Analysis on Characteristics of Fault Location of 500kv Transmission Line Tripping Caused by Wildfires

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Abstract. In recent years, with commissioning of EHV transmission projects, main power system network has a successive increasing scale, causing a dramatic increase of transmission lines extend through forest region. Influenced by global warming and widespread drought, wildfire has a obviously rising trend in frequency, which brings about more tripping faults of transmission line. Even worse is that, the operation safety of main power system network can be greatly threatened under circumstance of forest fire breaking out near transmission lines corridor. For the reasons above, in this article, based on the operating data of 500kV transmission lines governed by an EHV transmission company in past 6 years, with consideration of evolution laws of wildfire, by statistical analysis of fault location distribution of line tripping induced by forest fires, the regional feature and spatial-temporal feature is studied, as well as the characteristic of low auto-reclosing success rate after wildfire-caused tripping faults. And on this basis, the suggestion on wildfire prevention in many respects is given, such as fire monitoring, vegetation clearing of line corridor, emergency management and so on.

Keywords: transmission line; wildfire-caused tripping fault; fault location; prevention measures

1 Introduction

China is a country with diverse mountainous terrain, especially in the southern regions where vegetation is lush. Power transmission line projects inevitably traverse densely vegetated mountainous or forested areas. Extreme weather conditions and human activities can lead to wildfires, and operational experiences indicate that wildfires can cause high-voltage transmission lines to trip. Thus, wildfires have a certain impact on the insulation safety and operational reliability of transmission lines [1].

The mechanism of power transmission line tripping due to wildfires is generally attributed to factors such as flame temperature, flame conductivity, and the drastic reduction of insulation levels in clearances caused by ashes and smoke . Existing control and protection measures mainly focus on fault detection and line selection for grounding faults [2,3], while reclosing strategies primarily address transient grounding faults. However, there is limited analysis of the characteristics and patterns of power transmission line tripping due to wildfires, both domestically and internationally. Moreover, there is a lack of targeted studies on the operation

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and control of transmission lines under wildfire conditions, making wildfire incidents a hidden danger affecting the safe and stable operation of transmission lines and power grids.

This paper takes the characteristic data of power transmission line tripping due to wildfires from a certain domestic 500kV voltage-level transmission company over the past six years as the object. By considering the behavioral characteristics of wildfires, it summarizes the statistical characteristics of fault points leading to power transmission line tripping due to wildfires. This analysis provides reference insights for the maintenance methods of transmission lines in regions prone to frequent wildfires.

2 Wildfires and Their Impact on Power Transmission Lines

2.1 Causes, Types, and Characteristics of Wildfires

Wildfires generally require three conditions: combustible materials, a source of ignition, and fire-prone weather [4,5]. Combustible materials and a source of ignition are necessary conditions for wildfires, and the occurrence of wildfires depends largely on weather conditions when both combustible materials and a source of ignition are present. Combustible materials can be categorized based on their ease of combustion and heat generation into easily combustible materials, slowly burning combustible materials, and difficult-to-burn combustible materials. Easily combustible materials, such as dry grass, twigs, fallen leaves, bark, lichens, and moss, ignite easily, burn quickly, produce little heat, and are easily extinguished. Slowly burning combustible materials, referring to larger and heavier combustible materials like dead wood, tree roots, large branches, fallen trees, and humus, are generally resistant to burning but can maintain heat for an extended period after ignition, making them difficult to extinguish and prone to re-ignition. Difficult-to-burn combustible materials primarily include growing herbaceous plants, shrubs, and trees. Ignition sources can be natural, like lightning, meteorites, heat generated from the fermentation of fallen branches and leaves, and spontaneous combustion caused by the friction of branches. Human-caused ignition sources result from human production activities. Fire-prone weather refers to climatic conditions conducive to wildfires, such as high temperatures, low rainfall, low relative humidity, strong winds, and prolonged drought.

Wildfires are classified into surface fires, crown fires, and underground fires based on the burning location [6]. These three types of fires can occur independently or concurrently, especially in large forest fires, where all three types may intertwine. Typically, a forest fire starts as a surface fire, progresses to a crown fire when it reaches the treetops, and transforms into an underground fire as it burns beneath the surface. Crown fires can also descend to the ground, forming surface fires. Underground fires may emerge from surface cracks and advance towards the surface. Coniferous forests are more prone to crown fires, while broad-leaved forests generally experience surface fires, with crown or underground fires occurring during prolonged droughts.

Statistical analysis reveals a close relationship between the occurrence of wildfires and weather conditions, geographical environments, vegetation, and the activity patterns of surrounding populations. The wildfire hazard exhibits distinct seasonal and environmental characteristics.

Wildfires are more likely to occur during the following periods: dry vegetation, clear weather, rising temperatures, and minimal rainfall in late winter and early spring; around the Qingming Festival during seasonal ancestral tomb-sweeping activities; in hot and dry summer months, especially in July and August; and during the customary burning of fields at the end of autumn and the beginning of winter.

Environmental conditions conducive to wildfires include forested areas adjacent to farmland, vegetable plots, and graveyards, densely vegetated areas with abundant trees, shrubs, or tall and dense grass, as well as mountainous and forested areas near urban-rural interfaces and scattered rural households. These areas exhibit complex human activities, casual use of fire, and inadequate fire prevention awareness, posing a high risk for wildfires, especially when rural households engage in burning fields and other fire-prone activities.

2.2 Impact of Wildfires on Power Transmission Lines

The 500kV transmission lines managed by the company primarily serve as the main channels for west-east power transmission in the southern region. These lines span a large east-west distance, traverse complex terrains in mountainous or hilly areas with dense vegetation, mainly consisting of forests with predominant trees, shrubs, or coniferous forests. Residents along these lines have a tradition of seasonal mountain burning.

The aforementioned factors create favorable conditions for wildfires. From 2009 to the end of 2014, the transmission lines of this voltage level experienced 892 wildfires along the channel, resulting in 93 instances of power transmission line trips due to wildfires (DC lockouts) and affecting 36 lines. Among them, 83 trips were caused by phase-to-ground short circuits, and 10 were caused by phase-to-phase short circuits, posing a significant threat to the safe and stable operation of the regional power grid's main framework.

Of the 93 power transmission line trips due to wildfires, reclosing was successful only 37 times, resulting in a reclosing success rate of 40%. This success rate is significantly lower than that of reclosing after lightning faults.

The success of reclosing primarily depends on the speed of the insulation recovery of the fault point. The faster the insulation performance recovers, the higher the success rate of reclosing. After lightning-induced trips, the insulation performance of the air medium rapidly recovers with the extinction of the electric arc, leading to a high success rate of reclosing. However, after power line trips due to wildfires, the reclosing device automatically recloses and energizes within a short time. During this period, the characteristic parameters such as wildfire temperature, flame height, smoke content in the air, etc., do not significantly decrease [7,8]. The insulation strength of the line does not recover promptly, and introducing a voltage higher than the normal operating voltage (operational overvoltage) between the previous discharge gaps will cause the air gap to break down again, resulting in a reclosing failure.

3 Statistical Analysis of Characteristics of Power Transmission Line Trips Due to Wildfires

3.1 Types and Causes of Wildfires Leading to Line Trips

According to data provided by the company,from 2009 to 2014, there were a total of 892 wildfires along the 500kV transmission line channels managed by the company, resulting in 93 power transmission line trips due to wildfires. The annual statistics of power transmission line trips due to wildfires are shown in Table 1:

Table 1. Statistics of 500kV voltage level transmission line wildfire tripping in the company from 2009 to 2014.

Year	Fire trip times
2009	10
2010	33
2011	15
2012	9
2013	10
2014	16

Based on on-site investigations and statistics of the 93 wildfires causing line trips, 89 were ignited by human activities, while 4 were caused by other reasons. A breakdown of wildfire types reveals that crown fires occurred 66 times, surface fires 27 times, and underground fires 0 times. It is evident that human activities are a significant cause of wildfires along transmission line channels, and crown or surface fires pose a greater threat to the safe operation of power transmission lines.

3.2 Types of Power Transmission Line Trips Due to Wildfires

According to data provided by the company,among the 93 recorded instances of power transmission line trips due to wildfires, phase-to-ground short circuits accounted for 84 cases, representing 89.3% of the total, while phase-to-phase short circuits occurred 10 times, constituting 10.7%. Notably, phase-to-phase short circuits exclusively occurred in AC lines, with no occurrences in DC lines. The distribution of these short circuits is detailed in Table 2.

Table 2. Classification and Statistics of Fault Types for Mountain Fire Trips in Transmission Lines.

Line type	Number of phase faults·times	Number of Interphase faults·times
DC line	21	0
Conventional AC line	50	3
Compact AC line	12	7

The data from the table indicates that for 500kV DC and conventional AC power transmission lines, phase-to-ground short circuits are the predominant cause of line trips in cases of wildfires. Additionally, compact AC transmission lines are more prone to phase-to-phase short circuit faults.

3.3 Spatial Distribution Analysis of Fault Points

A statistical analysis of the spatial distribution of fault points in the 93 instances of power transmission line trips due to wildfires reveals that 16 occurrences were near tower locations (i.e., discharges at towers), while 77 occurrences were at the central point of the span between towers. This corresponds to a distribution of 17% near towers and 83% in the central span.

The significantly higher occurrence of fault points in the central span compared to locations near towers is attributed to the challenges associated with comprehensive vegetation clearance along the entire transmission line channel. Maintenance personnel typically focus more on clearing vegetation around towers than on the entire channel. In segments with complex terrain, the difficulty of clearing vegetation around towers is greater and more apparent, contributing to the prevalence of fault points in the central span.

3.4 Analysis of Fault Point Terrain Characteristics

The combustion characteristics of vegetation fuel and the speed of wildfire propagation are directly proportional. The speed of wildfire propagation is influenced by both wind and terrain. When the slope is less than 20°, the behavior of the fire is mainly influenced by changes in wind direction and speed. In slopes ranging from 20° to 50°, wildfires advance quickly, accompanied by a humming sound and dense smoke. With slopes exceeding 50°, wildfires advance extremely rapidly, with high flames, significantly impacting power line operations [9]. After examining the terrain slope at fault points in the 93 instances of power transmission line trips due to wildfires, it is evident that most fault points are located on hillsides or near the tops of slopes, as illustrated in Figure 1.

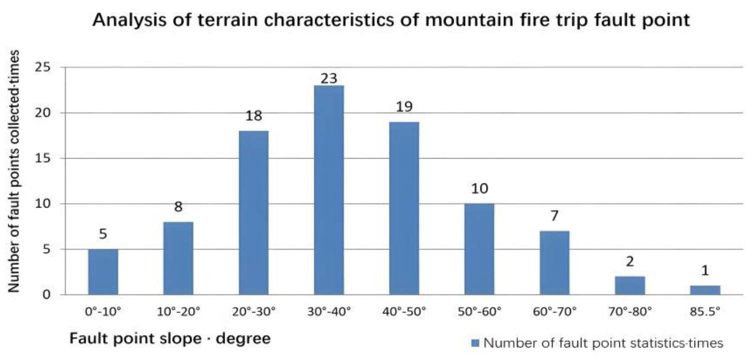

Fig. 1. .Analysis of Topographic Characteristics of Fault Points for Mountain Fire Tripping.

According to data provided by the company, the terrain slope of transmission line wildfire fault points is mostly steep slopes greater than 10°. As the slope increases, the number or probability of triggering wildfire tripping also increases accordingly. 75% of the fault points are distributed on slopes between 20° and 60°.

3.5 Statistical analysis of clearance distance at fault points

The clearance distance between transmission line conductors and vegetation is also an important factor affecting the tripping of transmission line wildfires. The operating regulations for transmission lines require that the clearance distance between 500kV transmission line conductors and trees during maximum wind deviation shall not be less than 7 meters. Before the transmission line fire tripped, it was found that the clearance distance of 93 fault points was greater than 7 meters. The results indicate that the transmission operation and maintenance personnel of the company have carried out the cleaning work of channel vegetation as required, and also indicate the problem of insufficient clearance distance of 7 meters between the conductor and combustible materials under mountain fire conditions. The statistical situation of the clearance distance between the fault point and combustible materials before the mountain fire trip is shown in Figure 2.

According to data provided by the company, it can be seen that the clearance distance between conductors and combustibles is within 32.5 meters, which can cause mountain fire tripping in transmission lines. Among them, 22 meters and below account for 92%, posing a significant safety hazard in mountain fires. Therefore, in the high incidence section of mountain fires in transmission lines, the clearance distance between conductors and combustibles can be appropriately increased to reduce the impact of mountain fires on transmission lines.

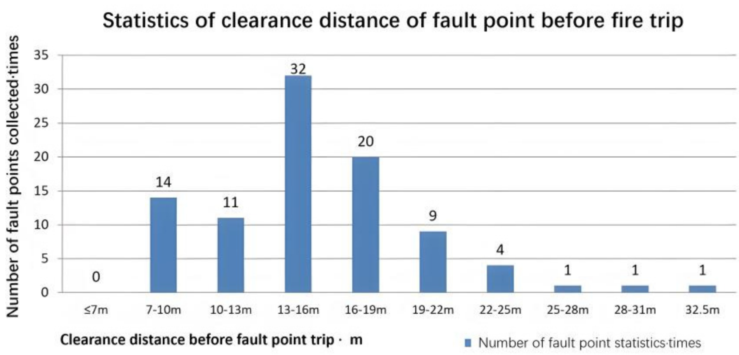

Fig. 2 Statistics of clearance distance at fault points before mountain fire tripping.

4 Recommendation

4.1 Strengthen publicity and strictly control fire sources

According to data provided by the company,94% of transmission line wildfires are caused by human factors, so strengthening publicity and controlling fire sources is the best strategy for wildfire protection. It is recommended that the line operation and maintenance unit work together with relevant functional departments of the local government to carry out publicity work on the hazards of wildfires. For example, distributing promotional materials, hanging billboards, setting up wall billboards in densely populated areas, setting up fire warning signs and alarm telephones in areas prone to wildfires, or using village broadcasts to promote the importance of ensuring the safety of transmission lines and the hazards of fires. October to

April of the following year is the season of frequent wildfires in the southern region, and it is also the fire prevention period in the southern region. It is recommended to deploy patrol personnel to guard the areas around the transmission line corridor where wildfires are prone to occur during this period, and timely detect and stop human arson behavior.

4.2 Intensify the cleaning of combustibles and avoid fires in circuit channels

As can be seen from the previous text, the terrain slope of transmission line wildfire fault points is mostly steep slopes greater than 20°. As the slope increases, the probability of line tripping under wildfire conditions also increases accordingly. The number of wildfire trips with a clearance distance of less than 22 meters accounts for 92% of the total number of trips. Therefore, it is recommended to increase the cleaning intensity of combustible materials in the line corridor, and appropriately increase the clearance distance between the conductor and combustible materials in combination with the slope of the line corridor. The types of wildfires that cause line fires to trip are mainly tree crown fires and surface fires. Coniferous forests are prone to tree crown fires, while broad-leaved forests, shrubs, or Artemisia annua are prone to surface fires. The fault point of mountain fire tripping is located near the tower and the position with the maximum sag in the middle of the line span, accounting for 17% and 83% respectively. Therefore, for the sections of transmission lines prone to wildfires, it is recommended to carry out the cleaning work of combustible materials along the entire channel, with a focus on removing coniferous and broad-leaved trees and shrubs in the line corridor, and to do a good job in the treatment of fallen trees [10].

4.3 Enrich the monitoring methods for wildfires on transmission lines

In densely populated areas, it is recommended to increase the number of public line guards appropriately, establish a public line guard network, achieve full coverage of personnel production and living areas, maintain close contact with public line guards, and establish a "mass prevention and control" mechanism for mountain fire prevention. In areas with complex terrain and difficult access for personnel, it is recommended to install an appropriate amount of online monitoring equipment for wildfires in areas prone to wildfires, to assist patrol personnel in achieving all-weather wildfire monitoring [11,12], to achieve the goal of early detection and disposal, and to avoid unplanned shutdowns of transmission lines or successive tripping accidents caused by large-scale wildfires, in order to ensure the safety of the main grid.

4.4 Strengthen emergency management of transmission line fire prevention

It is recommended that the operation and maintenance unit pay attention to the emergency management of transmission line wildfires, establish a joint prevention emergency mechanism with the local government fire prevention departments along the line, and improve the emergency response capacity of wildfires. Develop emergency plans and disposal plans based on the geographical conditions of the route corridor, establish emergency teams, complete emergency material reserves, and conduct emergency drills in a timely manner. After discovering a wildfire, dispose of it according to the emergency plan requirements, and if necessary, apply for line shutdown to reduce the probability of equipment damage caused by wildfires.

4.5 Improve the level of fire protection design for power lines

The threat of wildfires to the safe operation of power transmission lines is gradually increasing, especially when large-scale wildfires occur or when wildfires occur in the same corridor, it will pose a serious threat to the safe operation of the power grid. Therefore, it is necessary to strengthen the scientific research work on wildfires in transmission lines. Suggest conducting research on the mechanism of transmission line wildfire tripping and improving the level of transmission line wildfire defense from an engineering design perspective[13].

5 Conclusion

For the problem of UHV transmission lines affected by wildfires, the spatial and temporal distribution of wildfire trips of 500kV transmission lines of a transmission company in China in the past six years and its impact are analyzed. The main conclusions are as follows:

a) human activities are an important cause of wildfires in transmission line corridors, and crown fire or surface fire pose greater threats to the safe operation of transmission lines.

b)500kV DC and conventional AC transmission lines trips caused by wildfires mainly refer to phase grounding, while compact AC transmission lines are prone to interphase short-circuit faults.

c)Wildfires hazard at the midpoint of transmission line spacing are more likely to cause line trips than those around the tower.

d) The terrain slope of wildfire fault points is mostly steep slope with an angle greater than 10°, and as the slope increases, the probability of wildfire trips also increases accordingly.

e) According to standard requirements, the safe distance between 500kV transmission line conductors and trees should not be less than 7 meters, but the net space distance between conductors and flammable materials within 32.5 meters may also cause wildfire trips of transmission lines.

The research conclusions in this paper can provide reference for reducing wildfire disasters in power grids and avoiding widespread power outages caused by wildfires.

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