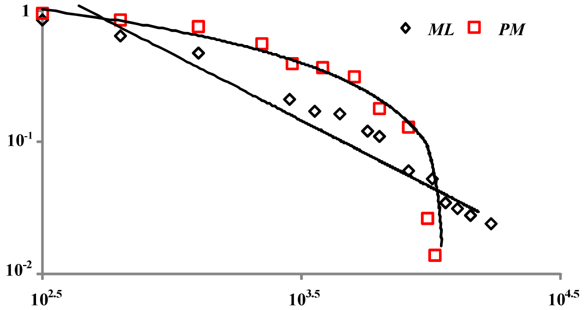
4.1. Self-organized Criticality of Electric Power Network in Improved Matching Model

This paper sets up load factor of transmission line using traditional load-capacity model and improved matching model under the example of IEEE118, IEEE145 and IEEE300 nodes. It did repeated test for 500 times to observe fault spreading action of power grid based on the SOC-PF model introduced in the quarter 1. The purpose of this test is to research the relationship between the probability of fault and the size of fault under different conditions of power grid. The vertical axis of the chart represents size of fault and horizontal axis represents probability of fault. The frame of axes uses logarithmic scale.

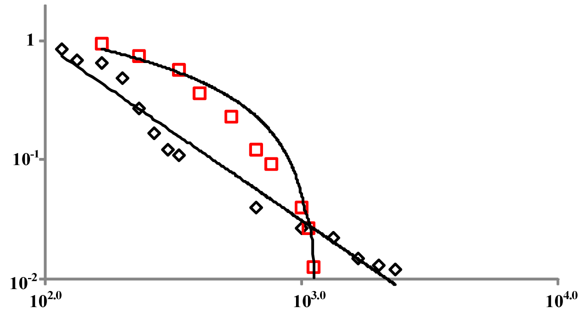
From experimental result of above chart we can find that the method of matching load rate of each line using the traditional load-capacity model can do nothing to prevent the happening of large scale fault of grid. When the redundant capacity of the power system is limited, the power system is easy to becoming self-organized criticality. The ML curve is as shown in **Figure 1**, when the tolerance coefficient of the three examples is smaller than 1.5, 1.3 and 1.2.

The probability of large scale of fault is big. The fault size and the fault probability are obeying the power distribution. The slope in the 3 examples is -0.82, -1.12 and -0.96.

The matching model had a better effect in inhibiting fault diffusion comparing with the traditional model. As shown in the PM curve of **Figure 1**, we let tolerance coefficient of the three examples remain unchanged. We adjusted the load factor of each line using improved model that it can be found huge change in the above curve. The probability of large scale fault drops when the system redundancy of three examples is the same. When the tolerance coefficient is 1.5 1.3 1.2, the curve in the logarithmic coordinate system is not straight line. The fault size and fault probability is obeying logarithmic distribution.



(a) IEEE300 nodes system



(b) IEEE118 nodes system

Figure 1. The relationship between frequency and scale of blackouts in different power grids.

The three systems are in the self-organized state.

4.2. Evolutionary Process of Distribution of Load Rate

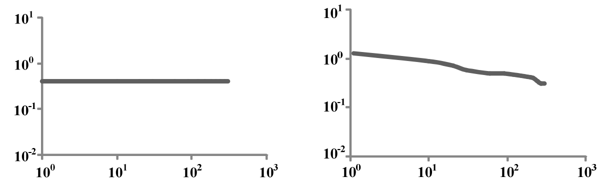
The experiments of last chapter proves that the transmission betweenness of line matching the operating limit can reduce the probability of large scale fault. Under the condition of transmission capacity redundancy is limited, it can prevent the power grid from becoming self-organized criticality. This section count the change of load rate in the two matching model to analysis the influence of improved model in the fault propagation process.

When tolerance coefficient using the two models of 300 IEEE nodes example is 1.5, system is at self-organized critical state and non-self-organized critical state. In this section we use the IEEE 300 nodes as a example and the tolerance coefficient is 1.5. We matched the transport limit of each line using the two matching model and attacked the transmission line which delivering the most active power to watch the evolutionary process of load rate in the two states. The results are in **Figures 2-3**. In the chart vertical axis represents load rate and horizontal represents number which is arranged according size sequence of load rate[16-18]. The formulation is:

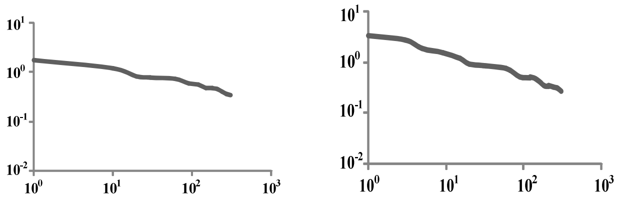
$$l_{avg} = \frac{\sum F_{ij}}{\sum F_{ij}^{\max}} \tag{9}$$

Figure 2 represents the evolutionary process of each line when the system is used load-capacity model to matching operating limit. 2(a) represents initial load rate distribution. 2(d) represents the load rate distribution when the fault is ending. **Figure 3** is the corresponding results using the improved model this paper has presented.

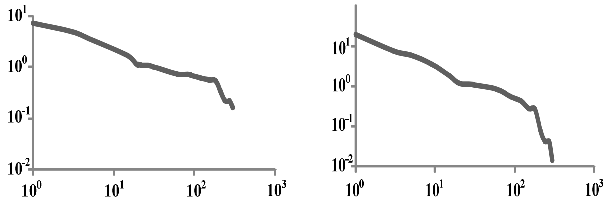
In the chart, we can find that the average load rate rise up fast and the transfer flow is leading to the system become self organized critical state, which is shown as 2(d). And the slope of curves is -1.9, so the grid is in critical state. If there is any disturbance in the power



(a) $l_{avg} = 0.40$ (b) $l_{avg} = 0.43$

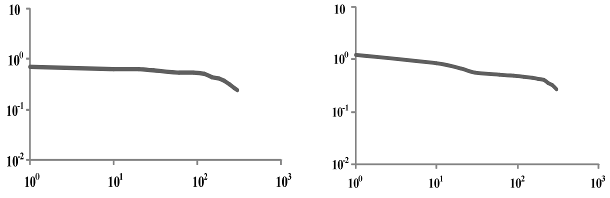


(c) $l_{avg} = 0.47$ (d) $l_{avg} = 0.61$

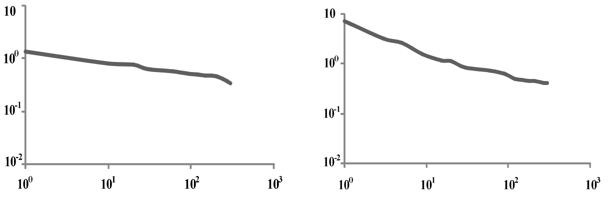


(e) $l_{avg} = 0.68$ (f) $l_{avg} = 0.73$

Figure 2. The evolution process of load rate in Load-capacity model.



(a) $l_{avg} = 0.43$ (b) $l_{avg} = 0.51$



(c) $l_{avg} = 0.58$ (d) $l_{avg} = 0.71$

Figure 3. The evolution process of load rate in new model.

system, it can leads to large scale of fault in the power system and the loss of load is rising which is shown as (e) and (f). If it used the improved model in this paper has presented we can find that it has a better effect in suppress the fluctuation of load. The rising extent of average load rate is small. The load distribution has a rising tendency and the slope is in the range of [-0.7, 0.1]. It can prevent the system from becoming self-organized critical state.

5. Conclusions

The load rate of power system has a direct impact on the self-organized criticality. For this reason this paper, based on the evaluation result (spread betweenness), propose a new capital match model. In this proved model, through the rational allocation of transmission capacity of the grid in planning process, the distribution of load rate of the system has been optimized. SOC-PF model-based simulation results has proved that this new model could prevent the system involved to the self-organized critical state, reduce the probability of occurrence of large-scale power outages.

REFERENCES

[1] J. Yi, X. X. Zhou and Y. N. Xiao, "Analysis on Power System Self-Organized Criticality and Its Simulation Model," *Power System Technology*, Vol. 32, No. 3, 2008, pp. 7-12.

[2] R.-R. Li, Y. Zhang and Q. Y. Jiang, "Risk Assessment for Cascading Failures of Complex Power System," *Power System Technology*, Vol. 5, No. 10, 2006, pp. 18-22.

[3] Q. Y. Xie, C. H. Deng, H. S. Zhao, *et al*., "Evaluation Method for Node Importance of Power Grid Based on the Weighted Network Model," *Automation of Electric Power Systems*, Vol. 33, No. 4, 2009, pp. 21-24.

[4] X. P. Ni, S. W. Mei and X. M. Zhang, "Transmission Lines' Vulnerability Assessment Based on Complex Network Theory," *Automation of Electric Power Systems*, Vol. 32, No. 4, 2008, pp. 1-4.

[5] M. Ding and P. P. Han, "Small World Topological Model Based Vulnerability Assessment to Large Scale Power Grid," *Proceedings of the CSEE*, Vol. 25, 2005, pp. 118-122.

[6] Q. Yu, N. Cao and J. B. Guo, "Analysis on Influence of Load Rate on Power System Self-organized Criticality," *Automation of Electric Power Systems*, Vol. 36, No. 1, 2012, pp. 24-30.

[7] Y. J. Cao, G. Z. Wang, L. H. Cao and L. J. Ding, "An Identification Model for Self-oganized Criticality of Power Grids Based on Power Flow Entropy," *Automation of Electric Power Systems*, Vol. 7, No. 35, 2011, pp. 1-8.

[8] H. Q. Deng, X. Ai and L. Zhao, "Discussion on Several Problems of Self-Organized Criticality of Blackout," *Power System Technology*, Vol. 31, No. 8, 2007, pp. 42-48.

[9] H. J. Sun, H. Zhao and J. J. Wu. "A Robust Matching Model of Capacity to Defense Cascading Failure on Complex Networks," *Physical Review A*, Vol. 20, 2008, pp. 6431-6435.

[10] B. Wang and B.-J. Kim, "A High-robustness and Low-cost Model for Cascading Failures, Europhysics Letters, Vol. 78, 2007, 48001. doi:10.1209/0295-5075/78/48001

[11] X. P. Ni, X. M. Zhang and S. W. Mei, "Generator Tripping Strategy Based on Complex Network Theory," *Power System Technology*, Vol. 9, No. 34, 2010, pp. 33-38.

[12] P. Hines and S. Blumsack, "A Centrality Measure for Electrical Networks," Hawaii International Conference on System Sciences, 2008.

[13] Y. J. Cao, X. G. Chen and K. Sun, "Identincation of Vulnerable Lines in Power Grid Based on Complex Network Theory," *Automation of Electric Power Systems*, Vol. 26, No. 12, 2006, pp. 27-31.

[14] A. E. Motter, "Cascade Control and Defense in Complex Networks," *Physical Review E*, Vol. 93, 2008, 098701.

[15] L. Xu, X. L. Wang and X. F. Wang, "Cascading Failure Mechanism in Power Grid Based on Electric Betweenness and Active Defense," *Proceedings of the CSEE*, Vol. 13, 2010, pp. 61-65.

[16] Ae Motter, "Cascade-based Attacks on Complex Networks," *Physical Review E*, Vol. 66, 2002, pp. 065102.

[17] W. Kai, B.-H. Zhang and Z. Zhang, *et al*., "An Electrical Betweenness Approach for Vulnerability Assessment of Power Grids Considering the Capacity of Generators and Load," *Science Direct Physica A*, Vol. 390, 2011, pp. 4692-4701.

[18] J.-F. Zheng, Z.-Y. Gao, X.-M. Zhao, "Modeling Cascading Failures in Congested Complex Networks," *Science Direct Physica A.*, Vol. 385, 2007, pp. 700-706.