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Lightning Strike Risk Assessment and Lightning Protection Approach for Highway Electromechanical Equipment

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Abstract. To ensure the normal operation of highway electromechanical equipment and avoid lightning disasters, it is necessary to design lightning protection devices in the highway electromechanical system. However, due to factors such as the technical level and life limit of the lightning protection device, some lightning protection devices are over-aged, and often fail, resulting in frequent lightning damage to the electromechanical system equipment. In this study, the design and comprehensive evaluation of the current lightning protection devices was carried out to ensure that they can work normally. Safety analysis was performed on the electromechanical system lightning protection device to ensure the safe and stable operation of the electromechanical system.

1. Introduction

The electromechanical system of the highway is a complex electronic system consisting of a large number of weak electrical equipment such as monitoring, communication and sensing equipment. If the electromechanical system does not been designed to the protection of lightning strike, it is easy to suffer the harm of direct lightning strike or lightning electromagnetic pulse, which causes the electromechanical system to lose functions or all system defects. This situation would bring great hidden dangers to the safe operation of the highway.

An important factor affecting the normal operation of highway electromechanical systems is lightning strike. Since most of the highway electromechanical systems are installed in an open environment, especially some electromechanical equipment is installed independently at high altitude. The natural environment here is more complicated so that it is more vulnerable to lightning strikes. In recent years, electromechanical equipment has suffered frequent lightning strikes, and some have caused damage to individual equipment modules, another more seriously has directly caused the collapse of all electromechanical systems. The normal operation of the electromechanical system is the basic guarantee for the safe operation of the highway. Once the operation of the electromechanical equipment is in trouble, the management personnel will not be able to carry out traffic problems such as large-scale vehicle detention and traffic jams caused by normal traffic dispatch, causing unnecessary losses to the state and enterprises. It even endangers the safety of people.

Because of this, the engineering field has carried out research and application on lightning protection measures for highway electromechanical systems. Wang ^[1] analyzed the general causes of frequent lightning strikes and proposed measures to strengthen the lightning protection of highway electrical and mechanical equipment. Yin ^[2] put forward the focus of lightning protection design in the design of highway electromechanical system by analyzing the lightning strike characteristics and lightning protection system of electromechanical systems. Sun et al ^[3] proposed lightning protection method for the detection of highway toll station. In addition, active lightning protection has also carried out some



trial work. Yang ^[4] took advantage of lightning location information to analyzed the lightning activity rhythm area. In this way, the estimation results of lightning damage and spatial and temporal distribution of lightning can be obtained. Zhang ^[5] introduced the mobile data acquisition technology to the highway lightning inspection in order to make the lightning protection devices play an effective role.

The above work has certain guiding significance for the lightning protection of highway electromechanical systems. However, due to factors such as technical level and life limit, some lightning protection devices are over-aged and the often ineffective. These dynamic factors need to be analyzed and evaluated to design and comprehensively evaluate the current lightning protection devices to ensure that they can work normally.

2. Influence of lightning on highway electromechanical equipment

The highway electromechanical system consists of basic technologies such as electronic and electrical technology, computer network technology, communication technology, and electrical control technology. The highway electromechanical system includes monitoring systems, communication systems, toll collection systems, and lighting power supply and distribution systems. The communication system provides network transmission services for the safe operation of the highway; the monitoring system is composed of the information collection system, the information distribution system and the central information processing system; the charging system is composed of the front-end lane charging equipment, the transmission network and the background charging processing system; The electrical system consists of external electrical access, high and low voltage power distribution equipment, diesel generators and uninterruptible power supplies.

Lightning damage of electromechanical equipment is mainly divided into direct lightning and induction lightning. Direct lightning strikes contain great energy, and the voltage peak can reach 5000 kV, which has great destructive power. If the lightning strikes directly on the building and the electrical facilities connected to the grounding of the foundation, the ground potential level of the grounding grid will be raised by tens of thousands or hundreds of thousands of volts within a few microseconds. Highly damaging lightning currents generate powerful electromagnetic waves and extremely high heat, induce extremely high pulse voltages on power lines and signal lines, damage power supply or data network systems. And it may cause a fire or explosion accident, which can cause the electromechanical equipment system to collapse in an instant.

The inductive lightning mainly generates high induction voltage hazard to the electromechanical equipment through the power cable and communication line of the electromechanical equipment. Trough analysis of the case of inductive lightning, the current hazards of inductive lightning on the electromechanical system are as follows:

1) Lighting and power supply and distribution system: The high and low voltage cables in the highway system will directly become “thunder transmission lines” in the event of lightning strikes. And lightning strikes will invade into the electromechanical system through the lines, thus causing damage to the lighting power supply and distribution equipment.

2) Communication system: Similar to the power supply and distribution system, the dual-stranded wires, coaxial cables, fiber optic cables and other media in the communication system are struck by lightning into the transmission line, resulting in the communication signal transmission equipment can not accurately transmit and damage the electrical equipment.

3) Monitoring system: The monitoring equipment is mainly concentrated in the monitoring and control center of the sub-center. Other equipment is scattered in the field outside the road. The monitoring equipment is mostly weak-electric system electronic equipment, which is susceptible to lightning impulses. For example, the transmission device interface is damaged, the monitor wall has no image, and the surveillance camera and other terminal devices are damaged.

4) Charging system: The lightning intrusion of the charging system is mainly for various direct lightning strikes and transient over voltages, which mainly cause the failure of the charging management computer, the lane control machine, the automatic railing machine or the damage of the power terminal.

3. Lightning risk and lightning protection reform of highway electromechanical facilities

3.1 Lightning strike risk assessment of highway electromechanical system

Due to the constraints of the project, the lightning protection of the highway electromechanical system should be based on the environmental factors of the system, the importance of the system and the severity of the consequences of the lightning strike. After a comprehensive evaluation, we determine the degree of protection of the lightning impulse electromagnetic pulse of the electromechanical system, and then take corresponding protective measures.

Lightning risk assessment can be calculated according to the following empirical formula to determine the electromechanical system lightning electromagnetic pulse protection level:

$$E = 1 - N_c/N \quad (1)$$

Where N_c is the maximum annual average number of lightning strikes acceptable for the region. This is related to the importance of the equipment, the impact resistance of the electromechanical system, and the protective measures in the area where the equipment is located. N is the expected annual average number of lightning strikes of the building where the electromechanical system equipment is located, and it can be calculated by the following formula:

$$N = K N_g (A_e + A_e') \quad (2)$$

Where N_g is the average density of the lightning strike; A_e is the equivalent area of the building (larger than the actual area); K is the correction factor.

According to the above process, the degree of protection required for electromechanical equipment can be obtained. Referring to the study by Liang et al [6], the degree of protection is determined according to the following threshold.

- 1) $E > 0.98$ is class A;
- 2) $0.95 < E \leq 0.98$ is class B;
- 3) $0.8 < E \leq 0.95$ is class C;
- 4) $0.8 \leq E$ is class D.

3.2 Lightning protection reform measures for highway electromechanical systems

The lightning protection design of highway electromechanical systems should adopt comprehensive protection measures such as direct protection, inductive lightning protection and lightning wave intrusion protection. In general, it includes two parts: external lightning protection and internal lightning protection, as shown in Figure 1.

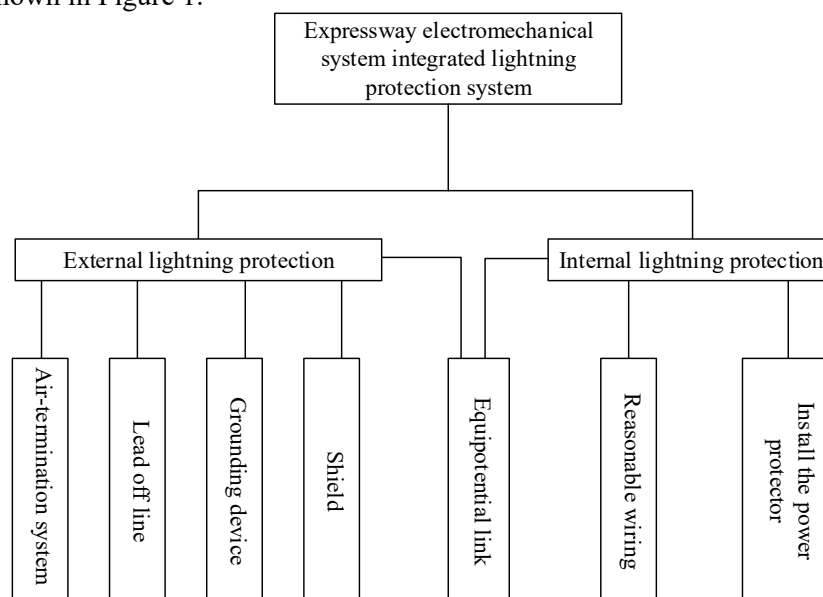


Figure 1. Highway electromechanical system lightning protection system

- 1) External lightning protection

It is mainly used for lightning protection work of high-rise buildings or power-inducing equipment. In terms of technology, it mainly deals with lightning protection measures such as lightning receptors, down conductors, grounding devices and Faraday cages.

Air-termination system: according to the actual situation of the building's location, existing structural features and importance, we consider whether to adopt lightning rod, lightning belt and lightning shield combined lightning connection mode.

Lead off line: we consider whether the mechanical strength meets the standard, whether the corrosion resistance and heat stability, the size of the fracture area, whether the connection is firm.

Grounding device: A good grounding system is a key link in lightning protection design. As an intermediary to send lightning current into the earth, it is necessary to use this kind of lightning in various forms of lightning strikes such as direct lightning strike or inductive lightning. In order to safely divert lightning energy to the earth and avoid excessive damage to the equipment, the lightning protection grounding design applied to the weak electrical equipment existing inside the road electromechanical system machine should be remedied by means of integrated wiring. Doing lightning protection grounding is an effective measure to avoid counter-shock voltage damage to the system in time.

AC power supply lightning protection grounding: It is mainly the neutral point of the transformer. In order to avoid the impact of the induced current through the line impact transformer on the safety of the equipment when the power supply line is struck by lightning, the neutral point of the transformer needs to be directly grounded. In this way, even in the event of an accident, the transformer can automatically trip to protect the safety of the equipment.

Grounding of metal casing: Some electromechanical equipment are insulated or collided due to long periods of inactivity. Once the device loses its conductive function, it will cause current to flow through the device-person-earth, which poses a safety threat to the operator. Therefore, in consideration of the safety of the operator, the ungrounded metal part of the electromechanical equipment during operation should be properly grounded. In the case of normal insulation of the device, the leakage current is directly introduced into the earth.

DC working ground: DC working ground ensures that all microelectronic devices are in the same low voltage DC system to prevent interference from external power sources. Therefore, a joint grounding system consisting of power distribution room and computer room monitoring is generally established in the toll station. It can effectively reduce electromagnetic interference between electronic devices to ensure the stability of electronic devices. In order to ensure the efficient operation of the grounding device in the station area, no less than two 40mm metal flat steel grounding devices should be installed to avoid the occurrence of ground potential counterattack.

2) Internal lightning protection

The electromechanical facilities include two parts: the external field and the monitoring room. The lightning protection measures for the entire electromechanical system mainly include power lightning protection and signal lightning protection, as shown in the following figure.

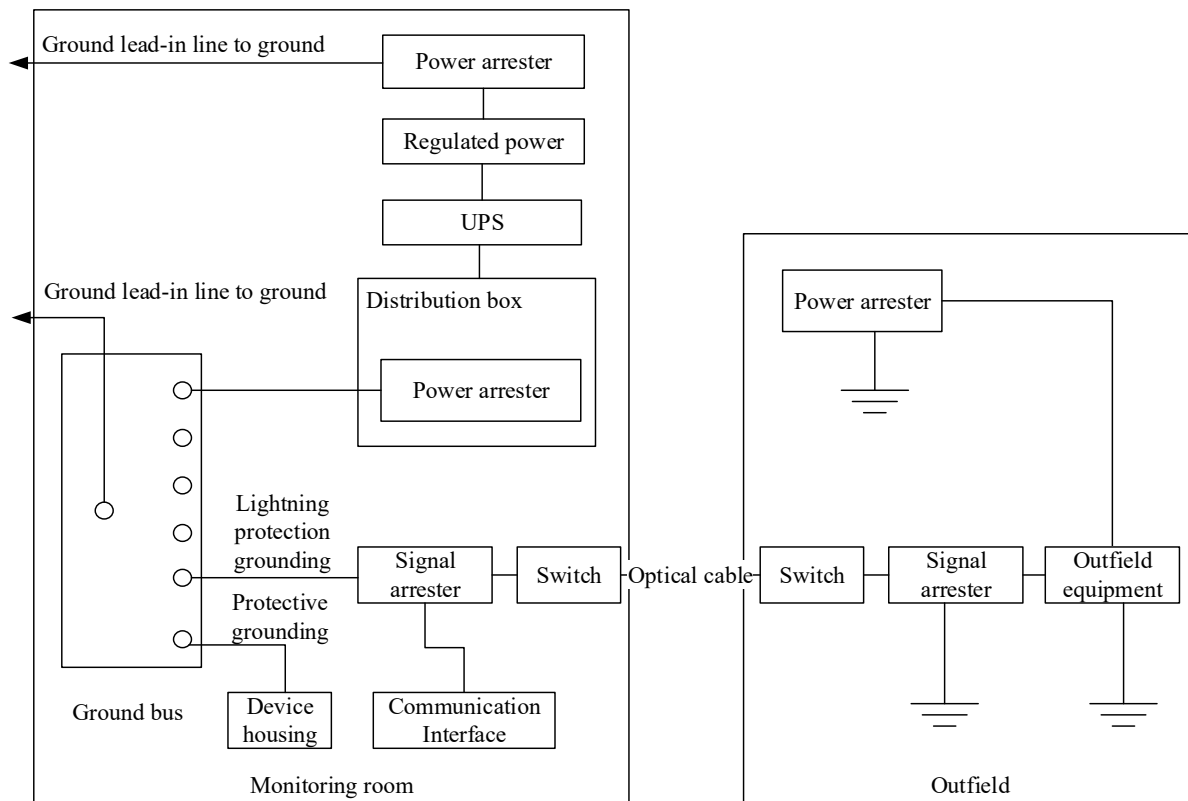


Figure 2. Schematic diagram of lightning protection and grounding

Power supply lightning protection: In order to prevent interference damage caused by lightning and over-current and voltage, we should adopt TN-S protection measures in the power supply system. Through the observation and research on the disasters of direct lightning and inductive lightning, in order to improve the safety factor, at least two levels of power lightning protection devices should be installed.

Signal lightning protection: In addition to metal cables, other weak electrical signals and control cables are also vulnerable to lightning strikes, which become a medium for lightning strikes and high voltage transmissions that damage equipment. To eliminate the impact of lightning caused by signals, we can consider the following aspects: laying the route as much as possible in areas with low resistivity such as plains and paddy fields; laminating wire with a diameter of 8mm is laid about 30cm above the buried cable; a lightning arrester is required to discharge the lightning current of the intruding cable every 200m between the cable cores.

4. Conclusions

Lightning strikes bring security threat to the normal operation of highway electromechanical equipment. Electromechanical systems without perfect lightning protection devices have serious safety hazards. At present, there are many deficiencies in lightning protection measures for highway electromechanical systems. It is necessary to carefully analyze the data of lightning strikes, strengthen the awareness of lightning protection of employees, prepare relevant lightning protection monitoring technical specifications, and improve the professional quality of relevant personnel to strengthen the prevention of lightning damage, ensure the normal operation of highway electrical and mechanical equipment, and make electromechanical engineering. It enables electromechanical engineering to better serve the construction and operational needs of the road. In addition, it is necessary to dynamically evaluate the risk of lightning strikes on highway mechanical and electrical equipment, use information means to predict the risk of lightning strikes, and carry out targeted transformation and active prevention and control.

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