The Operational Risk Research for Power Grid Using Electrical Dissection Method

Cong Zhang[1,a], Ming Li[2,b], Zhen Liu[1,c] and Wenzhu Zhang[3,d]
[1] *Shandong Zibo Power Supply Company, Zibo, China*
[2] *State Grid Shan Dong Electric Power Research Institute, Ji'nan, China*
[3] *Department of Electrical Engineering Shandong University, Ji'nan, China*
[a]51102522@qq.com, [b]lm_sdpj@163.com, [c]18366116537@163.com, [d]940024322@qq.com

Keywords: Power grid, risk analysis, electrical dissection.

Abstract: Operational risk analysis plays an important role in ensuring the safe and stable operation of power grid. A novel electrical dissection approach was applied to analyse the operational risk for the grid. This method can validly determine the power transmitted for each line between generator and load, and the application of the new electrical dissection method is quantified according to the power transmission limitation of line. This new method was tested by an IEEE 39-bus system, and the analysis results had proved the validity and rationality of this proposed method.

1 INTRODUCTION

Power system risk analysis has gradually become a widely researched work, because there are many cascading failures caused by severe failures in recent years. (Moore, 1999). The method for finding the vital route or "fragile line" is significantly important for warnings and protecting critical links (Smith, 1998).

Complex network method is one of the main research methods at present. It analyses the grid risk from the structure aspect (Datta, 2017; Gan, 2003; Holmgren, 2006). The metrics are assumed to be the shortest path, only studying structural risk in a pure topological structure. Moreover, the power between lines requires certain objective constraints and it is difficult for the metrics to capture main features of grids.

In (Rosato, 2007), Sensitivity analysis technology is adopted to study power grids in the operation status (Rosato, 2007). If the grid parameters change, the method in(Rosato, 2007) can capture the degree of influence of the system parameters. But it only considers the circuit parameters and load changes, so the result is one-way.

To eliminate the defect in (Rosato, 2007), the electrical dissection method has been studied in the power grid risk analysis (Raza, 2017; Jankovic, 2017; Tang, 2006; Tang, 2009; Shao, 2009). The grid risk index is formed by using the electrical dissection information of paths. Thus both the topological structure characteristics in original network and influence on system risk for operation state changing can be considered. So the comprehensive power grid risk can be accomplished.

The rest of this document is as follows. Section II gives the electrical dissection method and defines the risk index. Section III introduces the network efficiency. Section IV presents the numerical simulation results of an IEEE 39 bus text system .Section V is the conclusion of full paper.

2 THE INTRODUCTION OF RISK INDEX

Figure.1 is an example of an AC code, which has three branches, one is imputing flow branch and the others are outputting flow branches. We use it to dissect as an initial deduce.

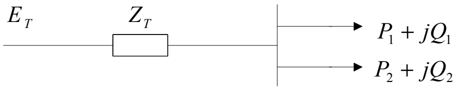


Figure 1: Simple example of an AC code.

Zhang, C., Li, M., Liu, Z. and Zhang, W.
The Operational Risk Research for Power Grid Using Electrical Dissection Method.
In *3rd International Conference on Electromechanical Control Technology and Transportation (ICECTT 2018)*, pages 648-651
ISBN: 978-989-758-312-4

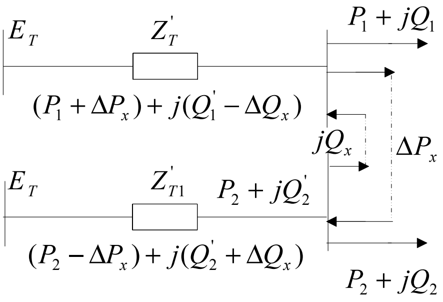


Figure 2: Final dissected results of figure 1.

The resulting of dissected for figure.1 is shown in figure.2. The parameters in figure.2 are as follows.

$$\Delta P_x = \frac{\Delta P \Delta Q^2}{\Delta P^2 + \Delta Q^2} = \frac{Q[P_2 Q_1 - P_1 Q_2]}{\Delta P^2 + \Delta Q^2} \tag{1}$$

$$\Delta Q_x = \frac{\Delta P^2 \Delta Q}{\Delta P^2 + \Delta Q^2} = \frac{P[P_2 Q_1 - P_1 Q_2]}{\Delta P^2 + \Delta Q^2} \tag{2}$$

$$Z_{T1} = \frac{P}{P_1 + \Delta P_x} Z_T \tag{3}$$

$$Z_{T2} = \frac{P}{P_2 - \Delta P_x} Z_T \tag{4}$$

The general deduce to be dissected is shown in figure.3.

There are n inputting and outputting branches in sending and receiving end respectively. There is a generator in sending end and a load in receiving end.

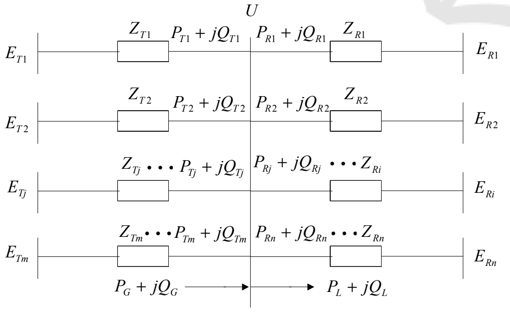


Figure 3: Ac code having n input and output branches.

Figure 4 and figure 5 show the final dissected results of figure.3. Parameters in figure.4 and figure.5 are listed below.

$$\Delta P_{Rix} = \frac{Q[PQ_{Ri} - P_{Ri} Q]}{(P)^2 + (Q)^2} \tag{5}$$

$$\Delta Q_{Rix} = \frac{P[PQ_{Ri} - P_{Ri} Q]}{(P)^2 + (Q)^2} \tag{6}$$

$$Z_{Tji} = \frac{P}{P_{Ri} + \Delta P_{Rix}} Z_{Tj} \tag{7}$$

$$P_{Gi} + jQ_{Gi} = (P_G + jQ_G)\frac{Z_{T\sum}}{Z_{Ti\sum}} \tag{8}$$

$$\Delta P_{Lx} = \frac{Q[PQ_L - P_L Q]}{(P)^2 + (Q)^2} \tag{9}$$

$$\Delta Q_{Lx} = \frac{P[PQ_L - P_L Q]}{(P)^2 + (Q)^2} \tag{10}$$

$$Z_{TjL} = \frac{P}{P_L + \Delta P_{Lx}} Z_{Tj} \tag{11}$$

$$P_L + jQ_{GL} = (P_G + jQ_G)\frac{Z_{T\sum}}{Z_{TL\sum}} \tag{12}$$

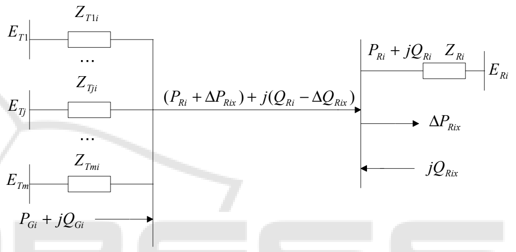


Figure 4: Dissected note for output branch.

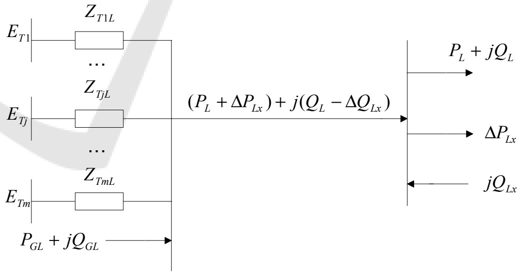


Figure 5: Dissected note for output load.

Paths connect various sources (generators) and flows (loads). The grid risk is determined by electrical parameters of the paths. So the grid risk evaluation is to be formed by electrical dissection information of the grid.

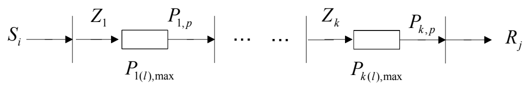


Figure 6: Path between source and flow.

A path L_p between S_i (source) and R_i (flow) is demonstrated in figure.6. The branch in path may have many sub-branches. The sub-branch risk index for its original branch can be expressed:

$$B_{k(l),p} = \sum_{i\in G, j\in R} \frac{P_{k,p}^2}{P_{k(l),\max}\sqrt{P_i P_j}} \tag{13}$$

where $P_{k,p}$ is active power flow in the sub-branch k of path L_p between S_i and R_i . $P_{k(l),\max}$ is the maximize power limit of sub-branch k . P_i is generator's output and P_j is the actual load value.

The results of electrical dissection illustrate the fact that even different paths with different risks still have the possibility of the same branches and sub-branches. So, the branch risk can be treated as the corresponding sub-branches risk. The risk index of branch l is as follows:

$$B_l = \sum_{p=1}^{n} B_{k(l),p} \tag{14}$$

So we can consider more information as much as possible, such as the grid structure, grid operation mode, power between generator and load by the utilization of each line, and quantifies for using relationship with the branch transmission power limit in the new risk index by using electrical dissection information.

2.1 The Grid Efficiency

For one source and a flow grid, the maximum power flow is set to equal to the power transmission capacity. To locate the critical sites and obtain the overall performance of the grid, the transmission capacity of the power grid is defined as the network efficiency.

$$E = \varphi_{\max}(A, C) \tag{15}$$

where $\varphi_{\max}$ is the function for the network maximum flow. A is the grid topology matrix. C is the branch matrix.

Without taking into account of the frequency, voltage, reactive power and other factors, the index in this paper is only a rough estimate. However, the rough estimate can find the relative size of the critical line fault to the system, which is sufficient.

2.2 Numerical Results

An IEEE 39-bus test system shown in figure.7 illustrates this proposed method. It has 46 lines, 10 notes and 19 load notes.

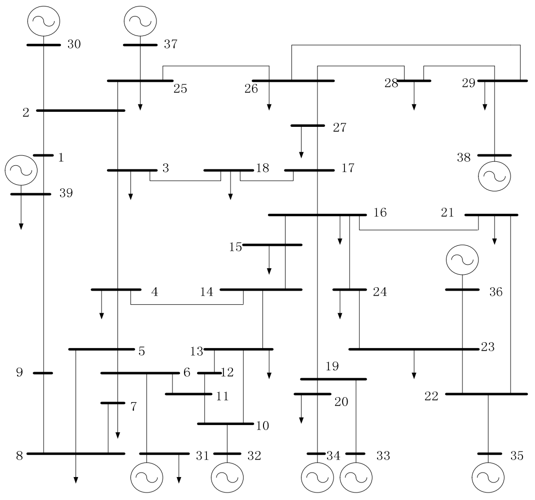


Figure 7: IEEE 39-bus text system.

Table 1: The sorting of critical lines.

Number	Name	Index
1	25-26	1.616836
2	26-27	1.241098
3	1-2	0.875855
4	38-29	0.729488
5	21-22	0.711351
6	2-30	0.427853
7	25-37	0.381796
8	2-3	0.318535
9	22-35	0.307188
10	16-17	0.303296

The lines with 10 larger risk index are calculated by using the proposed approach and are shown in table 1.

To demonstrate accuracy of the sorting results in table 1, the deliberate attack strategy that removes any of 10 lines according to results in table 1 is used to attack the grid. Figure 8 shows the network efficiency after remove one line.

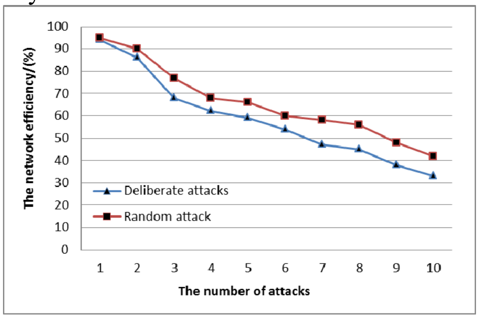
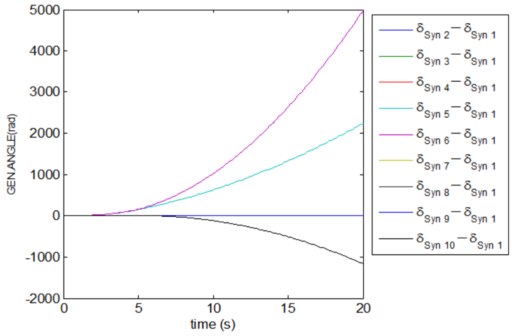
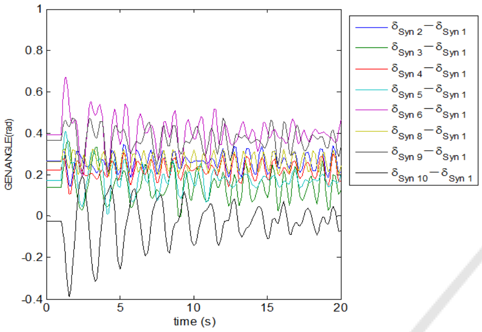


Figure 8: The effect of different strategy attacks on the network efficiency.



(a) Line 25-26 faults



(b) Line 15-16 faults

Figure 9: The generator power-angle curve.

At first, the two curves changed very little because there was no cut set network. As the number of attacks increases, the curve that is deliberately attacked falls faster and faster. The lines in table 1. play a hub role in forming cut set. The comparison results show that the higher risk index line results in more vulnerable for power system during attack.

In another aspect, the time domain simulation that solves randomly selected three-phase short circuit on the high voltage side of line 25-26 and line 15-16 is accomplished. Figure 9 shows the generator power-angle curve. As shown in figure.9, the power-angles of generator 3, 6 and 10 become larger as time goes by and can not back to the normal status. This proves that the system can not maintain transient stability. However, power-angle curves in figure 9(b) have only a little attenuation oscillation. We can conclude that the system is transient stability. This can further verify the validity of the proposed method.

3 CONCLUSIONS

The paper presents an electric dissection method used to analyse the risk of power grid. The proposed risk index reflects not only the relatively static fixed topology structure but also the operation state of power grid. The relationship between the line utilization ratio and the line limit is very intuitive and can be quantified. This method can quickly select relatively weak lines in the grid. Therefore, the method proposed in this paper will be widely used in power grid risk assessment in the future.

REFERENCES

Moore, R., Lopes, J., 1999. Paper templates. In *TEMPLATE'06, 1st International Conference on Template Production*. SCITEPRESS.

Smith, J., 1998. *The book*, The publishing company. London, 2nd edition.

Datta, S., & Vittal, V. 2017. Operational risk metric for dynamic security assessment of renewable generation. *IEEE Transactions on Power Systems, PP*(99), 1-1.

D. Q. Gan, J. Y. Hu, and Z. X. Han, J, 2004.Thinking of several international power outages in 2003[J]. *Automation of Electric Power Systems,*28(3), pp: 1-4.

Holmgren, A. J. 2006. Using graph models to analyse the vulnerability of electric power networks. *Risk Analysis An Official Publication of the Society for Risk Analysis, 26*(4), 955.

Rosato, V., Bologna, S., & Tiriticco, F. 2007. Topological properties of high-voltage electrical transmission networks. *Electric Power Systems Research, 77*(2), 99-105.

Hines, P., & Blumsack, S. 2008. A centrality measure for electrical networks. 185.

Raza, S., Mokhlis, H., Arof, H., Laghari, J. A., & Mohamad, H. 2017. A sensitivity analysis of different power system parameters on islanding detection. *IEEE Transactions on Sustainable Energy, 7*(2), 461-470.

Jankovic, N., Kryvchenkova, O., Batcup, S., & Igic, P. 2017. High sensitivity dual-gate four-terminal magnetic sensor compatible with soi finfet technology. *IEEE Electron Device Letters, PP*(99), 1-1.

Tang, Y., & Yu, J. L. 2006. A new dissecting method for AC power system. *International Conference on Future Power Systems* (pp.6 pp.-6). IEEE.

Tang, Y., Wu, Y. J., & Li, Y. 2009. A proposal for investment recovery of TCSC based on electrical dissecting method. *Power & Energy Society General Meeting, 2009. PES '09. IEEE* (Vol.25, pp.1-6). IEEE.

Shao, Y., & Ji-Lai, Y. U. 2009. Power grid vulnerability assessment based on electrical dissection information of the electric power network. *Proceedings of the Csee, 29*(31), 34-39.

Yu, J. L., & Tang, Y. 2007. United electrical dissection of ac branch and bus. *Proceedings of the Csee, 27*(16), 37-42.

Yi, T., Ji-Lai, Y., & Lin, L. X. (2004). *An electrical dissecting method of AC branch with FACTS for ancillary service assessment.*