RESEARCH ON POWER EQUIPMENT RAINSTORM WARNING COMBINED WITH WEATHER FORECAST DATA INTERPOLATION AND REGIONAL ASSESSMENT

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ABSTRACT

This paper analyzes the early warning of urban power grid equipment under heavy rain, especially for the prediction and early warning of power equipment safety hazards caused by short-term large-scale rainfall. The historical data is used to analyze the specific impact form of heavy rain on power equipment. The algorithm of rainfall data interpolation based on inverse distance weighting method is proposed. The granularity of meteorological data is refined from 5km×5km to 500m×500m. Through the dynamic adjustment of the power parameters, the interpolation data of the black point rainfall in the city is optimized, and the monitoring and statistics of the meteorological forecast data of specific power equipment or station are realized. At the same time, combined with the meteorological warning of the meteorological department, the prediction and early warning of the flooding risk of power equipment is realized. As an example, this paper uses the weather data of a certain city in southern China to carry out calculations. The result shows that the comprehensive optimization results can not only effectively improve the accuracy of the rainstorm warning of specific power equipment, but also avoid the data error caused by the traditional inverse distance weighting algorithm, and effectively improve the practical application value.

INTRODUCTION

The southern Chinese cities belong to the subtropical ocean monsoon climate with heavy rains. The dangers caused by heavy rains in urban areas can cause water immersion short-circuits on power equipment. Heavy rain and waterlogging warnings for urban power grid equipment, especially for the prediction and warning of power equipment safety hazards caused by short-term large-scale rainfall, are very important to ensure the reliable operation of the power grid. At present, the functions of rainstorm warning in the power industry are mainly divided into two categories. One is based on further modeling of meteorological department forecast data to provide early warning for power equipment, and the other is more inclined to directly use meteorological department's early warning for prevention and control. Re-modeling may further reduce the accuracy of predictions, while direct use of meteorological departments for early warning lack of targeting. Reference 1 discussed in detail the relationship between the distribution characteristics of urban waterlogging and rainfall. Reference 2 quantitatively carried out research on the vulnerability of cities in different rainfalls in Beijing, China. Reference 3 used the meteorological rainfall data from Guangzhou, China for nearly 30 years to study the rainfall characteristics, constructed a model analysis, and proposed different types of control measures based on the analysis of waterlogging causes. Reference 4 combined big data technology and Internet of Things technology to realize real-time information monitoring of urban flooding points. Reference 5 studied the temporal and spatial changes and trends of rainfall in Guangdong Province in the past 50 years. The above studies have carried out detailed research on the formation mechanism of waterlogging disaster, but they have not been analyzed in combination with the reliable operation of power equipment. Research on disaster prevention and mitigation of power equipment is currently concentrated in lightning protection and typhoon prevention of power equipment. Reference 6 studied the causes of lightning strikes on 10kV distribution network lines through statistical analysis. Reference 7 focused on transmission lines and studied the probability of failure of lines under different weather conditions as a support for line risk assessment. Reference 8 focused on the impact of distribution equipment such as lines and towers under typhoon attacks, and put forward relevant suggestions on power grid construction and investment.

Overall, there is no relevant research on the impact of urban rainstorm and waterlogging on power grid equipment. The relevant weather warning is basically based on the general warning issued by the meteorological department. In the research algorithms of meteorological data, some people have tried to further down-scale the meteorological data, but there is no special research on rainstorm meteorology.

This paper is devoted to the study of the impact of urban rainstorm on the reliability of power equipment, using statistical data to analyze the hidden dangers of waterlogging disaster on power system, and down-scaling the weather station data by inverse distance weighting method. At the same time, combined with the rainstorm warning of the meteorological department, the risk warning to the specific power equipment is realized through the optimization of the power parameters.

IMPACT OF SHORT-TERM HEAVY RAINFALL ON POWER EQUIPMENT

Impact of Heavy Rainfall on Power Equipment

Statistical analysis of power grid trips caused by natural disasters in a large city of southern China in 2018 can be divided into heavy rain, lightning strikes, typhoons and others. The distribution is shown in Fig.1.

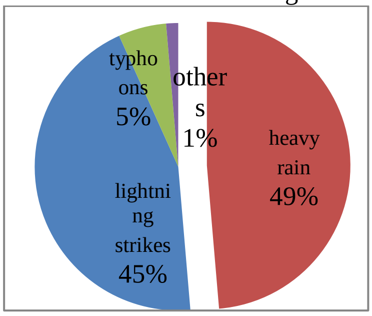


Fig.1 Grid trip statistics caused by natural disasters

In all kinds of extreme weather, heavy rain is the main cause of hidden dangers in electrical equipment. Heavy rainfall in southern China is generally distributed from May to October. Urban power grids will suffer different degrees of impact in the event of heavy rainfall, threatening equipment safety and personal safety. The following table summarizes the types of equipment failure caused by short-term heavy rainfall based on the data of heavy rains in a southern city in the past three years.

Tab.1 Types of equipment failure caused by short-term heavy rainfall

Hidden danger	Cause	Equipment
Water immersion short-circuit	Low-lying regions	Substation equipment
	River water flow backward	Substation equipment, Pole and tower
	Old equipment and substation	Substation equipment
	Cable landslides	cable
	Underground distribution station	Substation equipment
Leaning or collapse	Electric pole scouring, cross-river line, rust-breaking, land subsidence, landslide	Pole and tower

In general, the equipment hidden dangers caused by heavy rainfall weather include short-circuiting of water immersion, leaning or collapse. The equipment involved mainly includes poles, towers, substation equipments, etc. In addition to the measures required in the design and installation of the equipment, measures can be taken to prevent the water before the arrival of the rainfall and when the water level reaches the warning point.

Short-term Rainfall and Depth of Water Accumulation Depth

The hidden dangers of power equipment caused by urban floods during heavy rains are mainly due to short-term heavy rainfall. According to statistics, the rainstorms that cause major waterlogging effects are generally less than 2 hours, and the maximum 1h rainfall is above 30mm.The rainfall feature in a city in southern China for the past 10 years is shown in the Tab. 2. As can be seen from the table, the maximum 1h rainfall accounted for more than 20% of 24h cumulative rainfall, which is more likely to lead to waterlogging disaster.

Tab. 2 Rainfall statistics for a city in southern China from 2009 to 2018

Year	Month	Cumulative rainfall (mm)		Propo-rtion
		24h	1h	
2008	June	254	61	**24%**
2009	March	143	64.7	**45%**
2010	May	218.9	99.1	**45%**
2011	October	164	85.3	**52%**
2012	May	93.1	76.8	**82%**
2013	May	328	77.6	**24%**
2014	June	288.7	96.3	**33%**
2015	July	249.9	49.3	**20%**
2016	May	236.5	95.9	**41%**
2017	May	542.7	184.4	**34%**

The numerical relationship between the establishment of short-term cumulative rainfall and the depth of water gathered is the data basis for waterlogging warning. Typical waterlogging black spots(totally 10 points) are taken for correlation analysis, and the correlation coefficient between long-term latitude total rainfall /hourly maximum rainfall and water depth is analyzed. Fig. 2 shows a relatively high correlation between the accumulation depth and rainfall. The correlation coefficient between the depth of water accumulation and the long-term latitude total rainfall is 0.36~0.95, for the same waterlogging point, in the case of the same total rainfall, different rainfall duration will result in water accumulation at different depths, so the correlation coefficient span between the water depth and the total rainfall of the process is large.

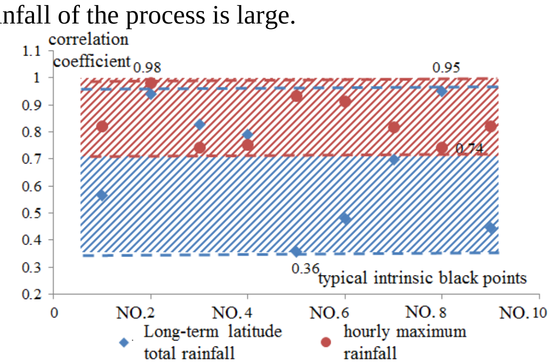


Fig.2 Correlation coefficient between long-term latitude total rainfall /hourly maximum rainfall and water depth

In contrast, the correlation coefficient between the depth of water accumulation and hourly maximum rainfall is between 0.74 and 0.98, and the interval span is significantly smaller. The correlation coefficient is significantly higher than the correlation coefficient between the depth of water and the long-term latitude total rainfall. Therefore, hourly maximum rainfall is the main factor affecting the depth of water accumulation. In other words, short-term heavy rainstorm is the main cause of urban accumulation.

DOWNSCALING OF METEOROLOGICAL DATA FOR POWER EQUIPMENT

Meteorological Data Interpolation

Meteorological data was obtained through satellite radar and weather stations. Due to the limited number of meteorological stations and the large spatial scale, it is necessary to locate the meteorological parameters of a specific power equipment through interpolation operations.

In this paper, the Inverse Distance Weighted(IDW) method is used to interpolate the meteorological data. IDW is a commonly used and simple spatial interpolation method. It assumes that the similarity of two objects decreases as the distance increases. This method uses the distance between the interpolation point and the sample point as the weight to perform weighted averaging, and the closer the interpolation point is, the greater the weight given by the sample. The algorithm steps are as follows:

Calculate the distance from the point to be interpolated to all known points:

$$Dis(a,b)=\sqrt{(a_x-b_x)^2+\left(a_y-b_y\right)^2} \qquad (1)$$

Calculate the weight of each point: the weight is a function of the reciprocal of the distance. The specific formula is as follows:

$$\lambda_i=\frac{1/d_i^m}{\sum_{i=1}^{n}(1/d_i^m)} \qquad (2)$$

Where, λ_i is the weight of the i-th known point for the current point, and d_i is the distance between the two points.

The weather warning result is a linear superposition of the product of the weight and the known point value.

$$V_a=\sum_{i=1}^{n}\lambda_i * V_a\,(i) \qquad (3)$$

Where, $V_a\,(i)$ is the interpolation point value.

Geographic Data Space Gridding

The rainfull data of any geographical location can be theoretically obtained by interpolation operation, but the calculation amount is too large. In this paper, the geospatial space is divided into 500m×500m grids by gridding, and the attribute data related to equipment and lines are extracted by grid scale, and then the database is constructed for association mining. This precision is sufficient for the needs of practical applications.

Take a map of a certain city in southern China as an example. As is in Fig. 3, taking the longitude 113.000668 and the latitude 23.872493 as the reference points, the map of the city is meshed by using the dividing rule of 0.004888 longitude (or latitude) as the side length, and the urban grid map is constructed, and the city map is included in 200*250 squares.

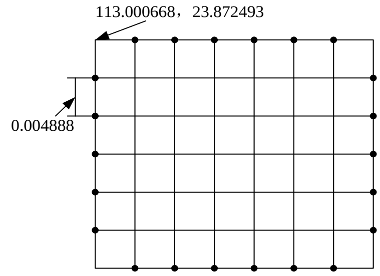


Fig. 3 Rules of space gridding

Fig. 4 shows the power equipment and latitude and longitude range for different voltage levels.Based on the big data platform, the rapid insertion of meteorological data can be realized, making it possible to obtain more accurate substation meteorological information.For an actually operating electrical equipment, its latitude and longitude will be converted into a square of Figure3. The data of the square (that is, the rainfull temperature, humidity, etc. after the interpolation) is more accurate than the uninterpolated meteorological data.

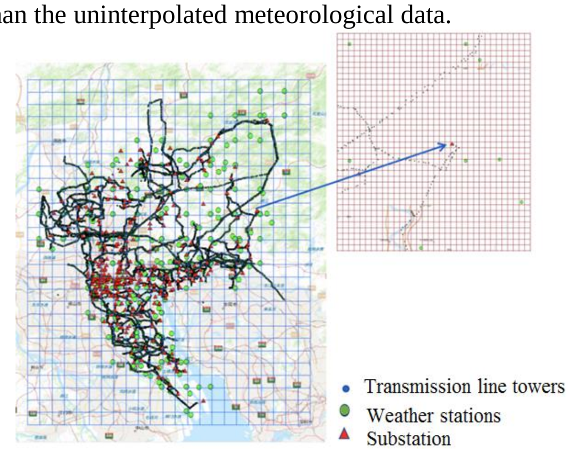
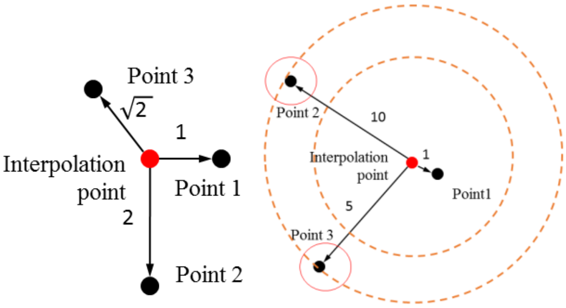


Fig. 4Geographic grid map with power equipment and weather station

The Influence of Power Parameters(m) on Interpolated Values

The IDW assumes that each point value has a local spatial influence, which is attenuated as the distance increases. In general, the more the surrounding points are selected by the interpolation operation, the more accurate the result is. Therefore, it is necessary to find the data of the nearest n weather stations at each interpolation point.

Taking n=3 as an example, Fig. 5 shows the distribution patterns. The interpolation results are compared when V_{ai} has the same values (V_{a1}=100, V_{a2}=20, V_{a3}=10).



a) Pattern1 b)Pattern2

Fig. 5 Interpolation pattern contrast

Tab. 3 V_a comparison when m is different

m \ V_a(mm)	Pattern 1	Pattern 2
m=1	52.92	79.96
m=2	62.83	95.28
m=3	71.79	99.2

It can be seen that the power parameter(m) can control the effect of interpolated values based on the distance from the adjacent point. By setting a higher m, the nearest point can be further emphasized. As m is increased, the interpolated value will gradually approach the value of the closest point. Setting a smaller power parameter will have a greater impact on the surrounding points that are farther away.

RAINFALL WARNING FOR POWER EQUIPMENT

Combination of Meteorological Warning and Equipment Rainfall Monitor

Meteorological departments generally adopt a grading warning strategy to classify rainstorm warnings into three levels: yellow, orange, and red. The warning rules are as shown in Tab. 4.

Tab.4 Rainstorm warning rules of meteorological departments

Warning level	Condition	Warning equipment
Yellow 	There will be heavy rain within 6 hours, or there will be obvious rainfall, and the rainfall will continue	Substation equipment in low-lying regions
Orange 	In the past 3 hours, local rainfall has reached more than 50mm and rainfall will continue	Water logging location equipment, Tower/pole near mountains, cable
Red 	In the past 3 hours, local rainfall has reached more than 100mm, and heavy rain will continue	Water logging location equipment, Tower/pole near mountains, cable

Source:*Guangdong Province Meteorological Disaster Warning Signal Release Regulations*

According to the above rules, after the meteorological warning is issued by the meteorological department, the historical accumulated rainfall of specific power equipment can be obtained by combining the historical rainfall data interpolation. According to the accumulated rainfall, the specific equipment defense measures are proposed: the yellow warning will focus on the safety of power equipment related to the station house and underground station in the low-lying area; the orange warning and the red warning need to pay more attention to possible landslides, land subsidence and other disasters. They are likely to result power outage, which is caused by tower and line accidents.

Correction of Early Warning Combined with Waterlogging Black Spots

The waterlogging black spot area in the city is the key area for urban flooding, and it is also the area where power equipment warning should be focused. waterlogging black spots are generally concentrated in smaller areas. On the one hand, meteorological warnings tend to target larger areas. On the other hand, when m value is low, meteorological interpolation rainfall may be lowered by surrounding meteorological stations, so the key areas cannot be effectively alerted. Just as is shown in Fig. 5， when the m is set to 1, although the weather station closest to the interpolation point is measured at 100, the actual interpolation value is at 52.92, which is much lower than the measured value. It may results in a low warning level.

In this paper, the power parameter is dynamically adjusted to solve this problem. For the equipment with the black point attachment, the m is moderately adjusted, and the nearest measurement value from the waterlogging black point is emphasized, and the warning leak is reduced. The process is shown as Fig. 6.

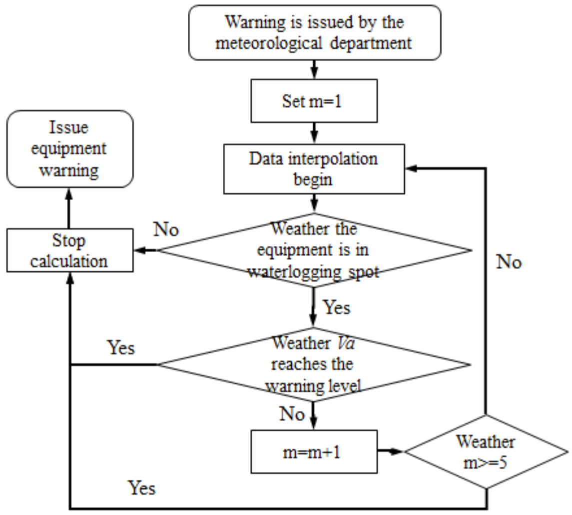


Fig. 6 Calculation process of power equipment rainstorm warning

In the above process, the initial value of m is set to 1, in order to ensure that the calculation result is reasonable, the maximum does not exceed 5.After receiving the warning from the meteorological department, the interpolation of historical rainfall data can be performed for all devices.For equipment within the inner black point range, it is necessary to further verify whether the rainfall meets the meteorological requirements limit. If it has not been reached, increase the *m* value again until the *m* value reaches the upper limit.After the entire calculation is completed, the final calculated value is matched with the warning level to achieve weather warning for a single device.

CASE ANALYSIS

Taking a certain city in southern China as an example, using the algorithm described in this paper to carry out the interpolation operation. On the same day, the meteorological department issued an orange warning for rain storm, and the regional historical 3-hour rainfall distribution map when the warning was issued is shown in Fig. 7. Each of these points represents a weather station, and the different colors represent the rainfall value of last 3 hours, with a maximum rainfall of 92.6mm.

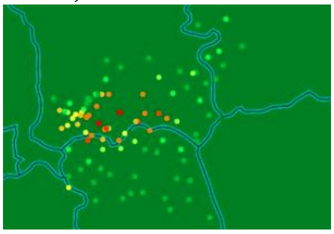
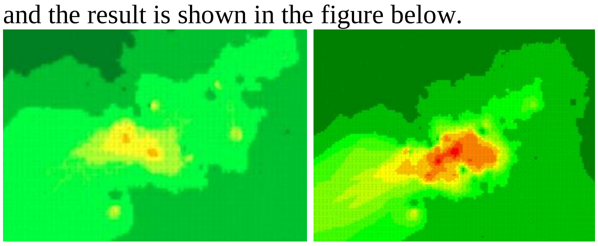


Fig. 7 Regional historical 3-hour rainfall distribution map

Let *m*=1, the regional rainfall is interpolated and the geographical grid after the interpolation is colored according to the color classification of the above figure, and the result is shown in the figure below.



a) after interpolation b) after optimization

Fig. 8 rainfall distribution

It can be seen that after the interpolation operation, the color distribution of the grid is generally the same as that of Fig. 8 , but the overall rainfall is lower than before the interpolation. By modifying the *m* to optimize, the *m* value is increased for the monitoring point located in the waterlogging black point, and the same visualization process is performed after the calculation is completed. The result is shown in Fig. 9.

It can be seen that after the algorithm optimization, the accumulated rainfall in the waterlogging spot area in the part of the figure is significantly increased, thereby increasing the alarm level of the power equipment in the relevant area.

CONCLUSION

In this paper, the IDW interpolation algorithm is used to reduce the meteorological data (rainfall) to 500m×500m grid, which realizes the acquisition of meteorological data of power equipment. Then, combining with the early warning data of the meteorological department and the different impacts of different levels of early warning on the power equipment, the early warning of the single equipment is realized. Through the dynamic optimization of the power parameters, the equipment flooding data of the waterlogging black point area is locally corrected to reduce the missed judgment. Through the actual case in a certain urban area in southern China, the results show that the algorithm in this paper can not only realize the flooding warning of specific power equipment, but also effectively reduce the false alarms and improve the reliability of the power grid.

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