A Preliminary Study on the Architecture Design of Comprehensive Lightning Protection Technology for Alpine Radio Transmitting Stations (Postprint)

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Abstract

The special and complex nature of the geographical and climatic environment at high-altitude wireless transmission station locations poses great challenges to the safe broadcast of programs and the life safety of on-duty personnel during thunderstorm seasons; scientifically and rationally planned and designed lightning protection facilities can provide reliable guarantee for the safe broadcast of high-altitude stations during thunderstorm seasons.

Full Text

A Brief Discussion on the Architecture Design of Comprehensive Lightning Protection Technology for High-Altitude Wireless Transmission Stations

Abstract: The unique geographical and climatic conditions at high-altitude wireless transmission stations pose significant challenges to safe broadcasting during thunderstorm seasons and threaten the lives of on-duty personnel. Scientific and rational planning of lightning protection facilities can provide reliable guarantees for safe broadcasting at mountain stations during thunderstorm seasons.

Keywords: high-altitude wireless; transmission station; lightning protection technology; architecture design

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Lightning protection technology is a critical component for any high-altitude transmission station, as it directly affects the normal and safe operation of the facility. Zhaotong is located in northeastern Yunnan Province at the junction of Yunnan, Sichuan, and Guizhou provinces, historically known as "the key to southern Yunnan and the throat of western Sichuan." The region is characterized by numerous mountains and deep valleys, with Liangfengtai forming the third highest peak in the area due to its unique geographical environment. This paper briefly introduces the lightning protection facilities and architectural design tailored to the specific conditions of the Liangfengtai high-altitude transmission station of Zhaotong Radio and Television Relay Station, providing a reference for technical research and industry peers.

The Liangfengtai transmission station of Zhaotong Radio and Television Relay Station is situated atop Liangfengtai Mountain in Xiaolongdong Township, Zhaoyang District, Zhaotong City, Yunnan Province. The site features steep slopes at an altitude of 3,154 meters with extremely harsh natural conditions. Throughout the year, the area is often shrouded in clouds and mist or covered in ice and snow, with consistently low temperatures and dry climate. The region experiences 47 thunderstorm days annually, classifying it as a high-lightning area. It is designated as a national Class-A hardship station and serves as the highest-altitude, most heavily tasked, and highest-power mountain backbone wireless transmission station in northeastern Yunnan. Despite the harsh environment and numerous difficulties, since its establishment in 1984, the Zhaotong Liangfengtai transmission station has continuously undertaken wireless transmission and coverage tasks for major central, provincial, and municipal radio and television programs, operating 24 hours a day with dedicated personnel on duty. The broadcast coverage extends to Zhaoyang, Ludian, Daguan, Yiliang, and other counties and districts, benefiting approximately 3.5 million people.

The unique geographical location and complex climatic environment of high-altitude wireless transmission stations make them particularly vulnerable to lightning strikes during thunderstorm seasons. Typically, the transmission equipment room and the transmission tower are separated by dozens or even hundreds of meters. Without effective lightning protection measures, lightning can destroy feed lines that transmit high-frequency energy, cause severe damage to the equipment room, and threaten the lives of on-duty personnel. Therefore, how to scientifically and rationally design lightning protection measures for high-altitude wireless transmission stations to maximize the protection of broadcasting safety and personnel lives during thunderstorm seasons has become a critical research topic for the entire Zhaotong Radio and Television Relay Station, particularly at Liangfengtai.

Based on practical conditions, technical personnel reviewed extensive relevant materials, conducted repeated discussions and research, and performed multiple experiments to fundamentally understand the patterns of high-altitude lightning and identify feasible countermeasures and approaches.

1. Characteristics of Lightning Waves and Their Intrusion Paths

Lightning is a discharge process that occurs when convective clouds carrying positive and negative charges in the atmosphere meet and create intense friction, causing the upper and lower cloud layers to carry opposite charges while the lower layer induces a large amount of opposite charges on the ground surface, forming an enormous capacitor. When the electric field strength reaches a certain intensity, discharge to the ground occurs, creating the "lightning phenomenon."

1.1.1 Direct Lightning

Direct lightning refers to the discharge of thunderclouds directly to tall structures or electrical installations on the ground, generating enormous energy in an extremely short time. The discharge voltage and current are relatively large, and when the powerful lightning current passes through prominent ground objects into the earth, it produces tremendous destructive effects along with thermal and mechanical effects, directly causing power outages, communication interruptions, and even casualties in buildings, power plants, hospitals, and residential houses.

1.1.2 Induced Lightning

When charged thunderclouds approach tall structures, electrostatic and electromagnetic induction effects cause lightning current to transition from pilot discharge to main discharge, inducing high voltages in metal objects. Induced lightning at high-altitude transmission stations manifests in two primary forms: first, lightning surges induced into the equipment room through the power grid; second, lightning currents induced through transmission cables.

1.1.3 Lightning Waves

Lightning waves refer to high-potential impulse waves generated when transmission lines are struck by lightning or experience lightning induction. These impulse waves propagate at approximately 150 m/s in different directions without regular patterns, severely interfering with radio and television transmission and emission, and causing varying degrees of damage to critical equipment such as power supply systems, transmission systems, and satellite reception systems.

1.2 Lightning Intrusion Paths at High-Altitude Transmission Stations

Lightning attacks primarily occur in two forms: direct lightning and induced lightning. Typically, damage to radio and television facilities and equipment occurs through three main intrusion paths: power supply line intrusion, signal cable intrusion, and ground potential counter-voltage.

2.1 Design Background

Based on the characteristics of lightning damage, lightning protection for high-altitude transmission station equipment should be approached with enhanced awareness and treated as an important systematic engineering project. The architecture design of lightning protection measures requires comprehensive, multi-level scientific consideration and multi-pronged layout planning.

The equipment room at the Liangfengtai transmission station of Zhaotong Radio and Television Relay Station houses a main distribution room, diesel generator room, storage room, monitoring room, transmission equipment room, and duty room, containing both strong-current and weak-current equipment. The strong-current systems include the main distribution system, diesel generator system, equipment room distribution system, and UPS, while the weak-current systems include cable television signal systems, network signal systems, telephone signal systems, and satellite reception systems. The equipment room is located on the southwest side of the transmission tower, while the duty dormitory and living area are on the northeast side. Satellite receiving antennas are positioned on the southwest side of the equipment room. The single-story equipment room has a height of 7.6 meters and is 19 meters from the transmission tower, which is 4 meters from the mountain slope edge (19m+4m). According to the "Code for Design of Lightning Protection of Buildings" standards, the rolling sphere radius for Class-II buildings is hr=23m. Calculated from the designed reference ground plane, the maximum protected building height is 7.12 meters.

The Liangfengtai transmission station is located on a mountaintop in a sloping terrain area with minimal surface soil and predominantly rocky ground, resulting in high soil resistivity and relatively difficult lightning current dissipation. With 47 thunderstorm days annually and intense lightning activity, the station is highly susceptible to lightning strikes. To address this, station engineers developed a practical and feasible comprehensive lightning protection system based on the specific conditions of Liangfengtai.

2.2 Lightning Protection for Transmission Tower and Buildings

Typically, the transmission antenna and tower constitute the highest points at mountain stations. The transmission antenna and tower itself can serve as both a lightning discharge conductor and a "lightning attractor," making it a critical link in station lightning protection.

2.2.1 Transmission Tower Lightning Protection Design

Due to its position as the highest point, the transmission tower is highly susceptible to lightning strikes during thunderstorms, which can enter the equipment room through the tower and antenna feed lines, causing overcurrent and overvoltage damage to transmission equipment. We installed a circular grounding grid around the transmission tower using 60$×$6 hot-dip galvanized flat steel, with an inner radius of 5 meters and outer radius of 8 meters, supplemented by vertically installed 1-meter pure copper ion grounding electrodes. Additionally, four horizontal grounding conductors were extended from the circular grounding grid, with grounding modules added to these extensions to achieve the broadcasting industry requirement of tower grounding resistance below 5Ω.

2.2.2 Business Building Lightning Protection Design

The transmission station business building measures 29.6 meters in length and 28.5 meters in width. The grounding grid design for the business building employs 60$×6hot−dipgalvanizedflatsteeltocreateagridnosmallerthan5×5meterswithinthebuildingfoundation
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dipgalvanizedanglesteelservesasverticalgroundingelectrodes.Fourhorizontalgroundingconductorsareextend
hot-dip galvanized flat steel encloses the external conductors to form a complete ring, creating an integrated equipotential system. If design requirements are not met, additional horizontal extensions can be added with efficient resistance-reducing agents to achieve approximately 2.5Ω. The equipment room and dormitory grounding grids are reliably connected to the tower grounding grid through external conductors to form an equipotential body, achieving a grounding resistance of less than 1Ω, which complies with national building lightning protection design standards.

2.3 Power Supply Lightning Protection

2.3.1 First-Level Power Supply Lightning Protection

To prevent surge voltage from directly entering the LPZ1 zone from the LPZ0 conduction zone at the distribution room power supply port, the design should limit surge voltages of tens to hundreds of thousands of volts to 3,000–4,000V. Three-phase power supply lightning protection modules with a current capacity of 50KA are installed in parallel at the main distribution cabinet and backup generator input terminals (2 sets total).

2.3.2 Second-Level Power Supply Protection

As the second-level protection, the power supply lightning protector at the distribution cabinet output further limits the residual surge voltage from the first-level protector to 2,000–2,500V. This voltage-limiting type power supply lightning protector should have a lightning current capacity no less than 40KA. Three-phase power supply lightning protection modules with a current capacity of 60KA are installed in parallel at the equipment room distribution cabinet input terminals (5 sets total).

2.3.3 Final-Level Protection for Power Supply System

The final level of lightning protection further limits the residual surge voltage passing through the second-level protector to below 750V and implements equipotential bonding between LPZ1 and LPZ2, with a lightning current capacity no less than 10KA. A third-level power supply lightning protector provides more complete absorption of the remaining surge energy from the second level, offering excellent suppression of transient overvoltage. Three-phase power supply lightning protection modules with a current capacity of 20KA are installed in parallel at dormitory floor distribution cabinets and equipment room UPS or important electronic equipment input terminals. For critical precision instruments, we designed rack-mounted lightning protection socket PDUs with a current capacity of 10KA to be installed at equipment terminals. This comprehensive approach perfects the lightning protection measures for the entire power supply system.

2.4 Lightning Protection Measures for Outdoor Antenna Feed Cables and Signal Introduction Lines

The station's transmission antenna feed lines, steel strand wires, waveguide fixing frames, tower bridges, equipment room cable racks, and various video/audio signal lines and communication lines are all vulnerable during thunderstorm seasons. The feed line outer sheath can easily introduce induced voltage into the equipment room, necessitating electrical blocking measures. First, both ends of the feed line must be properly grounded. Before entering the equipment room, the feed line outer sheath should be connected to the grounding grid nearby, with steel strand wires, fixing frames, and bridges reliably grounded to the grid at intervals. Second, the shielding layers of all cables entering the equipment room must be connected to the grounding grid nearby. If the leads are long, they can be buried horizontally underground. Any unused core wires in cables entering the equipment room should be properly grounded at both ends.

2.5 Lightning Protection for Equipment Room and Business Premises

First, copper sheets are laid in the equipment room cable trench to create a grounding grid, with the casings of transmitters, network cabinets, and reception systems connected to the outdoor grounding grid at multiple points to create an equipotential environment. Second, based on the actual conditions of the Zhaotong relay station, lightning protection devices are scientifically and selectively employed to protect electronic equipment. Third, the casings and power grounding (neutral lines, zero lines) of the distribution room and generator room are all reliably connected to the shared equipment room grounding grid. Various conductors in the equipment room, including aluminum doors and windows, heating pipes, water pipes, and cable racks, are connected nearby to busbars or the grounding grid to form a comprehensive equipotential shared body.

Based on the various lightning intrusion paths at high-altitude transmission stations and through in-depth study of lightning formation characteristics, combined with the actual building structure and tower height at the Liangfengtai high-altitude transmission station, we have designed a complete comprehensive lightning protection system forming a three-level lightning protection system for high-voltage distribution, low-voltage distribution, and on-site equipment. After undergoing multiple thunderstorm seasons, all equipment continues to operate normally. Practice has proven that the comprehensive lightning protection system at the Zhaotong relay station can effectively prevent electrical impacts from lightning and surge voltage, protect the normal operation of various equipment room devices, and ensure efficient, high-quality, and safe broadcasting of radio and television programs at the Zhaotong Radio and Television Relay Station.

References

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Note: Figure translations are in progress. See original paper for figures.