Research on Micro-terrain Classification of Transmission Line Galloping

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Abstract. Micro-terrain and micro-weather have an important impact on transmission line galloping. In order to carry out galloping prediction of micro-terrain, the classification of galloping micro-terrain is studied in this work. Firstly, we collect historical data of 1537 galloping points from the State Grid Corporation of China, and select 208 galloping points located in the micro-terrain area by analyzing the altitude and the topographic relief characteristics around each galloping point. Then the galloping micro-terrain types are extracted by Empirical Orthogonal Function method, the first four spatial modes of galloping micro-terrain are the windward slope of east-west mountain area, the windward slope of north-south mountain area, the independent hill, and the saddle back of mountain/ hill. Finally, the regional characteristics of typical micro-terrain are analyzed according to the actual lines.

Keywords: Transmission line; Galloping; Micro-terrain; Classification.

1. Introduction

Overhead transmission line galloping refers to the low-frequency and large amplitude self-excited oscillation of slightly iced transmission line under the excitation of strong wind. Mild icing and stable wind are the necessary conditions for transmission line galloping. Therefore, transmission line galloping mostly occurs in plain areas prone to light ice and stable wind. According to statistics, the three plain areas, the central Hubei, central Henan and Bohai rim, are the most prone areas of galloping in China\textsuperscript{[1]}.

However, during the transmission line daily operation and maintenance work, it is found that there are transmission line galloping events in some hilly and mountainous areas\textsuperscript{[2-4]}. During the large-scale galloping event around the Bohai rim on February 14-16, 2020, a total of 13 500kV lines tripped or emergency shut down due to galloping, of which 10 lines were located in the plain area, and the other 3 lines were located in the micro-terrain area. For example, a 500kV line located in mountain area of Beijing tripped due to galloping, but no other galloping phenomenon was observed in Beijing at the same time.

The analysis shows that, under the influence of micro-terrain, the near ground temperature, humidity, wind speed and wind direction change, and the transmission lines in micro-terrain areas may galloping\textsuperscript{[5-8]}. With the rapid development of power grid, the influence of micro-terrain and micro-weather on transmission line galloping is becoming more and more significant in recent years. However, the current research only puts forward the conceptual model of galloping micro-terrain, and does not systematically carry out the research on classification and feature recognition of typical
transmission line galloping micro-terrain. In order to carry out the rapid identification of galloping micro-terrain and support the prediction and early warning of transmission line galloping in micro-terrain area, it is necessary to carry out the classification research of galloping micro-terrain. Based on the historical observation data of transmission line galloping in recent 10 years, the topographic characteristics of line galloping area are analyzed firstly, then the galloping micro-terrain types are extracted by Empirical Orthogonal Function method (EOF), and finally the regional characteristics of typical micro-terrain are analyzed.

2. Topographic Characteristics of Galloping Area

According to the galloping observation historical data of the State Grid Corporation of China, there are 1537 galloping observation records from 2009 to 2018. The topographic characteristics of galloping area are analyzed based on the surrounding topographic data.

2.1. Altitude Characteristics

Based on the 30m resolution Digital Elevation Model data (DEM), we analyzed the altitude of the galloping positions. It is found that 59.6% of the altitude of galloping points are lower than 100m, 78.3% are lower than 200m, 11.7% are 200-500m, 5% are 500-1000m, and 5% are higher than 1000m. Through the altitude analysis of galloping points, it is found that transmission line galloping mainly occurs in low altitude areas (below 200m), but there are also galloping records in hilly and mountainous areas with altitude above 500m, which confirms the existence of galloping micro-terrain.

| Altitude of galloping points | Number of galloping points | Percent |
|-----------------------------|---------------------------|---------|
| <50m                        | 315                       | 20.5%   |
| 50-100m                     | 601                       | 39.1%   |
| 100-200m                    | 288                       | 18.7%   |
| 200-500m                    | 179                       | 11.7%   |
| 500-1000m                   | 77                        | 5%      |
| >1000m                      | 77                        | 5%      |

2.2. Topographic Relief Characteristics

Draw a 3km×3km square grid around each galloping point, and the axis of the grid is north-south direction and east-west direction. Based on 30m DEM data, the topographic relief around the galloping point is judged according to the topographic altitude in the 3km×3km grid. The topographic relief for each grid is defined as the height difference between the highest altitude point and the lowest altitude point in the 3km×3km square grid. The greater of the topographic relief in the grid, the more uneven of the terrain in the grid, and the micro-terrain characteristic is more obvious.

Figure 1 is the joint analysis of the altitude and topographic relief for galloping points, it can be seen than, for the 1204 points with an altitude of less than 200m, the topographic relief around the galloping point is very small, and the 1204 points are considered to be in plain area; for the 179 points with an altitude of 200-500m, 123 points have the topographic relief of less than 50m, and the 123 points are considered to be in a open area; The topographic relief of 56 points exceeds 50m, and the 56 points are considered to be in micro-terrain area; for the 154 points with an altitude higher than 500m, 2 points with topographic relief of less than 50m, the 2 points are considered to be in open area; 152 points with topographic relief of more than 50m, and the 152 points are considered to be in micro-terrain area.

According to the altitude and topographic relief analysis, it is found that 86.5% of transmission line galloping points are located in plain or open area, and 13.5% of transmission line galloping points are located in micro-terrain area.
3. Micro-terrain Classification of Galloping Point

Based on the analysis of the topographic characteristics of the 208 galloping points in micro-terrain areas in the previous chapter, the classification of the galloping micro-terrain areas are analyzed, and the topographic characteristics of the typical galloping micro-terrain areas are analyzed.

Empirical orthogonal function (EOF) is a method to analyze the structural features of matrix data and extract the main data features. In this work, Based on 30m DEM data, the altitude data in each 3km×3km square grid around the galloping point can be described by an array A[101,101], and the altitude data in 3km×3km square grids around the 208 galloping points can be described by array H[101,101,208]. The first 101 represents the amount of data in the east-west direction of the 3km×3km square grid, and the second 101 represents the amount of data in the south-north direction of the 3km×3km square grid, 208 represents 208 galloping points in micro-terrain areas.

First, calculate the average altitude of each 3km×3km square grid, and the altitude anomaly array of each grid obtained by subtracting the grid average altitude from the original altitude of each point in the grid. Then, the altitude anomaly array is decomposed to extract the main spatial modes of micro-terrain areas based on the EOF method. Finally, the galloping micro-terrain classification is obtained according to the main spatial modes of EOF. Figure 2 is the first four spatial modes of galloping micro-terrain extracted by EOF decomposition. The first mode is the windward slope of east-west mountain area, the second mode is the windward slope of north-south mountain area, the third mode is the independent hill, and the fourth mode is the saddle back of mountain/hill. The proportional contributions of the first four modes are 21.5%, 17.5%, 13.4%, and 11.9%, respectively, with the cumulative contribution being 64.3%.

4. Analysis of Topographic Characteristics of Typical Galloping Micro-terrain area

4.1. The Windward Slope of East-west Mountain Area

A typical galloping micro-terrain case of the windward slope of east-west mountain area is the #391-#394 section of 500kV Hangu-I line, which tripped due to transmission line galloping in 2015. Figure 3 is a schematic diagram of the transmission line and the terrain for the #391-#394 section of 500kV Hangu-I line. The line is located on the windward north hillside. Due to the topographic uplift of the hillside, the water vapor in the air is easy to condense, resulting in icing on the line. At the same time, affected by the gully on the hillside, the local wind speed increases due to the narrow tube effect, so the icing transmission line galloping is easy to occur.

4.2. The Windward Slope of North-south Mountain Area

A typical galloping micro-terrain case of the windward slope of north-south mountain area is the
#293-#312 section of 500kV Shuoyun line, which tripped due to transmission line galloping in 2009 and 2012.

Figure 4 is a schematic diagram of the transmission line and the terrain for the #293-#297 section of 500kV Shuoyun line. The line is located on the windward east hillside. Due to the topographic uplift of the hillside, the water vapor in the air is easy to condense, resulting in icing on the line. At the same time, affected by the gully on the hillside, the local wind speed increases due to the narrow tube effect, so the icing transmission line galloping is easy to occur.

4.3. The Independent Hill
A typical galloping micro-terrain case of the independent hill is the #218-#225 section of 500kV Guanli line, which tripped due to transmission line galloping in 2015 and 2018.

Figure 5 is a schematic diagram of the transmission line and the terrain for the #218-#222 section of 500kV Guanli line. The line crosses the top of an independent hill. Due to the open terrain at the top of the hill, strong wind and icing are easy to occur, resulting in transmission line galloping.

4.4. The Saddle Back of Mountain/Hill
A typical galloping micro-terrain case of the saddle back of mountain/hill is the #171-#173 section of 500kV Langshun-I line, which tripped due to transmission line galloping in 2020.

Figure 6 is a schematic diagram of the transmission line and the terrain for the #171-#173 section of 500kV Langshun-I line. The two adjacent transmission towers are located on both sides of the saddle back of mountain. The transmission line crosses the saddle back of mountain. Forced by the terrain of the saddle back of mountain, the wind speed inside the saddle back of mountain increases, resulting in transmission line galloping.

![Figure 3. The schematic diagram of the transmission line and the terrain for the #391-#394 section of 500kV Hangu-I line (Black triangle indicates transmission tower, black line indicates transmission line, and shadow indicates the altitude).](image)

![Figure 4. Same as figure 3, but for the #293-#297 section of 500kV Shuoyun line.](image)
5. Conclusion

Micro-terrain and micro-weather have an important impact on transmission line galloping. The current research only puts forward the conceptual model of galloping micro-terrain, and does not systematically carry out the research on classification and feature recognition of typical transmission line galloping micro-terrain. In order to solve the lack of classification method for galloping micro-terrain, we analyze the topographic characteristics of transmission line galloping historical observation data in recent 10 years firstly, and selects 208 galloping points located in the micro-terrain area by analyzing the altitude of the galloping points and the topographic relief characteristic around the galloping points. Then the galloping micro-terrain types are extracted by Empirical Orthogonal Function method, the first four spatial modes of galloping micro-terrain are the windward slope of east-west mountain area, the windward slope of north-south mountain area, the independent hill, and the saddle back of mountain/ hill. Finally the regional characteristics of typical micro-terrain are analyzed according to the actual lines. Based on this work, we classify the galloping micro-terrain scientifically, which provides a basis for galloping micro-terrain recognition and galloping prediction.

Acknowledgments

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