Research Progress of On-line Monitoring Technology for Electromagnetic Environment of Power Transmission and Transformation Projects

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Abstract Based on the collection of relevant literature and cases, the research and application status of on-line monitoring technology for electromagnetic environment of power transmission and transformation projects at home and abroad were introduced. Moreover, the problems existing in the on-line monitoring of electromagnetic environment were expounded, and the development prospect was forecasted.

Key words On-line monitoring technology; Electromagnetic environment; Power transmission and transformation project

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With the development of China's social economy, urban power supply load has grown rapidly, and power transmission and transformation projects have developed rapidly. As of 2018, the power grid of Jiangsu Province has more than 2 990 substations (35 kV and above) and 87 000 km of transmission lines, and the scale of the power grid exceeds that of the United Kingdom and Italy. The construction of power transmission and transformation projects will inevitably bring about the impact of electromagnetic environment and other problems while supporting economic and social development. As the public's awareness of safeguarding their own environmental protection rights and interests continues to increase, the electromagnetic environment problem brought about by power transmission and transformation projects has received attention day by day. In recent years, complaints and disputes arising from electromagnetic environment problems in power transmission and transformation projects have occurred frequently, and malignant mass incidents in which the public obstructs the construction of power transmission and transformation projects have occurred from time to time, seriously affecting the construction and safe operation of power grids[1-3]. According to statistics, the environmental protection complaints of power transmission and transformation account for about one-third of the complaints received by the national environmental protection department, especially in some provinces and cities in relatively developed regions such as East China and North China.

Electromagnetic environment monitoring is an important part of the environmental protection work of power transmission and transformation projects as well as an important basis for the environmental protection acceptance assessment of environmental protection facilities for power transmission and transformation projects. Its effective monitoring has become one of the important indicators of the scientific level of environmental management. Power transmission and transformation projects are distributed widely, and the sites are scattered. At present, the electromagnetic environment monitoring of power transmission and transformation projects is mostly manual on-site monitoring, which has low efficiency and poor timeliness. It is difficult to achieve full-time and all-round dynamic monitoring. Meanwhile, a large number of monitoring data should be stored in the form of paper documents, and it is difficult to perform large-scale query, statistics and analysis[4].

Compared with traditional environmental monitoring methods, on-line monitoring technology has obvious advantages in acquiring and storing large amounts of environmental data, improving environmental monitoring methods, solving environmental dispute arbitration and emergency, supporting decision-making and management of environmental management departments and meeting the public's environmental informed rights and requirements, and has been rapidly developed and widely used in the monitoring of pollution sources of wastewater and exhaust gas[5-7]. However, it has not received sufficient attention in the field of electromagnetic environment monitoring, especially in the electromagnetic environment monitoring field of power transmission and transformation projects. In this study, the research and application status of on-line monitoring technology in the electromagnetic environment monitoring field of power transmission and transformation projects were analyzed, and its shortcomings and future development trend were discussed.

1 Current status of on-line monitoring technology of electromagnetic environment at home and abroad

1.1 Foreign countries European countries started early in

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the on-line monitoring field of electromagnetic environment. The major cities such as Italy, Britain, Spain, Switzerland, Germany, and Greece have started the automatic monitoring of electromagnetic environment since 2002, and the monitoring data have been all published on the network. However, the above monitoring systems are mainly used to monitor radio frequency (RF) electric fields (frequency range 100 kHz – 3 GHz) of broadcasting, television, mobile communication base stations, *etc.*, and there are few monitoring systems for low-frequency electric fields and magnetic fields (1 Hz – 10 kHz) around power transmission and transformation projects. Taking Italy as an example, Italy has relatively sound electromagnetic radiation regulations and standards, and the electromagnetic radiation management system is relatively mature. From 2003 to now, nearly 8 000 automatic monitoring stations of electromagnetic environment have been built in the major cities of Italy, of which only about 20 sets can measure electromagnetic environment for power transmission and transformation projects, and Italian Environmental Affairs Center and other functional organizations are responsible for the investment and release of monitoring data. After an on-line monitoring system of electromagnetic environment was installed widely in Italy in 2003, the public's complaint rate plummeted by 52%, creating a good space for the development of related industries and bringing a good order for environmental management[8]. The current basic conditions of cities conducting on-line monitoring of electromagnetic environment in foreign countries are shown in Table 1.

Table 1 On-line monitoring of electromagnetic environment in foreign countries

China	Project name	Monitoring content	Number	Construction year
Greece	HERMES, Pedion24 and FASMA	RF electric field	106, 160 and 30	2002, 2006 and 2008
Germany	EMF-Datebank	RF electric field	14	2007
Italy	Fond azione Bordoni	RF electric field and power frequency electric field	7 920	2002
Portugal	monIT	RF electric field	144	2007
Switzerland	REMS-Netwok	RF electric field	25	2003
United Kingdom	Cassiopea	RF electric field	110	2004

1.2 China In China, the research on the on-line monitoring system for electromagnetic environment of power transmission and transformation projects started late. The main research institutions are local power grid companies, and relevant scholars have deepened their research.

Since the country put forward the strategic policy of "building a resource-saving and environment-friendly society" and "developing a green economy and a low carbon economy", power grid companies across the country have set off a wave of building green power transmission and transformation projects, and the on-line monitoring technology of electromagnetic environment has also developed rapidly.

The on-line monitoring of power frequency magnetic field 220 kV Wangjing substation in Beijing is the first on-line monitoring project of electromagnetic environment for power transmission and transformation projects in China. The 220 kV Wangjing substation is a part of the Olympics in 2008. Due to the large opposition from the public around the construction site, it is difficult to determine the substation site. In order to stabilize the society during the Olympics, the state provides financial allocation to the Beijing Environmental Protection Bureau to build an on-line monitoring project for the power frequency magnetic field of the substation. After the completion of the project, Beijing Radiation Station was responsible for the public release of monitoring data. Subsequently, power grid companies in Shanghai, Guangdong, Jiangsu, and Zhejiang carried out research and pilot work on the on-line monitoring technology of electromagnetic environment for power transmission and transformation projects. The current basic conditions of cities conducting on-line monitoring of electromagnetic environment in China are shown in Table 2.

Table 2 On-line monitoring technology of electromagnetic environment for power transmission and transformation projects in China[8]

City	Substation form	Voltage//kV	Monitoring content	Data display mode
Shanghai	Tacheng indoor substation, and Jing'an underground substation	35 and 500	Power frequency electric field, magnetic field, and noise	Display screen at the station gate
Beijing	Wangjing indoor substation	220	Power frequency electric field	Display screen at the station gate
Shenzhen	Binhe indoor substation	220	Power frequency electric field and magnetic field	Display screen at the station gate
Nanjing	Indoor substations on HuaiHai Road, at Gupinggang, and in Houzaixiang	110	Power frequency electric field and magnetic field	Display screen at the station gate
Hangzhou	Henghe indoor substation	110	Power frequency electric field, magnetic field and noise	Display screen at the station gate
Suzhou	Xumen indoor substation	110	Power frequency electric field and magnetic field	Display screen at the station gate
Zhenjiang	Shuangjing indoor substation	110	Power frequency electric field and magnetic field	Display screen at the station gate

Except that local power grid companies have carried out pilot work on on-line monitoring technology of electromagnetic environment for power transmission and transformation projects, relevant scholars have deepened the research on the overall structure of the on-line monitoring system and the influencing factors of each link. Feng Zhihui *et al.* [9-10] introduced the distributed architecture into the on-line monitoring field of electromagnetic environment for power transmission and transformation projects, optimized the overall architecture and functional system of the monitoring system, and designed clear and logical software system through standardized hierarchical analysis, which increases the reuse rate of enterprise objects, reduces the maintenance cost of the entire system, and improves the scalability, fault tolerance and load balancing capability of the application system. Zhang Guangzhou *et al.* [11] optimized the on-line monitoring system from the sensor parameter design, signal processing circuit and non-magnetic bracket of power frequency electric field, and used the Lagrangian interpolation method to linearly correct the sensor, which could improve the sensitivity and linearity of the sensor and the monitoring capability of the on-line monitoring system under high humidity conditions. Through studying the setting of electromagnetic on-line monitoring systems at home and abroad, Chen Wenlong *et al.* [8] preliminarily discussed the quality assurance system of the on-line monitoring system from the rationality of measurement method, measurement accuracy of monitoring instrument, data transmission system, maintenance and so on, and discussed the reliability of data and the authority of departments releasing monitoring data. At the same time, it was proposed that shielding and other measures can be used to solve the problem of larger value of power frequency electric field by an on-line monitoring system in a high-humidity environment. Long Yu *et al.* [12] proposed a new power management system and physical isolation module design method by analyzing the interference of direct power supply to the on-line monitoring system, which could reduce the measurement error caused by the introduction of the power cable and solve the problem of power supply for long-term operation of the sensor. Sun Tao *et al.* [13] analyzed the influence of humidity on the measurement of power frequency electric field, and believed that the distortion of the electric field near the probe caused by the change of the insulation performance of the instrument bracket is the main reason for the larger measurement data. Moreover, it was proposed that using hydrophobic organic insulating materials or smearing silicone grease and other hydrophobic compounds on the stand to reduce the influence of humidity on the insulation performance of the stand can reduce the influence of high-humidity conditions on the measurement data of the monitoring system.

2 Problems in the on-line monitoring of electromagnetic environment

2.1 Foreign countries Although the on-line monitoring of electromagnetic environment in foreign countries started earlier, due to the limit of technical conditions at that time, there are some problems as follows.

Firstly, RF electric fields (frequency range 100 kHz – 3 GHz) of broadcasting, television, mobile communication base stations, *etc.* are mainly monitored, and the electromagnetic environment of AC transmission and transformation projects (1 Hz – 10 kHz low-frequency electric fields and magnetic fields) is less monitored.

Secondly, the on-line monitoring system usually has no display screen, so the monitoring results are shown only on the website and can be downloaded every 4 h. It cannot provide real-time data to the public and management departments. At the same time, the public cannot obtain environmental data in time and satisfy their strong right to know.

Thirdly, data transmission technology is backward. GPRS wireless mode is usually adopted, and data transmission is unstable and easy to be lost.

Fourthly, The functions of the system only include data acquisition and display, and there is a lack of data post-processing and analysis.

2.2 China In recent years, the research and pilot work on the on-line monitoring technology of electromagnetic environment for power transmission and transformation projects have been carried out in some areas of China, and the shortcomings of similar systems in foreign countries have been overcome, but there are still some problems as follows.

2.2.1 Low coverage and single function. In China, the on-line monitoring system of electromagnetic environment is constructed with the intention of solving the environmental protection disputes during the construction of power transmission and transformation projects. At present, only the substations where the opinions of surrounding residents are concentrated and the location of urban substation construction cannot be reached are monitored on-line except general substations and transmission lines. At the same time, the monitoring system has a single function, and can only display the real-time monitoring results through a large screen. The overall structure and function system of the monitoring system is not systematically designed and optimized. Functions such as abnormal data analysis, historical trend analysis and early warning are not developed. The monitoring points are independent of each other, and they are not organically linked together by Internet technology to realize the analysis and sharing of big data.

2.2.2 Quality assurance system needs to be improved. There is a lack of a complete quality assurance system, and data acquisition instrument selection, point setting, data transmission mode, maintenance, *etc.* are not standardized and unscientific, and often lead to data anomalies, instability and so on.

2.2.3 Real-time monitoring under full meteorological conditions are not achieved. In the case of high humidity (>80%), the measurement error of power frequency electric fields is large[14-15]. At present, the on-line monitoring system of electromagnetic environment running in various places does not pro-

pose effective control measures or solutions to the influence of high-humidity environment on the measurement value of power frequency electric fields.

2.2.4 Lacking relevant supporting technical specifications. Affected by factors such as the layout of electrical equipment in a substation and lines outside a station, the distribution of electromagnetic environment around the substation is complex. Considering the safety of equipment in the monitoring system and the investment of funds, it is necessary to use as few monitoring probes as possible to reflect the actual electromagnetic environment around the substation. This needs to formulate relevant supporting documents for on-line monitoring distribution methods and technical requirements for power transmission and transformation projects. Although there are technical specifications and standards for electromagnetic environment monitoring of power transmission and transformation projects in China, they are all aimed at manual handheld equipment monitoring. There is a lack of relevant specifications for on-line monitoring systems, which makes the on-line monitoring of electromagnetic environment difficult and then results in insufficient data quality control and chaotic management.

2.2.5 Lacking effective connection with management departments. At present, the on-line monitoring system of electromagnetic environment is implemented mostly by power grid companies in China, and it has not been effectively connected with the supervision system of environmental management departments. As a result, environmental management departments cannot obtain effective data in time in the supervision work, and on-line monitoring data have not been supervised by environmental management departments.

3 Development trend of on-line monitoring of electromagnetic environment

3.1 Informatization of the on-line monitoring system of electromagnetic environment Based on the integration of on-line monitoring systems and modern information technology, advanced means and methods such as global positioning system (GPS), geographic information system (GIS), automatic control technology, network and communication technology, database technology, and management information system (MIS) are used to realize real-time and high-precision on-line monitoring of electromagnetic environment of power transmission and transformation projects. Meanwhile, according to the environmental protection management requirements and policy requirements of power transmission and transformation projects, massive electromagnetic environment data are analyzed deeply, and a variety of environmental business analysis models are established to automatically complete the multi-dimensional coupled statistical analysis of monitoring data and provide data analysis results for multiple topics or dimensions. Finally, the on-line monitoring platform of electromagnetic environment with automatic collection and sharing of business information, real-time monitoring of electromagnetic environment, change trend analysis and over-standard warning, full-process quality control, and multi-dimensional analysis of decision management is realized.

3.2 Standardization of the on-line monitoring system of electromagnetic environment It is necessary to study and formulate technical specifications and standards for the on-line monitoring system of electromagnetic environment, standardize the general requirements, technical content, quality assurance, data processing, and system verification of the monitoring system, and improve the scientific, procedural, standardized, and refined level of the monitoring system through standardized means. At the same time, from the data acquisition equipment selection, installation, data transmission methods, data analysis and storage, and maintenance, a sound quality assurance system for an on-line monitoring system is established to form a standardized system.

3.3 Real-time monitoring without the restriction of meteorological conditions High-humidity environment will affect the measurement value of power frequency electric fields, resulting in a large measurement result. It is a constraint factor that the monitoring system cannot realize real-time monitoring under full meteorological conditions. By optimizing the internal structure of monitoring probes and developing a new type of hydrophobic insulating material bracket, the problem can be solved.

3.4 On-line monitoring system of electromagnetic environment for direct current transmission projects UHV DC transmission technology is a strategic approach to achieve a large-scale optimization of energy allocation in China, as well as one of the most advanced transmission technologies in the world. As of November 2017, China has completed ten ±800 kV UHV DC transmission projects among the 18 UHV transmission lines. Due to the existence of space charge, the electromagnetic environment around the HVDC projects is more complicated than the AC transmission projects, and there are more electromagnetic environment parameters to be controlled. Higher requirements are imposed on the monitoring system of electromagnetic environment. Currently, there is no DC transmission project. Research and application of on-line monitoring of electromagnetic environment. There is no research and application work for on-line monitoring of electromagnetic environment for HVDC projects.

4 Conclusions

With the continuous deepening of urbanization construction, more and more high-voltage power transmission and transformation facilities need to go deep into the main urban area and densely populated areas, and the electromagnetic environment problems brought about by power transmission and transformation projects will receive increasing attention. The on-line monitoring system of electromagnetic environment has obvious advantages in respect of acquiring and storing large amounts of environmental data, improving environmental moni-

toring methods, solving environmental dispute arbitration and emergency, supporting decision-making and management of environmental management departments, and meeting the public's environmental informed rights and requirements. It has great application potential in the environmental protection work of power transmission and transformation projects. Although some research results have been obtained at present, how to improve the informationization and standardization level of the system, realize real-time monitoring without the restriction of meteorological conditions, and promote the engineering and industrialization of this technology is worthy of attention.

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(From page 66)

by not accepting incentive contract. It does not correspond with the assumption that enterprises seek the maximization of their own utility, and enterprises will not accumulate ecological capital.

(3) If adding comprehensive utility β shared by enterprises, when ρ and σ_θ^2 are $1-b\rho\sigma_\theta^2>0$, seen from $\alpha=\overline{w}-\frac{\beta^2}{2b}(1-b\rho\sigma_\theta^2)$, government should decrease fixed subsidy α to enterprises. When $1-b\rho\sigma_\theta^2<0$, government should increase fixed subsidy α to enterprises.

(4) Since agency cost grows with measurement ρ of enterprise risk aversion rise, government should vigorously publicize ecological capital accumulation, and make enterprises understand important significance of ecological capital accumulation, further declining risk aversion measurement ρ of enterprises accumulating ecological capital, which is favorable for government decreasing agency cost of ecological capital accumulation.

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