Analysis on Management Strategy of Lightning Protection in Hunan Distribution Lines

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Abstract. The lightning activity is frequent in Hunan, and frequent lightning activities seriously affect the safe and stable operation of distribution network equipment. The statistical analysis of lightning trip-out in Hunan distribution line is made in this paper. According to the current situation of lightning protection in Hunan distribution lines, the differentiated lightning protection management strategy is proposed, which takes into account the ground flash density and special landform factors. And the field application in the past year shows that the effect of lightning protection is good. However, there are also corresponding management and technical problems in the implementation process. The corresponding solution ideas and suggestions are put forward in this paper based on the fully investigation and the experimentation simulation, which has the certain reference value for further improving the lightning withstand level of hunan distribution lines.

1. Introduction
In China, Hunan Province is one of the provinces with frequent lightning activities which have great impact on the operation of the distribution network equipment[1-2]. According to statistical analysis, the proportions of lightning stroke fault of 10 kV overhead distribution lines in Hunan have reached 24.6% and 21.3% respectively in 2018 and 2019, which shows that lightning stroke fault has become one of the major problems that affect reliable operation of the distribution network. However, the major distribution line lightning protection method at present is realized by the discharge clamp insulator and the lightning arrester that needs to be subject to grounding modification, and there are less covering surfaces. The line lightning protection measures are limited.

In view of this problem, this paper puts forward a differentiated lightning protection strategy that is established on overall consideration of ground flash density and special terrain & landform factors based on statistical analysis of the lightning stroke trips and the lightning protection status of the distribution lines in Hunan, puts this strategy to field application, analyzes the technical & management problems in application, and proposes solving ideas and suggestions[3-4].
2. Lightning Protection Strategy

2.1. Selection Principle for Lightning Protection of the Distribution Network
Post lightning arresters having fixed external series gap (lightning protection post insulators for short) shall be applied to lightning protection of distribution lines. For the lightning protection post insulator, the rated voltage shall be 13 kV, the nominal discharge current shall not be less than 5 kA, the residual voltage shall not be higher than 45 kV, the high-current impulse withstand capacity shall not be less than 65 kA, and the external insulation shall be made of composite material. Composite insulation cross-arm can be applied to the new lines in an area with the ground flash density level of Class D2 for pilot project [5].

Gap-free zinc oxide lightning arresters shall be applied to lightning protection of distribution equipment (pole-mounted switches, transformers and grounding cables). For such lightning arresters, the rated voltage shall be 17 kV, the nominal discharge current shall not be less than 5 kA, the residual voltage shall not be higher than 50 kV, the high-current impulse withstand capacity shall not be less than 65 kA, and the external insulation shall be made of composite material. Gap-free zinc oxide lightning arresters having the disconnector can be applied to protecting equipment such as pole-mounted switches and transformers.

2.2. Application Principle for Differentiated Lightning Protection of Distribution Lines
The differentiated lightning protection principle of distribution lines shall be formulated comprehensively based on ground flash density distribution of the line corridors, historical lightning stroke trip data of the lines and special terrain & landform information[6].

For the new or operating distribution lines in an area with the ground flash density level of Class D2, lightning protection post insulators shall be applied to the whole section. For the new distribution lines in an area with the ground flash density level of Class D2, composite insulation cross-arm can be applied to the whole section. However, composite insulation cross-arm shall not be applied to the micro-topographic and micro-climatic area where icing is easy to occur.

For the new or operating distribution lines in an area with the ground flash density level of D1, C2 or C1, the differentiated section lightning protection shall be applied based on ground flash density distribution, historical lightning stroke fault locations of the lines and special terrain & landform information. Special terrain & landform information includes ridge (mountain top) section, cross-valley section, hillside section and the section along river/lake (including cross-section) of open space. Lightning protection post insulators shall be installed on, in front and back of the historical lightning stroke fault pole and on the special terrain & landform pole section respectively based on ground flash density levels.

During installation, the lightning protection post insulator shall be subject to natural grounding, and grounding reinforcement is unnecessary. It is necessary to make sure the grounding resistance of the gap-free zinc oxide lightning arresters meet requirements. The grounding resistance of the lightning arrester for protection of the pole-mounted switch and the grounding cable shall be less than 10 Ω, and that of the lightning arrester for protection of the pole-mounted transformer shall be less than 10 Ω (when the distribution transformer capacity is less than 100 kVA) or less than 4 Ω (when the distribution transformer capacity is equal to or greater than 100 kVA).

State Grid Hunan Electric Power Company Limited has provided its 10kV distribution lines with lightning protection in 2020 as per the lightning protection strategy. According to the statistics, the lightning stroke trip rate of over 200 lines that have been subject to lightning protection is only 0.72 times/100 km·year, presenting a year-on-year decrease rate of 90.02% with remarkable lightning protection effect. However, there are also some technical and management problems that need to be solved are found out in the lightning protection process.
3. Main Problems Existed

3.1. Technical Problems

(1) Lightning stroke trip and breakage line caused by improper installation of discharge clamp insulators

A part of distribution lines has excessively high contact resistance since the discharge clamp insulator puncture installation process does not meet the requirement. Firstly, two-phase short circuit breakage mechanism caused by lightning stroke was simulated. It was assumed that the current flowing through the line is 2,000 A, the ambient temperature was set at 25 ℃, and the contact resistance was 2 Ω. According to simulation calculation and analysis, the temperature in the central area of the contact point within 0.1 s after short circuit was higher than 700 ℃ (as shown in Fig.1), which was higher than the melting point of aluminum. At this time, the line was very easy to be broken under the tensile forces on both sides. Similarly, the breakage mechanism caused by lightning stroke under single-phase current was simulated. The ambient temperature was set at 25 ℃, the single-phase grounding current was 8 A, and the contact resistance between the conductor core and the insulator puncture clamp was 2 Ω. The highest temperature of the contact was 624 ℃ 500 s after single-phase short circuit. At this time, the aluminum conductor was extremely easy to be deformed under the tensile forces on both sides. Furthermore, the line heating due to excessively high contact resistance might be aggravated, which was easy to result in melting of the contact point at the puncture position or the line damage, thus leading to breakage. For example, XX pole of XX line of XX company was installed with a discharge clamp insulator. However, breakage lines of Phase A and Phase C during lightning stroke (as shown in Fig.2) happened due to improper puncture of insulated lines during installation, which led to power failure of the entire line.

![Figure 1. Temperature Rise of the Two-phase Short Circuit Contact Point](image1)

![Figure 2. Breakage lines of XX Pole of XX Line due to Lightning Stroke](image2)

(2) Pin insulator cannot be used together with lightning protection post insulators due to the low insulation level

Since the pin insulator has low lightning withstand level, the lines that are subject to lightning protection by means of “installing 1 group of lightning protection post insulators every 3 poles” have multiple faults of “insulated lines breakage and porcelain insulators burst due to lightning stroke in the section that is not installed with lightning protection post insulators”. For the reason above, simulation analysis of induced the lightning stroke flashover of the distribution line were performed. It was assumed that #1, #3 and #5 poles of the line was installed with lightning protection post insulators, and #2 & #4 poles were installed with P10 pin insulator. Induced over-voltage with the magnitude of 125 kV showed up on the pole when -50 kA lightning current occurred 100 m away. According to simulation calculation, #3 pole had no flashover, but #2 pole had lightning stroke flashover. Moreover, based on simulation calculation of the lightning stroke flashover probabilities under different installation schemes of lightning protection post insulators, it can be learnt that when the entire line is installed with lightning protection post insulators, the flashover probability is the lowest; when PS20 post insulators are used together with lightning protection post insulators, the flashover probability is relatively low; when P10 pin insulator is used together with lightning protection post insulators, the flashover probability is high. For example, despite #13 pole and 16# pole of XX line of XX company
had been installed with lightning protection post insulators during lightning protection, burst of Phase A and Phase B pin porcelain insulators of #14 pole due to lightning stroke happened, which led to breakage of Phase A line.

(3) Frequent quality problems of the lightning arresters in courts
The supporting lightning arresters of the complete sets of transformer platform purchased by partial organizations have poor quality and frequent problems of poor lightning arrester sealing, out-of-standard residual voltage, small high-current impulse withstand capacity of valve block, etc., leading to line faults due to faults of the lightning arresters in courts. For example, the entire XX line of XX company was tripped due to fault of the lightning arrester in courts (as shown in Fig.3). Based on inspection, a part of the samples in the same batch of lightning arresters have the following problems: non-uniform resistor disc thicknesses that are not up to standard (as shown in Fig.4). DC reference voltage is less than 20 kV, and such problems have direct impact on the protection action performance of the lightning arrester. Furthermore, the forming process of the composite jacket of the lightning arrester has defects, and the interior of the lightning arrester is affected with damp due to poor sealing, leading to the faults of lightning arresters.

![Figure 3. Faulted Lightning Arresters](image1)

![Figure 4. Resistor Discs with Abnormal Thickness](image2)

3.2. Management Problems

(1) Poor implementation of lightning protection technical scheme
Partial organizations failed to perform field construction strictly as per the distribution line lightning protection scheme prepared, leading to that fact that partial lines still have lightning stroke fault trip after treatment. For example, #1-#12 poles of XX branch line in the lightning protection scheme for XX line of XX company need to be installed with lightning protection post insulators. However, based on field overhaul, since this branch line had not been subject to lightning protection, the insulator of #7 pole of the branch line had lightning stroke flashover, leading to power failure.

(2) Inadequate lightning protection for dedicated lines and dedicated transformers
Partial organizations failed to supervise and urge users to complete the lightning protection for dedicated lines and dedicated transformers or take fault isolation measures based on centralized overhaul, leading to power failure of the entire line caused by lightning stroke fault of dedicated line and dedicated transformer after line treatment. For example, breakdown of Phase C lightning arrester of XX dedicated transformer led to power failure of the entire line after treatment of XX line of XX company.

4. Solutions

4.1. Strengthening Control of the Whole Process of the Line Treatment
Planning and deployment prior to centralized overhaul shall be strengthened, and overall planning on allocation of construction power shall be made, thereby making sure that the overhaul task can be completed as required. Furthermore, safety control, quality control, process control and quality service control shall be fully provided during overhaul. In addition, site investigation prior to lightning protection shall be strengthened, and the cross arm model, positions of strain power pole, angle pole and double cross arm pole shall be recorded clearly during investigation. Last but not the least, control
of field installation process, use of electric reaming tools and integrated pre-assembly of cross arm and lightning protection device shall be strengthened to shorten lightning protection treatment period and improve the lightning protection efficiency.

4.2. Perfecting Lightning Protection Strategy for the Distribution Network
The problems encountered by all organizations during lightning protection treatment shall be collected and analyzed, and the lightning protection strategy for the distribution network shall be discussed and completed on a regular basis to obtain better lightning protection effect. To eliminate frequent discharge clamp insulator accidents, the rule of “the discharge clamp insulators installed on lines shall be replaced by lightning protection post insulators or post insulator based on power failure chances” shall be added.

4.3. Strengthening Quality Control of Lightning Protection Device
Material quality testing centers at all levels shall fully strengthen special spot check of lightning protection device with the focus on lightning arrester seal test, valve block through-current capability & the disconnector reliable action test, insulator mechanical property and lightning impulse test as well as insulated cross arm mechanical property and ageing test. Besides, companies of all districts and counties shall strengthen control of handover test of lightning protection devices, so as to ensure quality of lightning protection devices and improve lightning protection effect of distribution lines.

4.4. Strengthening the Lightning Protection for Dedicated Lines and Dedicated Transformers
Lightning protection of distribution lines is a systematic project. In addition to distribution lines, dedicated transformers and dedicated lines are also easy to have lightning stroke fault. To minimize lightning stroke fault rate of distribution lines, users shall be supervised and urged to perform lightning protection as per the lightning protection strategy for distribution lines during centralized overhaul and lightning protection treatment of lines. Or boundary switches shall be installed at the division locations of property rights to reduce user faults synchronously.

4.5. Performing Lightning Protection Design of Network Modified or New Lines
For the lines modified or put into operation having lightning protection requirements, all organizations shall supervise and urge the design institute to perform lightning protection design as per lightning protection strategy for distribution lines, so as to make sure lightning protection design is done at the project feasibility study stage, improve lightning withstand level of distribution lines form the origin, and avoid the lightning protection governance again when the lines are modified or put into operation.

4.6. Performing the Effect Evaluation of Lightning Protection
All organizations shall maintain the power failure causes of modified lines as required, perform the effect evaluation of treated lines on a regular basis, evaluate and analyze the trip causes of the lines that are not treated, thereby laying the foundation for follow-up lightning protection of distribution lines.

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