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A method for monitoring and early warning of meteorological disasters in cross regional large power grid based on Doppler radar data

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Abstract: In order to improve the accuracy of meteorological disaster warning and shorten the monitoring and warning time, a cross regional large power grid meteorological disaster monitoring and warning method based on Doppler radar data is proposed. Firstly, based on the characteristics and requirements of the cross regional large power grid, atmospheric data obtained from Doppler radar is utilised. Secondly, various meteorological disasters based on the characteristics of Doppler radar data for different meteorological disasters are classified and identified. Finally, based on the monitored meteorological disaster results, the level of meteorological disasters in cross regional large power grid, and accurately generate meteorological disaster warning results for cross regional large power grid is analysed. The experimental results show that the proposed method can accurately monitor and warn of meteorological disasters in cross regional large power grid, and effectively shorten the time for monitoring and warning of meteorological disasters.

Keywords: Doppler radar data; cross regional large power grid; meteorological disasters; monitoring and warning.

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1 Introduction

Cross regional power large grid refers to a large-scale transmission network composed of multiple regions, which plays a crucial role in modern society (Hou et al., 2021). However, due to the impact of climate change, cross regional large power grid are facing the threat of meteorological disasters, such as storms, ice and snow disasters, and strong winds. These meteorological disasters pose serious challenges to the operational stability and power supply reliability of the power system (Liu et al., 2023). By establishing a cross regional meteorological disaster monitoring and warning method for large power grid, relevant disaster information can be obtained in a timely manner and effective measures can be taken to address potential hazards (Han et al., 2021). This will help improve the safety of the power grid and reduce the risk of accidents. Meteorological disasters may cause problems such as line breaks and equipment failures, resulting in power supply interruption or quality degradation (Liu et al., 2022). Through monitoring and early warning systems, power companies can take corresponding preventive measures before disasters occur, avoid or reduce the risk of power supply interruption, and ensure the reliability of power supply. Power outages and equipment damage caused by meteorological disasters may lead to economic losses, especially for key industries

and infrastructure (Hao et al., 2023; Wang et al., 2022). By timely warning and response measures, power outage time and equipment damage can be reduced, and economic losses can be reduced. The research on meteorological disaster monitoring and warning methods for cross regional large power grid is also of great significance for the planning and design of power systems. By deeply understanding the characteristics and distribution patterns of different meteorological disasters, disaster factors can be better considered, and the accuracy and efficiency of energy planning can be improved.

Hu et al. (2022) proposes a method for monitoring and warning of meteorological disasters in power grid based on deep sparse self coding networks and scene classifiers. After dynamically weighting meteorological disaster factors, sparse constraints are added to the deep self-coding network and classifiers are added to complete the monitoring of meteorological disasters. Establish a meteorological disaster warning model using support vector machines to complete the warning of meteorological disasters in the power grid. However, due to insufficient data collection accuracy, this method is difficult to accurately monitor meteorological disasters in the power grid. Zhao et al. (2021) proposes a method for monitoring and warning meteorological disasters in power grid based on refined meteorological data. This method finely collects various meteorological data from the data centre and stores the collected meteorological data in a database. Analyse the degree of harm caused by meteorological disasters by combining vulnerability and risk indicators, and issue alarm instructions. However, there is a significant gap between the meteorological disaster warning results issued by this method and the actual results. Yuan (2023) proposes a method for monitoring and warning of meteorological disasters in power grid based on satellite remote sensing and database synchronisation. In the local area network of the meteorological monitoring centre station, the remote sensing image display module is connected to the meteorological disaster warning module, and meteorological disasters are monitored based on the stacking coefficient of satellite remote sensing. By using remote sensing monitoring data synchronisation technology, the degree of impact of meteorological disasters is obtained and an alarm is issued to the power grid management centre. However, this method requires the design of modules and extensive data processing, resulting in a longer overall meteorological disaster monitoring and warning time.

In order to solve the problems of the above methods, a cross regional lightning disaster monitoring and early warning method based on Doppler radar data is proposed in this study. The innovative technological route of this method is as follows:

- 1 *Data acquisition and pre-processing*: using Doppler radar to obtain atmospheric data and pre-processing it, including denoising, filtering, calibration, etc., to obtain high-quality radar data.
- 2 *Feature extraction and classification recognition*: based on the characteristics of Doppler radar data from different meteorological disasters, feature extraction and classification recognition are performed on atmospheric data. By analysing the characteristic parameters of different meteorological disasters and establishing corresponding models for disaster classification and identification, including but not limited to storms, typhoons, thunderstorms, etc.
- 3 *Disaster level analysis and warning generation*: based on the monitored meteorological disaster results, analyse and evaluate the disaster level, and generate accurate and reliable meteorological disaster warnings for cross regional power grids

based on this. The warning result is based on pre-set standards and rules, taking into account factors such as the severity and timeliness of meteorological disasters, to achieve warning notifications for the power grid.

- 4 *Experimental verification and application reliability evaluation:* by conducting experimental verification on real data, the proposed method is evaluated for performance and compared with traditional methods. At the same time, based on practical application scenarios and requirements, evaluate the reliability of the method in cross regional power grids to ensure its effectiveness and reliability in practical applications

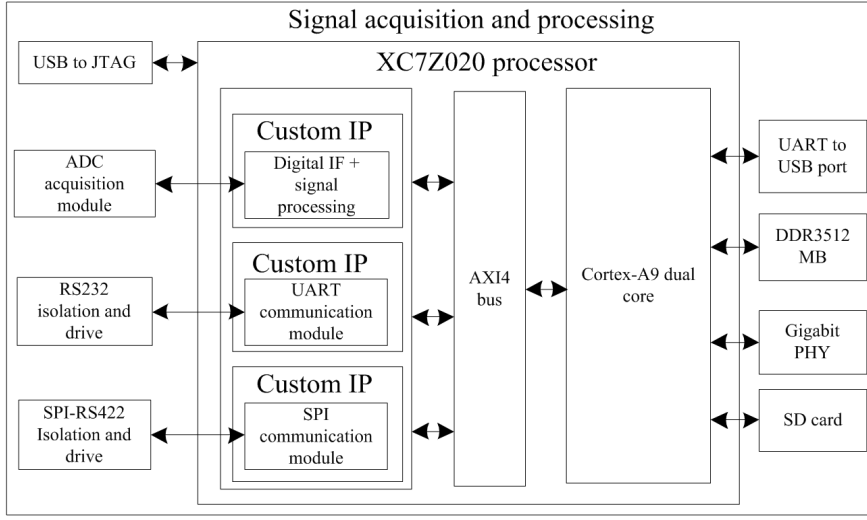
2 Doppler radar data acquisition

The main technical difficulties faced by Doppler radar data acquisition include Doppler effect, weather interference, radar system construction, and data processing and analysis. The Doppler effect causes changes in the frequency of the target echo, and correct estimation and processing become crucial. Weather disturbances such as precipitation and clouds can interfere with the superposition of target signals and need to be effectively removed. The construction of radar systems requires overcoming various technical and equipment difficulties. The amount of data processing and analysis is large and complex, requiring advanced algorithms and technical support. In the face of these challenges, continuous research and innovation are crucial to improve the accuracy and reliability of data collection. The cross regional large power grid has wide coverage and high operational stability. In order to ensure the safe operation of the power system, the need for meteorological disaster monitoring is very important. The characteristics of cross regional large power grid include large coverage, high stability requirements, multiple disaster types, and high spatio-temporal resolution. Therefore, meteorological disaster monitoring needs to have a strong coverage ability, timely warning and accurate monitoring of the development trend and spatial distribution of various types of disasters (Luo et al., 2021). At the same time, measures should be considered to prevent and mitigate disaster risks, improve the reliability and stability of power systems, and provide accurate information and support for decision makers.

In order to accurately monitor meteorological disasters in cross regional large power grid and avoid serious interference from meteorological disasters on grid operation, it is necessary to analyse meteorological disasters based on Doppler radar data.

In this research, the XC7Z020 device is used as the core device to build a high-speed data collector to collect the data of the Doppler radar.

From Figure 1, it can be seen that the Doppler radar data acquisition work is a continuous process that integrates scanning, acquisition, processing, and transmission, requiring a large amount of data to be processed. Therefore, the collector is required to have high stability and reliability. The ADC acquisition module is equipped with a 16 bit 250MSPS sampling rate analogue-to-digital converter AD9467, which can achieve a signal-to-noise ratio of 75.5 dBFS and meet the requirements of high-performance weather radar data acquisition.

Figure 1 Schematic diagram of Doppler radar data acquisition

When using Doppler radar for meteorological disaster analysis, there is often a problem of clutter interference from various interference sources. Therefore, suppressing clutter interference in Doppler radar data is crucial. Firstly, clutter interference can reduce the detection and measurement accuracy of Doppler radar, making it difficult to accurately extract and analyse target signals. Secondly, clutter interference may lead to misjudgment and erroneous analysis, affecting the accurate analysis and identification of target features. In addition, clutter interference can also affect the performance and efficiency of Doppler radar systems.

The estimation of ZVW parameters can be achieved through time-domain pulse pair processing, which is a technology used to process Doppler radar data and has the advantage of suppressing clutter interference. PDP achieves high-resolution target detection by optimising pulse width and repetition frequency, and can effectively expand the dynamic range. It utilises the Doppler effect to exclude irrelevant Doppler frequency shifted signals from target detection, thereby suppressing clutter interference beyond stationary or slow target signals. In addition, PDP has the characteristic of adaptive performance optimisation, which can adjust and optimise in real-time based on environmental conditions and target characteristics, improving the effectiveness of clutter interference suppression. In this study, time-domain pulses were used to suppress clutter interference in the processor.

The calculation formula for the equivalent reflectivity factor is:

$$Z(A_z, E_1, R) = 10 \log(\bar{P}_r) + 20 \log(R) - 10 \log(L_A) + 10 \log(C) \quad (1)$$

In the formula, P_r represents the average echo power of the radar, R represents the echo distance, L_A represents linear path attenuation, and C represents the radar constant.

The calculation formula for the radar constant C is:

$$C = 2.6935 \times 10^6 \times \frac{\lambda^2}{P_t \tau G_T G_R \theta \phi L_T} \quad (2)$$

In the formula, λ represents the radar transmission wavelength, P_t represents the transmission pulse power of the radar signal, τ represents the transmission pulse width of the radar signal, G_T and G_R represent the signal transmission and reception gain of the radar antenna, θ and ϕ represent the elevation beam width of the radar signal, and L_T represents the feeder loss (Zhou et al., 2021).

Based on the above parameters, calculate the average radial velocity of the speed fuzzy working mode of the staggered repetition frequency link:

$$V = \frac{\lambda(\theta_l - \theta_h)}{4\pi(\tau_l - \tau_h)} \quad (3)$$

In the formula, τ_l and τ_h represent alternating pulse intervals with a ratio of 5:4, θ_l represents the phase angle of the first-order correlation $\hat{R}_l(\tau_l)$ of the two pulse echoes under the τ_l -pulse interval, and θ_h represents the phase angle of the first-order correlation $\hat{R}_h(\tau_h)$ corresponding to τ_h (Fan et al., 2023).

Based on the above calculation, the width of the echo velocity spectrum can be calculated based on the 0-order correlation power spectrum of $\hat{S}_l$ and $\hat{S}_h$:

$$\hat{\sigma}_v = \frac{5\lambda}{16\pi\tau_l\sqrt{2}} \sqrt{\ln\left(\frac{\hat{S}_l}{|\hat{R}_l(\tau_l)|}\right)} + \frac{\lambda}{4\pi\tau_h\sqrt{2}} \sqrt{\ln\left(\frac{\hat{S}_h}{|\hat{R}_h(\tau_h)|}\right)} \quad (4)$$

Based on the above calculation, the ZVW parameter estimation of the weather radar is completed through the processor in the Doppler radar data collector. The processed data is used as the sample data for this study to monitor and warn of meteorological disasters in cross regional large power grid.

3 Monitoring of meteorological disasters in cross large regional power grid based on Doppler radar data

This method can significantly improve the accuracy of meteorological disaster monitoring by utilising atmospheric data obtained from Doppler radar. At the same time, this method also has the ability to classify and identify various meteorological disasters, which can accurately identify and analyse different types of disasters. In addition, the monitoring results based on this method consider the needs and characteristics of cross regional power grids, providing level evaluation information for the power grid, and providing important reference for the management and scheduling of the power system. More importantly, this method can effectively shorten the time of meteorological disaster monitoring and early warning, improve real-time performance and response speed. In summary, the cross regional meteorological disaster monitoring method based on Doppler radar data for large power grids has significant innovation in monitoring accuracy, classification recognition, adaptability, and time efficiency, providing a reliable solution for the power industry. When it comes to meteorological disasters in the power grid, strong winds, lightning, hail, and heavy precipitation are the main causes. Strong winds often cause power lines to break, equipment to collapse, or trees to collapse, and their occurrence is usually related to factors such as pressure differences, typhoons,

storms, and terrain. Lightning can cause overvoltage, which may cause damage to power equipment, switch tripping, or even fire, and it often occurs in areas with unstable atmospheric conditions such as high temperature and humidity in summer (Wu et al., 2021). Hailstones directly hit wires and equipment, causing them to be damaged or even broken, and their formation is related to strong convective weather. Severe precipitation can cause floods, equipment failures, and power outages, which are usually related to convective activities, low-pressure systems, monsoons, and terrain. Therefore, monitoring meteorological disasters can improve the resilience of cross regional large power grid and ensure the stability of power supply.

3.1 Strong wind identification

In the identification of strong wind meteorological disasters in the power grid, the main method is to calculate the shear value. The radial shear of radial velocity refers to the variation of radar radial velocity along a certain radial direction starting from the origin. The expression for radial wind shear is:

$$\frac{\partial v}{\partial r} = \frac{\sum_{i=1}^n v_i - n \sum_{i=1}^n (v_i r_i)}{\sum_{i=1}^n r_i \sum_{i=1}^n r_i - n \sum_{i=1}^n r_i^2} \quad (5)$$

In the formula, r represents the number of radar centre distance circles, v_i represents the radial velocity of the i -th point at azimuth θ , r_i represents the distance between the i -th monitoring point and the radar centre, and n represents the number of monitoring points.

The expression for radial velocity tangential shear is:

$$\frac{\partial v}{r \partial \theta} = \frac{\sum_{j=1}^m v_j \sum_{j=1}^m \theta_j - n \sum_{j=1}^m v_j \theta_j}{r \left[\sum_{j=1}^m \theta_j \sum_{j=1}^m \theta_j - n \sum_{j=1}^m \theta_j^2 \right]} \quad (6)$$

In the formula, m represents the number of radial velocities, and θ_j represents the azimuth angle of the j -th monitoring point (Zhang et al., 2021).

Combining the radial and vertical variations of Doppler radar radial velocity, a two-dimensional convergence tangent index is constructed to identify strong wind disasters in cross regional large power grid. The calculation formula for the two-dimensional convergence shear index is:

$$Q = \sqrt{\left(\frac{\partial v}{\partial r} \right)^2 + \left(\frac{\partial v}{r \partial \theta} \right)^2} \quad (7)$$

Usually, when the two-dimensional convergence tangent index value is $Q < 0.003$, it indicates weak wind force. When the two-dimensional convergence tangent index value is $0.003 < Q < 0.01$, it indicates that the wind force is moderately weak. When the two-dimensional convergence tangent index value is $Q > 0.01$, it indicates strong wind force.

3.2 Lightning identification

In this study, the lightning identification of cross regional large power grid is based on the identification of storm cells. If there is a storm cell, further judgment is made on whether the cell has experienced lightning. The lightning identification factor is based on the echo peak height of 40 dBZ, the echo volume above -15°C layer exceeding 30 dBZ, and their percentage in the total volume of thunderstorms. The specific steps for lightning identification are as follows:

- 1 Observe whether the top height of the 40 dBZ echo of a thunderstorm is lower than the height of the -20°C layer during its development. If the above situation occurs, it indicates that the dynamic conditions of the thunderstorm are insufficient and the electrification ability is weak at this time. If this situation does not occur, it indicates that the lightning activity of the thunderstorm is not in an imminent state (Hou et al., 2021).
- 2 After meeting the above conditions, calculate the echo volume exceeding 30 dBZ above the -15°C layer of the thunderstorm. If the echo volume exceeds 230 km^3 , it indicates that there are many ice phase particles at the starting point of the thunderstorm and the electrification ability is strong.
- 3 When the above conditions are met, the percentage of echo volume exceeding 30dBZ above the 15°C layer in the total volume of the thunderstorm. If the percentage is less than 1%, it indicates that the lightning will end within 30 minutes. If the percentage is greater than 1%, it indicates that the lightning activity of the thunderstorm will continue for a long time.

3.3 Hail identification

Due to the complexity of hail occurrence, in order to accurately identify hail meteorological disasters, multiple hail discrimination factors need to be considered. The hail discrimination factors are shown in Table 1.

Table 1 Hail discrimination factors

<i>Discriminant factor</i>	<i>Illustrate</i>
Radar echo intensity	The maximum radar echo intensity of hail clouds is greater than or equal to 55 dBZ
Echo top height	Generally, the top height of hail cloud echoes is above 9–10 km
Height of 45 dBZ echo	The height of the top of the 45 dBZ echo is an important indicator for identifying hail clouds. Hail weather occurs when the height of the 5 dBZ echo is greater than or equal to 7.6 km
Vertical liquid water content	During the descent of hail, there will be a sudden increase in the vertical liquid water content, indicating the continuous expansion of particles within the hail cloud. In general hail areas, the vertical liquid water content is greater than or equal to $35\text{ kg}\cdot\text{m}^{-2}$
Vertical liquid water content density	The vertical liquid water content density can reflect the relationship between the vertical liquid water content and the echo thickness. When the vertical liquid water content density is greater than or equal to $3.5\text{ g}\cdot\text{m}^{-3}$, hail will occur

Identify hail disasters based on the above five discriminant factors:

$$W = W_1 \cdot X_1 + W_2 \cdot X_2 + W_3 \cdot X_3 + W_4 \cdot X_4 + W_5 \cdot X_5 \quad (8)$$

In the formula, $X_1, \dots, X_5$ represent the discriminant factor, and $W_1, \dots, W_5$ represent the weight of the discriminant factor.

When $W < 50$, it indicates no hail, when $50 \leq W \leq 80$, it indicates that there may be hail, and when $W > 80$, it indicates hail.

3.4 Strong precipitation identification

The high centre of mass structure usually refers to the upward movement of strong airflow in the echo area, indicating that there may be strong convective activity near the echo centre. This is usually related to strong precipitation, large-scale upward movement, or convective development, implying higher precipitation intensity. The low centre of mass structure refers to the sinking motion of weak airflow in the echo area, indicating that there may be weak convective activity near the echo centre. The low centre of mass structure is usually associated with processes where precipitation is weak or weakening, implying lower precipitation intensity.

In this study, heavy precipitation was analysed by distinguishing whether the precipitation type meets the low centroid structure or the high centroid structure.

Low centre of mass structure

- 1 The precipitation echo on the PPI is banded, with a movement direction similar to the long axis direction of the echo.
- 2 The echo velocity is greater than or equal to $40 \text{ km} \cdot \text{h}^{-1}$.
- 3 The reflectivity factor is greater than or equal to 40 dBZ.
- 4 The vertical liquid water content ranges from $12 \text{ kg} \cdot \text{m}^{-2} \sim 32 \text{ kg} \cdot \text{m}^{-2}$.
- 5 The echo extension height above 50 dBZ is within the range of 2~4 km and does not exceed the 0°C layer height.

High centre of mass structure

- 1 The echo velocity ranges from $10 \text{ km} \cdot \text{h}^{-1} \sim 30 \text{ km} \cdot \text{h}^{-1}$.
- 2 The reflectivity factor is greater than or equal to 40 dBZ.
- 3 The vertical liquid water content is greater than or equal to $50 \text{ kg} \cdot \text{m}^{-2}$.
- 4 Echoes above 50 dBZ extend within the range of 5~8 km, reaching above the 0°C layer, and have weak echo areas under high hanging strong echoes.

4 Meteorological disaster warning for cross regional large power grid

By utilising Doppler radar data, this method achieves high-precision monitoring and early warning of meteorological disasters. At the same time, this method focuses on the needs and characteristics of cross regional power grids, providing an adaptive design warning scheme for the power system. The warning results consider the layout and structure of the power grid, providing important information for power system management and scheduling. In addition, based on the rapid processing and analysis of Doppler radar data, this method can generate warning results in a shorter time, greatly improving the efficiency of warning. Taking into account various types of meteorological disasters, this method provides comprehensive disaster monitoring and early warning capabilities. In summary, the meteorological disaster warning methods for cross regional power grids have shown significant innovation in data application, adaptive design, time efficiency, and comprehensive disaster monitoring, providing reliable and efficient warning solutions for the power industry. In order to evaluate the meteorological disaster risk of power grid units and determine the level of meteorological disaster risk, the meteorological disaster risk of cross regional large power grid units is calculated according to the ‘Quantitative Assessment Method for Power Grid Safety Risk (Trial)’:

$$R = S \times P \quad (9)$$

In the formula, R represents the safety value of the power grid, S represents the safety risk consequence value, and P represents the probability value.

Based on the calculation results of the safety risk value of the cross regional large power grid, the safety level of the power grid is divided. The safety level of the power grid is shown in Table 2.

Table 2 Safety risk levels of cross regional large power grid

<i>Risk level</i>	<i>Risk value range</i>
I (Significant risk)	$1,000 \leq \text{Risk value}$
II (Major risk)	$300 \leq \text{Risk value} < 1,000$
III (Large risk)	$60 \leq \text{Risk value} < 300$
IV (Generally A type of loss)	$20 \leq \text{Risk value} < 60$
V (Generally B type of loss)	$5 \leq \text{Risk value} < 20$

According to formula (9), it can be inferred that obtaining the risk value requires a consequence severity score analysis based on the severity and risk probability of the consequences. The severity score of the consequences of security risks in cross regional large power grid is shown in Table 3.

According to the emergency plan for meteorological disasters and accidents in the power grid, combined with the severity grading results in Table 3, the levels of meteorological disasters and accidents in the power grid are divided. The classification results of meteorological disasters and accidents in the power grid are shown in Table 4.

Table 3 Severity score of consequences of security risks in cross regional large power grid

<i>Project</i>	<i>The severity of the consequences</i>	<i>Score</i>
Significant loss of power grid	The provincial capital power grid reduces the load by more than 60%, or the number of power outage users accounts for more than 70% of the total power supply users	Above 3,000
Major losses to the power grid	1 The provincial capital city reduces the power supply load by 40% to 60%, or the number of power outage users accounts for 50% to 70% of the total power supply users 2 Urban power grid in other regions have reduced their load by more than 60%, or the number of power outage users accounts for more than 70% of the total power supply users 3 Other events that may cause major accidents or significant adverse effects on the power grid	500~3000
Large loss of power grid	1 The provincial capital power grid reduces the load by 20% to 40%, or the number of power outage users accounts for 30% to 50% of the total power supply users 2 The power grid in other regions has reduced the load by 40% to 60%, or the number of power outage users accounts for 50% to 70% of the total power supply users 3 County level city power grid reduces load by more than 60%, or the number of power outage users accounts for more than 70% of the total power supply users 4 Other events that cause major accidents or significant adverse effects on the power grid	100~500
The power grid is generally A type of loss	1 The power grid in provincial capital cities reduces the load by 10~20%, or the number of power outage users accounts for 15% to 30% of the total power supply users 2 The power grid in other regions has reduced the load by 20% to 40%, or the number of power outage users accounts for 30% to 50% of the total power supply users 3 County level cities reduce power supply load by 40%~60%, or the number of power outage users accounts for 50%~70% of the total power supply users 4 Potential power grid accidents or adverse impact events identified by the power supply bureau	30~100
The power grid is generally B type of loss	1 The 110 kV power grid is unstable, and the power grid of 110 kV and above can be understood as three or more pieces when flying normally 2 The automation system of the power grid dispatching organisation fails for more than 1 hour, and the communication system terminal fails for more than 2 hours 3 Stop operation of any section of busbar with a voltage level of 220 kV or above in the substation 4 Events identified by the power grid dispatching agency that may cause grid obstacles or adverse effects	0~30

According to Table 4, it can be seen that this study intends to exclude major power grid accidents in Table 3. Therefore, a scoring criterion for the severity level of drivers will be developed and a severity level scoring criterion will be constructed, as shown in Table 5.

Table 4 Meteorological disaster accident levels of power grid

<i>Hazard nature</i>	<i>Range</i>	<i>Particularly significant</i>	<i>Significant</i>	<i>Larger</i>	<i>General</i>
Proportion of load reduction caused by power grid	The whole area	>25%	12~25%	6~12%	3~16%
	District administrative centre	≥40%	≥25%	12~25%	6~12%
	County-level city	-	≥40%	≥25%	12~25%
	All counties	-	-	≥40%	≥25%
Proportion of power outages caused by power supply users	District administrative centre	≥50%	≥35%	20~35%	10~20%
	County-level city	-	≥50%	≥35%	20~35%
	All counties	-	-	≥50%	≥35%
Casualty situation	Whole area system	≥ 10 deaths	5–9 deaths	2–4 deaths	1 person died
		≥ 20 people severely injured	10–19 people severely injured	5–9 people are important	1–4 people severely injured

Table 5 Criteria for severity rating

<i>Severity score</i>	<i>Severity grade</i>	<i>Meteorological disaster level</i>	<i>Project</i>
500~3000	Catastrophic	Particularly significant accident	Major losses to the power grid
100~500	Fatal	Major accident	Large loss to the power grid
30~100	Grievous	Larger accident	The power grid is generally A type of loss
0~30	Heavier	General accident	The power grid is generally B type of loss

In order to more accurately assess the risk of meteorological disaster damage to the power grid and evaluate the risk level of the power grid, the calculation formula is:

$$R_u = \sum R_i \quad (10)$$

In the formula, R_i represents the risk component.

The risk component R_i refers to the risk of loss caused by various losses in the power grid within a specific period of time, and its calculation formula is:

$$R_i(\xi/X_t) = \sum P_i(E/X_t) \cdot S(\xi/E) \quad (11)$$

In the formula, E represents the number of occurrences of disaster accidents, X_t represents the operating status of the power grid before the disaster accident occurred, ξ represents the consequences of the disaster accident, $P_i(E/X_t)$ represents the probability of disaster

accident E occurring in X_t state, and $S(\xi/E)$ represents the severity of the consequences of the disaster accident.

According to the intensity and probability of meteorological disasters, the risk of meteorological disasters in cross regional large power grid is divided into red warning, orange warning, yellow warning, and blue warning from high to low. Meteorological disasters and warning levels are shown in Table 6.

Table 6 Meteorological disasters and warning levels

<i>Meteorological disaster</i>	<i>Red alert</i>	<i>Orange alert</i>	<i>Yellow alert</i>	<i>Blue alert</i>
Strong wind	Winds may reach force 8 or gusts above force 9 within 12 hours and may persist	Winds may reach force 6 or above in 24 hours, or gusts of force 7 or above, and may persist	The average wind can reach a force 6 or above in 36 hours, or a wind gust of a force 7 or above, and may persist	The average wind may reach a force 6 or above in 48 hours, or a force 7 or above, and may persist
Aegis	The possibility of lightning activity within 2 hours is very large, or there has been a strong lightning activity, there is still a great possibility of lightning disaster accidents	There is a high possibility of lightning activities within 2 hours, or has been affected by lightning activities, and will continue to continue, the possibility of lightning disaster accidents is greater	Lightning activity may occur within 6 hours, which may cause lightning disaster accidents	-
Hailstone	There is a high possibility of hail within 2 hours, and may cause heavy hail disaster	There may be hail weather within 6 hours, and may cause hail disaster	-	-
Heavy precipitation	Precipitation reached more than 50 mm in 6 hours, or rain still exists	Precipitation will reach more than 50 mm within 12 hours, or it has reached more than 50 mm and the rain is still there	Precipitation will reach more than 50 mm within 24 hours, or it has reached more than 50 mm and the rain is still there	Precipitation will reach more than 50 mm within 36 hours, or it has reached more than 50 mm and the rain is still there

Based on the above analysis, calculate the risk warning index for meteorological disasters in cross regional large power grid:

$$J = R_u \cdot r_i \quad (12)$$

In the formula, r_i represents the meteorological disaster risk warning index.

Based on the calculation results of the risk warning index for cross regional large power grid, the level of meteorological disaster risk warning for the power grid is generated, as shown in Table 7.

Table 7 Meteorological disaster risk warning levels

<i>Warning index J</i>	<i>Risk level</i>	<i>Control strategy</i>	<i>Warning level</i>
100~500	Major risk	Move up to the higher organisation plan	Level I (Red)
50~100	Larger risk	External resource controls need to be mobilised	Level II (Orange)
30~50	General type A risk	Need measure control	Level III (Yellow)
0~30	General type B risk	Need attention	Level IV (Blue)

According to the risk warning levels of meteorological disasters in the power grid shown in Table 7, a warning is issued to the power grid security prevention and control centre. Upon receiving the warning information, the power grid security prevention and control centre will immediately take corresponding measures to respond to possible faults and disaster situations, in order to improve the stability of the power grid operation.

5 Experimentation

In order to validate the proposed cross regional meteorological disaster monitoring and warning method based on Doppler radar data for cross regional large power grid, the monitoring and warning performance was tested.

5.1 Test sample data

This experiment takes the Northwest Power Grid, a cross regional large power grid in Xinjiang, as an example to conduct meteorological disaster monitoring and warning experiments. As one of the systems managed and operated by State Grid Corporation of China, Northwest Power Grid covers the power transmission and distribution networks in northwestern regions such as Xinjiang, Gansu, Qinghai, Ningxia, etc. This power grid system is one of the important hubs connecting the western and eastern power grid. The Northwest Power Grid is an important energy transmission channel, responsible for transporting the rich energy resources (such as coal, natural gas, and wind energy) in Xinjiang to the eastern and central regions.

Taking some towers, wires, and insulators in the Northwest Power Grid as examples, testing was conducted to monitor meteorological disaster risks and generate warning results.

The parameters of the tower, conductor, and insulator are shown in Table 8.

After completing the selection of power grid parameters, it is necessary to deploy the Doppler radar system in the area covered by the power grid to obtain information on meteorological disasters such as precipitation, wind speed, hail, and lightning. The parameters of the Doppler radar system are shown in Table 9.

Table 8 Grid parameters

<i>Tower parameters</i>		<i>Wire parameters</i>		<i>Insulator parameters</i>	
<i>Project</i>	<i>Parameter</i>	<i>Project</i>	<i>Parameter</i>	<i>Project</i>	<i>Parameter</i>
Voltage level	500 kV	Stress/MPa	58	Number of strings	1
Line type	Single circuit	Diameter/mm	26.82	String length/mm	5,335
Horizontal span/m	420, 420	Cross section area/mm ²	425.24	Number of each string	28
Height difference on both sides/m	0.00, 0.00	Self weight kg/m	1.349	Single piece self weight/kg	10.0
Number of lines	3	Suspended height/m	30	Disc diameter/mm	300
Corner	0.0000	Splitting number	4	Single disc height/mm	155

Table 9 Parameters of Doppler radar system

<i>Project</i>	<i>Parameter</i>
Pulse repetition frequency	1,000~4,000 Hz
pulse width	0.5~2 μ s
Radar beamwidth	1~2°
Doppler velocity resolution	Under restraint mode: 1~2 m/s In frequency domain noise reduction mode: 0.1~0.5 m/s

5.2 Test scheme

In order to fully validate the practical application performance of the proposed cross regional large power grid meteorological disaster monitoring and warning method, the method proposed in this paper was compared with the methods in Hu at al. (2022) and Zhao et al. (2021), with meteorological disaster monitoring accuracy, warning accuracy, and overall monitoring and warning time as indicators.

- *Meteorological disaster monitoring accuracy*: The meteorological disaster monitoring accuracy of the cross regional large power grid refers to the correlation between the monitoring results of potential meteorological disasters in the cross regional large power grid system and the actual results. The higher the meteorological disaster monitoring accuracy, the stronger the monitoring performance of the method.
- *Meteorological disaster warning accuracy*: The meteorological disaster warning accuracy of the cross regional large power grid refers to whether the warning levels issued for different meteorological disasters match the actual meteorological disaster levels. The higher the meteorological disaster warning accuracy, the stronger the warning performance of the method.
- *Meteorological disaster monitoring and warning time*: Meteorological disaster monitoring and warning time refers to the time elapsed from the beginning of

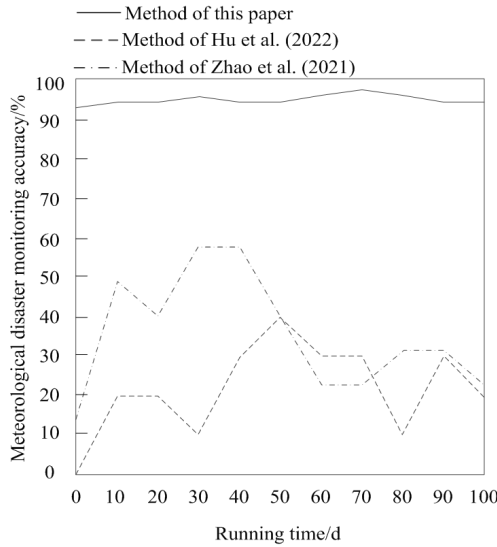
monitoring to the issuance of warning information. It is an important indicator to measure the response speed and efficiency of monitoring and warning methods. The shorter the overall monitoring and warning time, the higher the monitoring and warning efficiency of the method.

5.3 Analysis of test results

5.3.1 Meteorological disaster monitoring accuracy

Extreme weather events such as storms and lightning can lead to problems such as damage to power equipment, transmission line breakage, and power supply interruption. By monitoring meteorological disasters, power grid managers can take timely measures, such as adjusting power supply strategies, strengthening equipment maintenance, and evacuating personnel, to reduce the impact of disasters on the operation of the power grid. The accuracy verification of meteorological disaster monitoring in cross regional large power grid can ensure that the monitoring capacity of the power grid system for meteorological disasters reaches a high-precision level. The accuracy results of meteorological disaster monitoring using three methods are shown in Figure 2.

Figure 2 Precision of meteorological disaster monitoring



From Figure 2, it can be seen that as the operating time increases, there is a significant difference in the accuracy of the three methods for meteorological disaster monitoring. Throughout the entire 100 day testing process, the meteorological disaster monitoring accuracy of the method proposed in this paper remained above 93%, with the highest monitoring accuracy reaching 97%. The monitoring accuracy of the methods in Hu et al. (2022) and Zhao et al. (2021) is lower than that of the methods in this paper. Therefore, it indicates that this method can accurately monitor meteorological disasters in cross regional power grids.

5.3.2 Accuracy of meteorological disaster warning

By issuing early warnings, grid managers can take timely measures to protect the safety of power facilities and personnel. In addition, accurate early warning can also help the power grid department and relevant emergency agencies coordinate and make decisions to respond to potential disasters. By verifying the accuracy of meteorological disaster warning, the reliability and effectiveness of the warning system can be evaluated. This helps to improve early warning technology, enhance early warning capabilities, and continuously improve the emergency management system of the power grid, enhancing the ability to respond to meteorological disasters. The accuracy results of meteorological disaster warning using three methods are shown in Table 10.

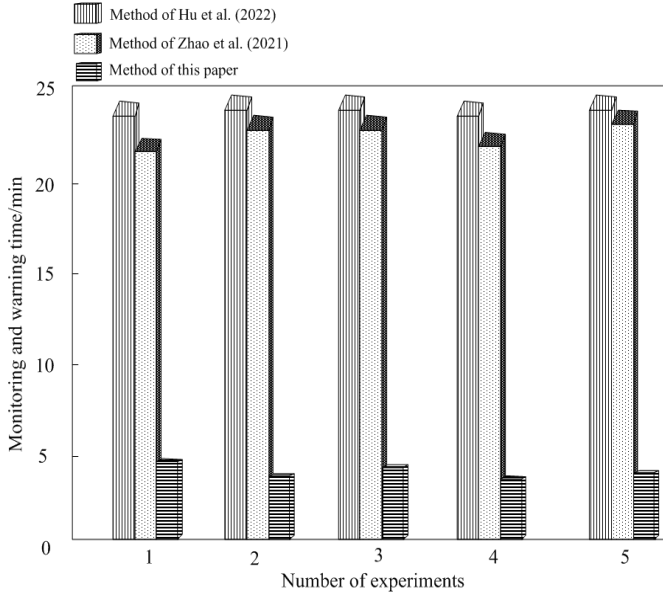
Table 10 Accuracy of meteorological disaster warning

Number of experiments	Actual meteorological disasters	Meteorological disaster warning results		
		Method of this paper	Method of Hu at al. (2022)	Method of Zhao et al. (2021)
1	Strong wind blue warning	Strong wind blue warning	Strong wind red warning	Strong wind blue warning
2	Lightning orange Warning	Lightning orange Warning	Lightning orange warning	Thunderbolt red warning
3	Hail orange warning	Hail orange warning	Hail Red warning	Hail orange warning
4	Heavy rainfall red warning	Heavy rainfall red warning	Orange warning for heavy precipitation	Strong precipitation yellow warning
5	Strong precipitation yellow warning	Strong precipitation yellow warning	Strong precipitation yellow warning	orange warning for heavy precipitation

The experimental results in Table 10 show that the proposed method can achieve consistent warning results with actual disasters in the early warning of strong winds, lightning, and hail disasters, while the methods in Hu at al. (2022) and Zhao et al. (2021) may not match the actual warning results in some cases. Therefore, the method presented in this article exhibits higher accuracy and reliability in early warning of strong winds, lightning, and hail disasters, but does not have significant advantages compared to the Zhao et al. (2021) method in early warning of heavy precipitation disasters.

5.3.3 Meteorological disaster monitoring and warning time

The power grid is an important infrastructure related to the national economy and people's lives. The impact of disasters on the power grid may lead to problems such as power supply interruption and equipment damage, bringing huge losses to society. Through rapid monitoring and early warning, power grid departments and relevant emergency agencies can have sufficient time to prepare and take measures to minimise the damage caused by disasters to the power grid. The monitoring and warning time results of meteorological disasters using three methods are shown in Figure 3.

Figure 3 Time of meteorological disaster monitoring and warning

Observing Figure 3, it can be seen that under multiple experiments, the meteorological disaster monitoring and warning time of the three methods has always been lower than the methods in Hu at al. (2022) and Zhao et al. (2021). The maximum monitoring and warning time of this method does not exceed five minutes, while the meteorological disaster monitoring and warning time of both Hu at al. (2022) and Zhao et al. (2021) methods are above 20 minutes. Therefore, it indicates that this method can achieve rapid monitoring and warning of meteorological disasters in power grid.

6 Conclusions

In order to detect and evaluate potential meteorological disasters that may cause cross regional large power grid in advance and ensure the stability of power supply, a monitoring and warning method for meteorological disasters in cross regional large power grid based on Doppler radar data is proposed. The performance of the method was verified from both theoretical and experimental perspectives. This method has high warning accuracy and short monitoring and warning time when monitoring and warning meteorological disasters in cross regional large power grid. Specifically, compared with the monitoring and warning methods based on deep sparse self coding networks and scene classifiers, the warning accuracy of this method is significantly improved, which is completely consistent with the actual meteorological disaster warning accuracy. Compared with the monitoring and warning method based on refined meteorological data, the monitoring and warning time of this method is effectively shortened, with a maximum monitoring and warning time of no more than five minutes. Therefore, the proposed monitoring and warning method based on Doppler radar data can better meet the requirements of meteorological disaster monitoring and warning for cross regional large power grid.

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