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Seismic Reliability Analysis of Large Scale Electric Power Network

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Abstract: This paper developed the analysis of seismic reliability of large-scale electric power network. First, the large-scale power system was analyzed, and the modeling of power system can be obtained according to the voltage level of power system. Then the power system can be modeled as the vertex weighted network or general weighted network with directed arc. And then the seismic reliability of the large-scale electric power system can be computed. The large-scale power system need to be considered as multi-input system. A real case of some large-scale power system was studied as well.

Key words: electric power network system; seismic reliability; lifeline system

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Introduction

Electric power system is an important lifeline system. The seismic damage of electric power system affects not only the electric power system itself, but also other system such as communication, water supply, emergency succoring, and recovery rebuilding. To the disaster of lifeline, a long time research has been doing. At the beginning, only the single unit had been studied. After the 1971 San Fernando earthquake, during which a lot of the lifeline facilities were damaged including high voltage power transmission facilities, expressway bridge, gas and water supply buried pipe, the essentiality of lifeline earthquake had been convinced. Duck and Moran introduced the concept of lifeline earthquake in 1972. The lifeline earthquake engineering had been studied as a system. In 1974, the Technical Council on Lifeline Earthquake Engineering (TCLEE) was established by ASCE. First major commitment of professional societies directed at the impact of earthquake on lifeline. Up to now, four specialty conferences had been held. The last conference was held in San Francisco, in 1995. From the papers presented at the Conferences on Lifeline Earthquake Engineering, we can see that only buried systems were paid attention to at 1 st and 2 nd conference, because of the timing of follow-up investigation, information on buried lifelines is more complete. The electric power facilities and systems were paid attention to at the 3rd and 4th Conference on Lifeline Earthquake Engineering[1,2].

China is one of the countries suffering the most severe earthquake disasters in the world. A lot of industrial equipment and electric power facilities were destroyed during the Tangshan Earthquake in 1976[3] and Haicheng Earthquake in 1975. Research on lifeline earthquake engineering in China was after middle of 1980's. Along with the research on earthquake resistance and disaster prevention in China, and for the purpose of aseismic strengthening of industrial establishment, the research on the industrial establishment facilities had been developed. The Conference on industrial equipment was held in 1987, which covered the petrochemical equipment, electric power facilities, etc. In 1990s, more researches on electric power facilities were done. But only in recent years, the aseismic research on electric power systematically is done. In this paper, the aseismic reliability of the large-scale electric power network is studied. The large-scale electric power network discussed in this paper is about scope of a province (above 220 kV network), includ-

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Biography: LI Tian (1960-), male, born in Ningbo, Zhejiang province, professor of Zhengzhou University of Technology, doctorate, research interests: structure engineering and earthquake engineering.

ing substations, power plants and power transmission systems.

1 The Characters of Large - scale Electric Power Network

Urban societies in developed countries heavily rely on electric power. Electric power system is a large - scale system, which is composed of subsystems of the energy production, transmission, distribution and control, which cannot be intersected. Modern electric power system develops to high - voltage, super high voltage. In case of earthquake, the disasters of electric power system are very severe and extensive. Many destroy in electric power system happened during earthquake both in China and abroad.

1.1 The destroy characters of electric power facilities

Due to recent earthquakes, numerous electric power facilities suffered severe damages, such as the 1976 Tangshan, the 1994 Northrige, and the Great Hanshin - Awaji events. Even not very great earthquake happen in Neimonggu 1996, the event significantly affected critical lifeline, particularly, the electric power supply, which caused more than one hundred million yuan losses due to power outage. The failure characters of various units in past earthquake are as follows.

1.1.1 Power generating plant

In general, the gas turbine generating units are inherently rugged and no seismic damage had been reported. However, the building structures of power plants are destroyed seriously, especially those had not strengthened. Some structures collapsed and thus affected the generating equipment.

1.1.2 Substations

Substation includes building structure and yard equipment. The buildings of substation are main control buildings, which are three stories. The buildings cracked at 7 magnitude and destroyed at 8 magnitude, because that they are usually opened. The transformers would move or fall over because that they were in adequately anchored to rails or unanchored. The porcelain of all types of electric equipment were failed and leaked at 7 magnitude, such as current transformers, disconnect swatches, circuit breaks, lightning arresters, etc.

1.1.3 Transmission towers

The earthquake performance of transmission was good. Generally, the collapse of transmission towers is because of foundation movement due to liquefaction. Sometimes, the transmission was still working after the earthquake.

1.2 The level of electric power network

According to the characters of electric power system, it is necessary to analyse the seismic reliability of electric power system as a whole, not only single power plant or substation. The voltages of large - scale electric power network in China include 500 kV, 220 kV, 110 kV. The network in a province is usually 220 kV. The electric power network in a province can be simplified as three levels. The first level is network, second level includes the units include power plants substations and transmissions, and third level includes electric power facilities, building structures in each power plant and substation.

1.3 Multi - source - to - multi - terminal of electric power system

A large - scale electric power system is multi - source - to - multi - terminal network not, the same as a general network only one source and one terminal, in that a electric power network is inputted electric energy by a lot of power plants. On the other hand, every substation, which is terminal in the network, is the source of subordinate network. Therefore, it is necessary to take a large - scale electric power network as multi - source - to - multi - terminal network in the analysis of the seismic reliability.

2 The Methodology for Seismic Reliability of a Large - scale Electric Power Network

For seismic reliability of a large - scale electric power network, the first point is to introduce a mathematical model of the network performance. The arc weighted network model is generally used in network reliability, which means the reliability of every edge of the network is considered in system analysis and the vertex would not fail[4]. The electric power network, however, is on the other hand. The edge of electric power network is transmission system and the vertex is power plant and substation, so that not only the edge would fail, but also the vertex would fail, and the vertex is easier to fail under the earthquake impact. The electric power network should be taken as a vertex weight network or general weighted network when the failure of transmission system needs to be considered.

2.1 Basic assumptions

(1) Consider a generic mesh for electric power system as the simple network.

(2) A Boolean function is assumed to represent the unit serviceability condition. Only two states are considered of all the units of the electric power network including edge and vertex. The unit is set equal to 1 if the unit is in service, is set to 0 if the same unit is out.

(3) The failures of each unit are independent. The failing relativity of each unit is not considered.

(4) To the failure of unit, only once earthquake impacting is considered in analysis.

(5) All the substations at the power plants are rise voltage substations, which are inputting to the network. Some of connections of the electric power network are directed, and some of them are undirected. The large – scale electric power network is multi – source and multi terminal. When we analyse the seismic reliability of the system, it is not necessary to consider output of each substation, so that when we consider the network reliability, only one output is considered. In this way, multi – source and one – terminal is considered in the system reliability analysis. The earthquake impact in the analysis is based on the earthquake zonation of China.

2.2 The methodology for seismic reliability analysis

(1) Building connection matrix[5]. For the computing of logical relation of each node, it is essential to build up the connection matrix ($\boldsymbol{M}$) of the network. The matrix $\boldsymbol{M}$ is not symmetric because of directed connection. For a large – scale network, it is difficult to build matrix directly. Therefor, the connection matrix from all the sources to the terminal is directly built by computer.

(2) Computing the minimum paths $\{L_i\}_m$ from all the sources to the terminal. General methods to computing the minimum are connection matrix method, and so on. Those methods are not suiting for a large – scale network. In this paper, the single path – finding algorithm is used to computing the minimum path. In this way, we can get all the minimum path from sources (S_i, i = 1,2, k, here k is number of sources) to terminal (T), $\{L_i\}_m = L_1$, L_2, L_m. And m is number of the minimum path.

(3) Computing discross minimum paths. After computed all the minimum paths, the system reliability of the network need to be computed, The minimum paths, however, are very large for a network. It is difficulty to compute system reliability on the minimum paths directly, because the sets of the minimum paths are intersected. Therefor, it is essential to discross the minimum paths. Firstly, the minimum paths are sorted according to the length of the path. Then, computing the unit sets $L_{i\leftarrow j}$ ($i < j = 2, 3, \cdots, m$), which are those minimum paths, included in L_i but not in L_j, by means of comparing and eliminating. And then the discross minimum path sets can be computed by the De Morgan formula to absorb and merger the sets $L_{i\leftarrow j}$.

$$\sum_{i=1}^{m'} L_{i,\mathrm{dis}} = L_i + \sum_{j=2}^{m} \Big(\prod_{1 \le i \le j-1} \bar{L}_{i\leftarrow j} \Big) L_j , \qquad (1)$$

(4) Computing system reliability from all the sources to the terminal. In generally, the network can be expressed as $G(V, E)$, here $V = \{V_1, V_2, \cdots\cdots, V_n\}$ is vertex set, $E = \{E_1, E_2, \cdots\cdots, E_m\}$ is arc set. Assuming the system with k sources, the system reliability $R(G)$ are given as following

$$R(G) = \sum_{i=1}^{k} R_{s_i t}(G) , \qquad (2)$$

The vertexes of the network can be divided into two types, extremity and middle vertexes. The extremity vertexes of sources are L_{s_j} ($j = 1, 2, \cdots k$), and the extremity vertex of terminal is L_t. The discross minimum path sets are $L_{1,\mathrm{dis}}, L_{2,\mathrm{dis}}, \cdots, L_{\mathrm{m},\mathrm{dis}}$. The system reliability are as following

$$R_s = P\Big(L_{s_j} \cdot L_t \cdot \bigcup_{i=1}^{m} L_{i,\mathrm{dis}} \Big) . \qquad (3)$$

3 Case Study

By simplifying to a large – scale electric power system about a province, the network for power system is showed in Fig. 1, in which 60 units are considered including 15 power plants and 45 substations. The seismic zonation is also showed in figure 1 according to the Chinese seismic intensity zoning map (1990), that expresses the seismic hazard of every substations and power plants. Most of the power plants and substations are located in the areas of earthquake intensity VI, about 3 power plants and 5 substations are located in high earthquake intensity area (VIII). According the prediction for building damage of the power plants and substations, the reliabilities of earthquake resistance of every unit can be computed. The reliabilities of electric power facilities have been computed in reference 6 as well. Integrating the results of the predicting for building damage and the reliabilities of earthquake resistance of electric power facilities, the reliabilities of every units can be get.

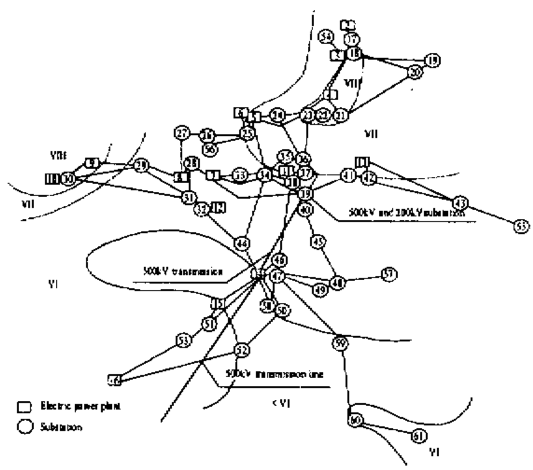

Fig. 1　Sample of the electric power network

Choosing some key units, we can compute the reliability from all the power plants to the substation. For example, the substation of number 47 is chosen. There are 410 minimum path sets from 15 power plants to this substation. This means that there is 410 possibility from sources to terminal. The reliability, furthermore, can be computed at basic intensity of earthquake,

$$R_s = 0.9998 ,$$

The reliability at the intensity of seldom occurred earthquake is computed,

$$R_s = 0.99539 ,$$

It can be seen that the values of reliability are very high, because the power system is high redundancy. The system reliability is still high when some values of reliability of units decrease more. The system reliability is sensible to extremity vertexes of sources and terminal. Some of substations are easily destroyed, especially those at the edge of the network.

4　Conclusion

In this paper a procedure for the evaluation of the seismic reliability of large – scale electric power system is proposed. The system performance function, based on Boolean variables, is provided. The seismic hazard is based on the seismic zonation, which is given on seismic intensity zoning map. According to the results computed to a large – scale electric power network, some conclusions can be made,

(1) To a large – scale electric power network, the voltage level of the system can be taken as condition of the system analysis. The model of seismic reliability of the power system to the same voltage level can be divided into three basic units, power plants, substations and transmission. To compute the system reliability, the vertex – weighted model is suited for the electric power network. Not only the vertex weight can be considered, but also the connection weight can be considered in this model which is applicability.

(2) The electric power system is with multi sources and multi terminals. It is necessary to analyse the system reliability which all sources are taken into consideration but only one terminal need be taken.

(3) The single path – finding algorithm is suitable for computing the minimum path of large – scale network. The number of minimum path sets is very numerous, especially when the system is with multi sources and multi terminals. During computing the discross minimum path sets, the element sets are increase in power.

(4) In general, the large – scale electric power system is of high redundancy. The middle unit 's influence of the system is not great when the system is of redundancy, but the terminal unit 's influence is great. To the system from multi sources to special terminal, the system reliability is sometimes dependent on the shortest length of the minimum path set from the source to the terminal.

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大型电力网络系统抗震可靠性分析

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摘　要：研究了大型电力网络系统的抗震可靠性问题．对于大型电力系统的抗震可靠性分析，首先，需要进行系统网络的分析，根据系统电压等级建立分析对象和模型，一般电力网络可以简化为具有有向弧的点权网络模型．在计算中，对于大型电力系统需要考虑具有多输入的系统．对于某大型电力网络系统抗震可靠性进行了实算，结果表明，该算法有较好的可行性．

关键词：电力网络系统；抗震可靠性；生命线工程系统