Power Network Lightning Accident Quick Inquiry with the Lightning Location System

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Abstract  At present, lightning is one of the 10 natural disasters, and it is also the top environmental factor of power interruption. It often causes huge losses to the electric system. The Wuhan High Voltage Institute of the State Grid Corporation of China and Huazhong University of Science and Technology have been researching and developing lightning location systems (LLSs) since the late 1980s. In the mid-1990s, a lightning detection network was created in 29 provinces and cities in China. It is primarily applied to rapidly find lightning accidents, which greatly reduces power interruption. Also, it ensures high efficiency and safe operation of the electricity system. Remarkable benefit is achieved. China’s LLS went through an “orientation positioning – time difference positioning – integrated positioning” development process. The positioning precision, detection efficiency, degree of automation, practicability and applied range are improved. Also, a lightning information system plan of the national network has been implemented, which services the whole society.

Keywords  lightning location; power network; lightning accident; accident inquiry; lightning information system

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Introduction

Thunderstorms are disastrous weather phenomena that often cause serious accidents and disasters. Disasters from lightning are one of the most serious disasters identified by the United Nations Mitigation Decade.

Lightning may cause casualties and damage to building and equipment. Thousands of people die annually from lightning in China. From 1996 to 1999, there were 6 143 lightning accidents, 669 casualties, 70 fire disasters in Guangdong Province and the direct loss was 0.15 billion Yuan. More than 70% of forest fires and blackouts are caused by lightning according to international statistics. Lightning also causes aerospace incidents. It has been reported that aerospace guidance systems have been destroyed and flights delayed. Lightning is also very dangerous to sensitive explosive objects, fireworks mill factories and chemical factories. They may explode when hit by lightning. In 1989, the oil storage in Huangdao, Shandong was set aflame because of lightning, resulting in more than $1 000 M economic loss. With human civilization entering the information age, lightning becomes an increasing threat to the security of information systems as more and more electronic equipment are utilized in homes and computers and information systems are becoming widely used. Because of lightning disasters, many government, enterprise networks and computers have been destroyed.

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According to statistical records, loss from lightning accounts for 70%-80% of total loss. In 1998, Shanghai insurance companies paid 0.3 billion Yuan for lightning disasters. In 2007, a lightning strike accident occurred in Xingye Primary School in Chongqing\[^1\-^3\]. Lightning disasters pose a serious threat to human society.

Lightning is the primary factor that causes power interruption. In developed countries, about 1/3-2/3 electric accidents are caused by lightning. This ratio in China is also higher. From Reference \[^4\], between 1990 and 1996, 100-500 kV transmission lines suffered 5,468 breaks from lightning, accounting for 61.97% of the total electric accidents. Specifically, for different voltage levels, 500 kV, 120 kV, 110 kV transmission lines accounted for 38.7%, 63.6% and 62.1%, respectively. Economic loss includes direct and indirect losses and the indirect loss is ten times more than the direct loss. In 1997-07-13, a lightning strike caused power interruption that resulted in huge economic losses and serious social problems in New York.

The decrease in oil output of the Daqing Oil Field caused by lightning strike power interruptions is approximately equal to one year’s worth of oil output in the Yumen Oil Field. When lightning accidents occur, rapid rescue should be implemented to reduce the loss. Because many transmission lines span over several provinces, especially in mountain areas, the complexity of transmission networks make it very difficult to pinpoint the location of the accident.

With all of the above, the new lightning location system is expected to become very popular and achieve rapid development and application.

1 Lightning location system

1.1 Lightning location

The advanced LLS was developed by US engineers in the 1970s to serve in spaceflight, and then adopted by the electric industry quickly. According to the sensor setup, there is a single sensor system and a multi-sensor system. The single sensor system has low location precision, so its application is limited. However, the high-precision multi-sensor system, whose networks can cover large areas (even a country), is used widely.

The multi-sensor LLS was developed from MDF, TOA and synthesis location technique. The advanced LLS adopted advanced technology such as GPS, GIS, space geodesy, computer and information technology, digital communication, network technology, and so on. When sensors receive an electric magnetic wave from lightning, then the corresponding signals are transmitted to the information processing center. The lightning position coordinates, time, intensity, polarity, and return strike times can be calculated, and displayed in real time on an electronic map based on GIS, and further analysis can be done. Also, the information can be released to the public\[^2\,^4\-^8\]. With the unified time scale, lightning accidents can be searched by the accident time in the power network, and other parameters can also be obtained, which can guide the rescue team to the accident site. Because the location precision is high (less than 1 km), it is easy to send the rescue team to the accident site and greatly reduce the failure time.

1.2 LLS development in China

The superiority of the lightning location system has been accepted by China’s state electric departments. In the late 1980s, the Wuhan High Voltage Research Institute of the State Grid Corporation of China and Huazhong University of Science and Technology started researching and developing an LLS, and established many lightning detecting networks in many provinces in the country in the middle 1990s to guide quick positioning and scientific research of lightning accidents. The research has made remarkable progress since then.

The development and applications of lightning detection systems are highly valued by national leadership sectors. The Electricity Department and the Ministry of Science and Technology of China provide a lot of support and guidance to system development through numerous technology projects. The country’s leadership attaches great importance to the development and applications of lightning detection systems.

A lightning detection system is a systematic engineering of multi-subject combinations and advanced technology application. It involves atmospheric
physics, high-voltage technology, space geodesy, computer technology, information systems (GIS included) and network technology, micro electron technology, controlling technology and so on. The HUST cooperates with the Wuhan High-Voltage Research Institute of the SGCC in the research, manufacture and study of multi-subject combinations. The two groups have formed a good and effective corporation system. They have invented third generation products in a short time, which were developed from “MDF, TOA and synthesis location technique”. A series of theoretical and technical problems had been solved$^{[2,3,8-26]}$. They have achieved system synchronization with the development of international technology. The development of the system was always based on itself, striving for innovation and had obtained many national invention patents. The lightning detection system has Chinese characteristics and independent knowledge authority. Because of the general superiority and technical strength, they have nearly 90% stable partners and users in native power systems. They maintain effective running and timely upgrading and shifting generations, accumulated entirely precious and long-term original data about lightning detection and exploited new studies and application fields. The study of establishing a lightning detection system for national online operation is being processed.

There are examples of importing foreign systems. However, in terms of transaction, not only is the price very high, which is many times that of the national system, but also the system maintenance and upgrading are very passive, which will result in system disability and cannot be used finally.

2 Lightning accident quick inquiry

2.1 Lightning information system

The multi-sensor lightning network is established in large areas, where sensors are installed separately with the spacing of 100-200 km. The sensor has a special antenna to obtain lightning information such as the lightning arrival time, direction, intensity, etc, then the information is transmitted to the center for further procession, the location calculation is performed. After processing, the results are sent to customers and network servers; the center also has a supervisory system running status function. User workstations have three forms: green-user workstations, dial-terminals and customer or network server systems. The LLS is shown in Fig.1.

The time scale precision used in the power network and lightning information system is 10-7 s. The transmission line’s tower coordinating database was created, which is based on the GIS platform. It is easy to obtain the lightning position and the rescue team can be quickly sent to the accident site to restore power.

The existing experiences show that the efficiency for probity of this system is over 90%, and the location precision is less than 1 km, even 500 m in many cases.
2.2 Lightning detection network of the state

Up to the present, the power network lightning location systems have been established in 29 provinces. Also, there are 26 provinces adopting the systems which are being developed by Wuhan High Voltage Research Institute, accounting for 85%. In some sites, the system has been running for more than 20 a. Because of the lightning incidence quick location, the time of power interruption is reduced, and remarkable benefit is achieved. The lightning detection stations are running uninterrupted, automatically. They record major lightning clouds towards ground in the detection region. These invaluable original data of the long-term accumulation and analysis have potentially significant scientific value to the research on lightning prevention and climatology. For example, there were 1,515,965 lightning flashes in Guangdong between 1997 and 1998, and there were 1,396,196 lightning flashes in Hubei between 1998 and 2002. Generally, there are several hundred thousand of flashes of lightning in a province annually. A variety of lightning activities can be obtained by these statistical data, such as lightning-day, lightning-hour, lightning density, the beginning and ending days of annual lightning, lightning polarity, frequency of return stroke, current intensity of lightning.

2.3 Lightning accident quick inquiry

With the support of the LLS, the lightning accident location can be displayed in real-time, and located automatically, rapidly.

For example, in Guangdong, for the first year of the LLS operation, 86 accident locations were carried out. Among these, there were 79 precision locations; the accuracy was 97.9%. In 1998, 118 lightning accident locations were carried out, the precision locations were 104, and the accuracy was 88.1%. The biggest error is 2.1 km, the least error is 0.1 km, and the average is 0.725 km. According to the report, in 1997, 26 lightning accident locations were carried out by the Guangzhou Transmission Line Operation Bureau. Among them, there was 1 for the 500 kV (the error was 100 m), 20 for 220 kV, 5 for 110 kV. The operation results showed that the accident tower location forecasted by the LLS agreeing with the actual reaches 16 times, accounting for 62%, and that agreeing with the actual within two towers reaches 6 times, accounting for 23% and 15%, respectively. Compared with manual work, LLS saves 720 work forces per day. The report also provided an example, because while using the LLS, 17.6 hours of power interruption was shortened for the 1997-06-10T00:30 Jiahe line, 1997-07-01T04:33 Jiaxia line and 1997-07-01T04:22 Jiahe line, saving direct economic loss of 125 M, and indirect loss of approximately ten million.

Also, the report from Chongqing showed that during the system operation in the first half of 1999, 18 accident locations were carried out accurately, and 16 accidents were done in 2000 successfully, saving direct economic loss of 279 m, and indirect loss of more than 2,000 M. From 2002-04 to 2002-10, 24 lightning accident locations were carried out. Among these, there were 23 precision locations, the accuracy was 95.8%, and the error was less than 500 m. The report figured out that the annual economic benefits of the LLS system can reach a hundred million.

Another example on the significance of the system can be presented. At 06:39 a.m. on 1st, July, 1997, the 500 kV Zengcheng-Guangzhou transmission line experienced a blackout because of a lightning strike. According to the system, the accident occurred on tower No.91-94. A rescue team was sent to the accident site and the accidents were found on towers 93 and 94. It just cost 2 h for this mission, and the high efficiency was so surprising that power was restored on the same day in Hong Kong. The transmission line was just for Hong Kong power supply, so the LLS has great significance.\[28,29\]

3 Application of lightning information system

3.1 Three main functions of the lightning Information system

1) The quick location of the lightning accident position is useful for electric operations, telecommunication departments, electric railways, insurance affairs, and forest fire protection.
2) The lightning development trend can be forecasted. It will be also significantly useful for many other departments. The LLS is a real-time spatial information system, and it will predict the generation of lightning and its development trend with the help of advanced software. The astronavigation department can choose proper launch windows according to the information; the aviation department can avoid thunderstorm districts; the power supply department can make arrangements for operation plans; the information department can make active decisions about forest fire protection and the production and storage of dangerous goods. Field works, excursions and the army can adjust to prevent accidents. Lightning and storms usually happen simultaneously, which can allow us to try to predict floods \cite{2,3,8}.

3) Statistics and analysis of time and space distribution of lightning would be obtained. With accumulations of lightning observation data, some important rules can be concluded. It will influence thunderstorm electricity climatology, lightning mechanism, the design of transmission lines and codes revision. Nowadays, there are many good examples in the lightning protection design of transmission lines \cite{8,28-34}.

3.2 National lightning information system is necessary

Although China has established a provincial LLS, each LLS network is independent and these networks only work for power supply departments. They are not connected to form a national LLS network. At the same time, they are not open to our society. These extremely precious resources have not been used sufficiently. This is a huge gap between our country and other developed countries.

The Wuhan High-Voltage Institute was carrying out this research for the national LLS network, and WRIHTE has established large regional networks in north China, east China and middle China and networks in 4-5 provinces have already been connected together.

The target is to establish a national LLS network as soon as possible, promulgate lightning information to society and contribute to avoid disasters with the use of the Internet and modern information technology.

3.3 Pay more attention to accumulate lightning observation data

Mass lightning data have already been collected in China, and these data, which could not be recollected in nature, are invaluable. However, these data may be missed for lacking corresponding methods to collect and process. Therefore, we should retrieve historical data, establish corresponding systems, and implement unified standards to process these collected data and store their potential values.

References

\begin{itemize}
  \item [1] Li Shengcai, Wang Yajun, Huang Ping(2004) Statistics of environment accidents in China during period May to August in 2004[J]. Journal of Safety and Environment, 4(5):89-96 (in Chinese)
  \item [2] Wen Yinping(2004) Study of lightning location technology and lightning information system[D]. Wuhan: HUST (in Chinese)
  \item [3] Wan Hua(2004) Research on the GPS location for lightning Dection Network[D]. Wuhan: HUST (in Chinese)
  \item [4] Xu Xiaofeng(2002) Technical analysis and construction of national lightning detecting network[J]. Engineering Science, 4(5):7-13 (in Chinese)
  \item [5] van House D L, Tuel J V(1996) National lightning detection network and the accident analysis and lightning location system[C]. 1996 International Lightning Detection Conference, Tucson Arizona, USA
  \item [6] Cummins K L, Pyle R B, Fournier G(1999) An integrated north American lighting detection network[C]. ICAE’99, Guntersville, Alabama, USA
  \item [7] Cummins K L, Krider E P, Malone M D(1998) The U.S. national lightning detection network and applications of cloud-to-ground lightning data by electric power utilities[J]. IEEE Transactions on Electromagnetic Compatibility, 40(4):465-480
  \item [8] Zhao Wenguang, Wen Yinping, Wu Weining(2002) Lightning location system and its application[C]. Progress in Safety Science and Technology, Shandong, China
  \item [9] Wu Pusan(1991) The lightning location system[J]. High Voltage Engineering, (4): 1-6 (in Chinese)
  \item [10] Xiao Li, Kang Wenbin, Wu Pusan(1992) Lightning position analyzer[J]. High Voltage Engineering, (2): 2-8 (in Chinese)
\end{itemize}
Chinese)

[11] Wu Pusan, Chen Jiahong, Xiao Li (1992) Selection of site of lightning direction finder[J]. *High Voltage Engineering*, (3): 44-50 (in Chinese)

[12] Kang Wenbin, Wu Weining, Xiao Li (1992) The lightning location signalizer with geographic simulation of power system[J]. *High Voltage Engineering*, (3): 40-43 (in Chinese)

[13] Wu Weining, Zhang Wenliang, Wu Pusan (1992) The development of intelligent remote display terminal (IRDP) of lightning location system[J]. *High Voltage Engineering*, (3): 36-39 (in Chinese)

[14] Chen Jiahong, Xiao Li, Kang Wenbin (1992) The lightning direction finder[J]. *High Voltage Engineering*, (3): 31-35

[15] Wu Pusan (1995) The lightning direction-finding location system and time difference system[J]. *High Voltage Engineering*, 21(9): 3-6 (in Chinese)

[16] Zhao Wenguang (1996) The position computation of lightning location system[J]. *High Voltage Engineering*, 22(1): 9-11 (in Chinese)

[17] Zhao Wenguang (1997) Spheroid geodesy study[M]. Wuhan: China University of Geoscience Press (in Chinese)

[18] Zhao Wenguang, Chen Jiahong, Zhang Qin, et al. (1999) Position computation on new combined lightning location system[J]. *High Voltage Engineering*, 25(4): 66-68 (in Chinese)

[19] Zhang Qin, Wang Guangcai, Wu Weining, et al. (2000) Error estimation on a new combined lightning location system[J]. *High Voltage Engineering*, 26(2): 54-64 (in Chinese)

[20] Zhao Wenguang, Hu Bin, Wu Weining, et al. (2001) The resolving of the lightning location based on time-of-arrival method under the special circumstances[J]. *High Voltage Engineering*, 27(4): 10-12 (in Chinese)

[21] Zhao Wenguang, Wu Xianzhi, Wu Weining (2001) The analysis of the error of the figure factor in the lightning location system based on the time-of-arrival method[J]. *High Voltage Engineering*, 27(4): 8-9 (in Chinese)

[22] Zhao Wenguang, Wen Yinping, Zhang Wenliang, et al. (2001) The analysis of the operation data in the lightning location system[J]. *High Voltage Engineering*, 27(5): 1-8 (in Chinese)

[23] Zhao Wenguang, Wang Hua, Wu Weiniang, et al. (2001) Lightning location system and lightning information system[J]. *International Journal Hydroelectric Energy*, 19(4): 59-62

[24] Chen Jiahong, Zhang Qin, Wu Weining (2001) The model of distributed lightning information system based on COM+ technology[J]. *High Voltage Engineering*, 27(6): 48-50 (in Chinese)

[25] Ji Jianmin, Zhang Qin (2001) The construction and application of Shanxi lightning location system[J]. *High Voltage Engineering*, 27(1): 77-81 (in Chinese)

[26] Zhao Wenguang, Zhang Ruifang, Wu Weining (2002) Precision estimation of lightning detection network[J]. *Journal of Huazhong University of Science and Technology (Urban Science)*, 19(1): 58-60 (in Chinese)

[27] Zhou Yanling, Li lijiat (1997) Development and application of lightning spotting system[J]. *China Electric Power*, 32(7): 31-35 (in Chinese)

[28] Sun Youhung, Ren Jingqi, Yan Ping, et al. (2004) Survey on factors influencing the lightning strike trip-out rate[J]. *High Voltage Engineering*, 30(12): 12-14 (in Chinese)

[29] Wang Qunjun, Liu Haijun, Zheng Shiling (2005) Analysis of lightning stroke tripping on 500 KV Transmission lines[J]. *High Voltage Engineering*, 31(1): 85-86 (in Chinese)

[30] Wu Weining, Zhao Wenguang (2004) Analysis of the lightning location system calculation[C]. WEC2004, Shanghai, China

[31] Zhao Wenguang, Zhang Ping, Wu Weining (2004) The lightning fault quick location and its application[C]. WEC2004, Shanghai, China

[32] Zhao Wenguang, Nie Zhiping, Wan Hua, et al. (2005) Lightning locating system and GPS[C]. The 14th International Symposium on High Voltage Engineering, Beijing, China

[33] Wu Weining, Zhao Wenguang, Wang Hua, et al. (2005) The lightning location system application in China[C]. The 14th International Symposium on High Voltage Engineering, Beijing, China

[34] Nie Zhiping, Zhao Wenguang, Wen Yinping, et al. (2006) Data processing of the lightning location system[M]// Huang Ping. Progress in safety science and technology. Beijing: Science Press