Postprint of Integrated Lightning Protection System Design Concepts

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Abstract

To ensure the secure, high-quality, and uninterrupted broadcasting of television signals relayed by Station 102, it is imperative to conduct comprehensive planning and design of the lightning protection system by incorporating the station's specific geographical location and terrain characteristics.

Full Text

Preamble

Abstract: To ensure the safe, high-quality, and uninterrupted broadcast of radio and television signals from Station 102, a comprehensive lightning protection system must be systematically planned and designed, taking into account the station's unique geographic location and terrain.

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Station 102 is located on a mountain at an altitude of 1,240 meters and serves as the main broadcast television transmission station in Henan Province. With the development of broadcast television and the increasing degree of digitalization and automation, comprehensive lightning protection design for the system has become increasingly necessary. The lightning withstand capability of equipment such as high-frequency heads, power dividers, receivers, modems, and satellite receivers used in broadcast television relay stations has become progressively weaker. Due to the special terrain of Station 102, which is prone to lightning strikes, lightning poses a significant threat to the broadcast television system. The reliability of the lightning protection and grounding system directly affects the safety of broadcast programs [1]. Comprehensive lightning protection systems are primarily applied in broadcast television, cable networks, and transmission stations, making lightning protection for related small-signal equipment systems particularly important. Station 102 has numerous active devices and is situated in a high-altitude location with frequent lightning strikes, causing incalculable economic losses to broadcast equipment. To ensure safe, high-quality, and complete signal transmission, reduce economic losses, and maximize the effectiveness of existing advanced equipment to create economic and social benefits, a comprehensive lightning protection system must be planned, designed, and implemented based on the station's specific geographic location and terrain.

1. Site Condition Analysis

As equipment at Station 102 has increased, the existing lightning protection system has been operating for many years without corresponding adjustments or upgrades. In 2006, the station suffered continuous lightning damage that caused broadcast interruptions. The satellite receiving system was struck by lightning twice, damaging the front-end high-frequency heads and destroying multiple devices in the microwave and monitoring rooms. The damaged equipment included: (1) one digital audio distributor; (2) one 20-inch LCD monitor; (3) five serial ports on automation equipment; (4) one digital audio intelligent switcher; (5) 14 ports on an audio signal monitor; and (6) two satellite signal high-frequency heads.

Satellite receiving antennas and microwave receiving antennas are directly exposed to the atmosphere and may suffer direct lightning strikes or induced lightning current intrusion. Main equipment rooms—including the microwave room, monitoring room, television room, FM room, and power distribution room—have undergone equipment upgrades without systematic equipotential bonding, which can cause lightning current discharge paths to become obstructed after intrusion, resulting in ground potential backflash that damages equipment. The spacing between down conductors of the rooftop air termination system is too large, which is unfavorable for lightning current discharge and diversion. Simple lightning rods on the roof can cause lightning strikes to occur near receiving antennas, introducing current into the equipment room through transmission cables. The signal section lacks lightning protection devices, while newly added equipment mostly uses integrated circuits with low voltage tolerance. The power supply system has certain hidden dangers; coordination with the power supply department is recommended for regular testing of high-voltage cable insulation performance. The internal low-voltage distribution system's existing lightning protection facilities and wiring should also be inspected regularly.

Ground resistance measurements at two points yielded values of 3.2Ω and 0.4Ω. Based on comprehensive analysis, the main causes of lightning damage incidents at Station 102 are: (1) direct and side lightning strikes occurring near the equipment room; (2) ground potential backflash; (3) high-frequency signal induction; and (4) overvoltage intrusion in the power system. Therefore, protection and improvements must be implemented in direct lightning protection, power distribution systems, signal systems, and equipment room equipotential bonding.

2. Lightning Protection System Design and Implementation

2.1.1 Improving the Original Simple Air Termination Device on Outdoor Equipment Room Roofs

A comprehensive lightning protection belt and mesh should be installed across the entire building roof. To defend against direct lightning, side lightning, and reduce lightning electromagnetic interference, a lightning mesh and belt with down conductors should be installed on the equipment room roof. The original lightning mesh has suffered severe corrosion after years of exposure and requires replacement. The roof lightning mesh should consist of 60cm$×60cmsquaregrids, weldedtothelightningbeltat60cmintervals.Thegridshouldbeconstructedfrom40mm hot-dip galvanized flat steel in a cross-welded configuration, with a galvanizing thickness of 20–60 m.

The lightning belt should use hot-dip galvanized round steel of at least $ 8mm, installedaroundtheroofperimeterataheightof15cmfromthewall, withuniformlyspacedsupportpillars hot-dip galvanized flat steel or round steel of at least $ $8mm, maintaining a distance greater than 1m from other electrical circuits. Multiple uniformly distributed down conductors should connect the lightning mesh and belt to the ground grid. Other metal facilities on the equipment room roof should also be welded to the lightning mesh and belt at nearby points.

2.1.2 Adding Two Lightning Rods

The southern slope is relatively steep and has overhead high-voltage power lines, making it vulnerable to side lightning and rolling mountain lightning. The equipment room's satellite receiving antenna has suffered high-frequency head damage from lightning strikes. To protect this equipment and the high-voltage lines, one SATELIT+ESE2500 early streamer emission lightning rod should be installed on this side.

2.2 Equipment Room Equipotential Bonding

To completely eliminate destructive potential differences caused by lightning, equipotential grounding connections are required. All equipment rooms at Station 102—including the microwave room, monitoring room, television room, FM room, and power distribution room—must implement local equipotential bonding, with each room's bonding strip interconnected and connected to the ground grid through multiple down conductors. Various grounding systems within the rooms—including shielding networks, equipment chassis, power supply, working circuits, security, and overvoltage protection—must be uniformly and reliably connected to the nearest shared ground grid. Cable trays, water pipes, heating pipes, doors, windows, and other conductors within the equipment rooms must be connected to the busbar or ground grid.

2.3 Grounding Grid Improvement

A combined grounding approach should be adopted, with the transformer ground grid and equipment room ground grid (or tower ground grid) welded together every 3–5 meters (with at least two connection points) to form a closed-loop perimeter ground grid [2-3]. Due to environmental and geological constraints, Station 102's ground grid is unevenly distributed. This renovation plans to add one or two ring grounding devices around the building perimeter. The ring grounding device consists of horizontal and vertical grounding electrodes, with the horizontal electrodes forming a closed loop [3-6], welded to the original ground grid. Radial extended grounding electrodes should be installed at the four corners of the tower, with lengths limited to 10–30 meters [4].

2.4 Power Distribution System Protection

The power distribution system should be equipped with lightning protection devices in zones and levels: Level I protection at the low-voltage side of the distribution room; Level II protection at the power incoming line of transmission equipment distribution cabinets and microwave power distribution cabinets; and Level III protection in the monitoring room with newly added automation electronic equipment.

2.4.1 Level I Protection The original Level I protection box, installed in 2002, was damaged in 2006 and requires replacement. The protection capability should be upgraded, with an American JOSLYN TK-SE200-3Y380 lightning protection box selected for the transformer low-voltage end, working with the original power lightning protection box to form multi-level protection that gradually discharges lightning current to reduce impact on equipment. The original Level I box will be repaired as a backup. JOSLYN products feature innovative and reliable modular design, multiple surge suppression technologies, thermal protection, full-mode protection, and are the only surge protection devices with automatic fault protection and backup protection capabilities.

2.4.2 Level II Protection Based on the existing power lightning protection system, a set of Level II lightning protection modules should be added for FM room equipment that lacks secondary protection. The German DEHNventil TT multi-phase composite surge protector is selected for installation at the 380V incoming line of the FM room distribution cabinet to prevent low-voltage equipment damage from surges and direct lightning strikes [8]. Its features include: (1) space-saving design with sealed spark gaps that emit no gas sparks during operation; (2) RADAX-Flow patented technology for limiting follow current; (3) low voltage protection level; (4) complete wiring suitable for general network configurations; (5) dual terminals and multi-function ports for wires and busbars; (6) remote monitoring capability via DEHNsignal modules; and (7) working status indicator lights.

2.4.3 Level III Protection Given the numerous microelectronic devices in the monitoring room with poor voltage withstand capability, the DEHNguard T275 power supply Level III protection module is added based on DEHNguard T and DEHNguard T…FM. This module is a surge protector for equipotential connection between phase and ground lines [9]. Features include: (1) coordination with Level II surge protection; (2) high-current discharge capability; (3) reliable protection for thermally sensitive elements with dual thermal disconnect devices; (4) fast response; and (5) indicator window that changes from green to red when faults occur.

2.4.4 Replacing All Power Sockets in Monitoring and Microwave Rooms with French CITEL MS103 Surge-Protected Sockets The MS103 surge-protected socket provides three standard outlets for connecting up to three devices requiring protection, suitable for single-phase 220V electronic equipment with a maximum total power of 2,400W. The maximum discharge current can be 10kA with residual voltage <1kV.

2.5 Signal Protection

2.5.1 Microwave and Satellite Receiving Equipment Feeder lines connecting to equipment room devices should be equipped with DEHNgate FF TV coaxial cable protectors or DEHNgate G BNC/DEHNgate GN antenna feeder protectors, with quantities and models to be finalized after verification. The grounding treatment of tower feeder lines must be improved: the metal protective layer of antenna feeders should be grounded near the entrance to the equipment room; when feeders are routed up the tower via cable trays, they should be properly grounded at 0.5–1 meter above the turning point; and a grounding lead should be connected near the entrance between the equipment room and ground grid [10].

The DEHNgate FF TV is the preferred surge protector for 75Ω coaxial systems, mountable on DIN rails or directly on walls, with test ports for easy inspection. Its frequency range is suitable for all satellite and TV systems, particularly multi-channel applications. Grounding is achieved through DIN rails or direct connection. The DEHNgate G BNC or DEHNgate GN surge protectors are used for protecting coaxial antenna feeder systems in microwave base stations.

Since automation equipment samples directly from transmission devices and is vulnerable to lightning intrusion, lightning protectors should be added to network and serial ports. For network ports, the Ailao DLP-IV-RJ45 type protector is selected. The DLP-IV-RJ45 protects switches, hubs, and network automation equipment with three-level internal protection integrating high-voltage discharge, current limiting, and clamping functions—an ideal network protection device [11]. For serial ports, the DLP-I-RS232 type protector is selected.

2.6 Rational Cabling

Due to equipment updates and additions over different periods, the station's cabling is complex. Signal cables are numerous, including both shielded and unshielded types, all requiring proper treatment per lightning protection standards. Power and signal lines must maintain adequate separation. Lightning protection standards specify minimum spacing between power and signal cables: when 380V power cables are $<$2kVA, both are in grounded trays, and parallel length is \$ \$10 meters, the minimum spacing can be 10mm. Metal cable trays should separate different cable types with proper spacing, grounding, and equipotential bonding. Abandoned cables must be properly grounded.

3. Maintenance and Management

3.1 Lightning Protection System Maintenance

Maintenance includes daily and periodic upkeep. For Station 102, daily maintenance should be performed after each lightning strike in areas with strong lightning activity, while periodic maintenance should be conducted annually.

Based on actual working conditions, the external lightning protection devices—including air termination belts, meshes, down conductors, and mechanical damage—should be inspected. Electrical insulation should be checked for rust, looseness, or poor welding, with electrical continuity testing performed when necessary. The grounding resistance of Station 102's grounding devices should be measured; if values exceed specifications, corrective measures must be taken. Internal lightning protection devices and equipotential bonding continuity should be inspected, with loose or broken connections repaired promptly. SPD operation should be checked, with abnormalities addressed immediately. For SPDs with degradation indicators and alarm functions, fault maintenance should be implemented, ideally conducting one inspection before each thunderstorm season.

3.2 Lightning Protection System Management

The relevant responsible department of Station 102 should manage lightning protection affairs. A management system should be established, with lightning protection device drawings, annual test records, design and installation documents properly archived. Each lightning incident should be summarized, analyzing equipment damage, causes, and corrective measures, with timely rectification reports prepared.

Conclusion

Following the overall planning, design, and implementation of the comprehensive lightning protection system for Station 102, the station will ensure safe, high-quality, and complete broadcast of radio and television signals, reduce economic losses, maximize the effectiveness of existing advanced equipment, and create economic and social benefits.

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