DOI: 10.54254/2755-2721/142/2025.KL21564

Optimized Configuration and Dispatching of Power System Reserve Capacity under Extreme Weather Conditions

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Abstract: The increasing frequency of extreme weather events caused by climate change, such as typhoons, tornadoes, and ice storms, not only affects the stability of power loads but can also cause severe damage to power infrastructure, leading to frequent large-scale power outages. To enhance the risk resilience of power systems, effective reserve capacity configuration and dispatch strategies are necessary. Therefore, studying the optimization of reserve capacity under extreme weather conditions is of great significance. This paper uses a literature review research method to analyze the impact of extreme weather events on power system components, assess the failure probability of system components during extreme weather, and optimize the reserve capacity accordingly. Research on the optimization configuration and dispatch of reserve capacity under extreme weather conditions can enable rapid response during extreme weather events, reduce losses caused by weather, and support the sustainable development of power systems.

Keywords: Extreme weather, power system, probabilistic assessment, standby optimization

1. Introduction

In recent years, the world has faced increasing risks from climate change, with the frequency and impact of extreme weather events growing. According to a 2008 report by the Edison Electric Institute (EEI), 67% of power outages in the United States are weather-related, with the cost of service restoration exceeding $2.7 billion in 2005 [1]. China, one of the countries most severely affected by tropical cyclones, experiences an average of 7.2 typhoons landing on its southeastern coast each year. Additionally, regional ice disasters have been frequent, with over 1,000 ice-related disasters affecting power systems above 6 kV since the 1950s [2-3]. Extreme weather events have severely impacted agriculture, industry, and other sectors, causing significant economic losses.

Studying the disaster-causing mechanisms of different extreme weather events on power systems, quantifying the disaster-causing factors, and accurately simulating extreme weather events are the foundations of researching the impact of extreme weather on power systems. Current research has made progress in assessing the impact of extreme weather on power grids. Some studies suggest quantifying the impact of extreme weather disasters on power grids by calculating the intensity of disaster-causing factors on power system components, enabling a multi-dimensional assessment of the grid [4]. With the increasing integration of renewable energy into the grid, system randomness has also increased, leading to larger prediction errors. Existing literature suggests several methods

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for power system reserve configuration, including deterministic methods, probabilistic methods, cost-benefit analysis methods (e.g., cost-benefit analysis), and stochastic optimization methods. These methods consider uncertainties in the power system while balancing economic efficiency and reliability [5-6]. This paper uses a literature review research method to analyze the impact of extreme weather events on power system components and summarize reserve capacity optimization.

Research on the optimization configuration and dispatch of power system reserve capacity under extreme weather conditions is of great significance. Rapid and effective reserve capacity configuration and dispatch can reduce the probability of power outages for users, balance the economic efficiency of the power system, and maintain social stability and steady economic development.

2. Review of the literature

Existing literature has constructed models to assess the impact of extreme weather on power systems. For example, one study used climate models and regional downscaling methods to obtain meteorological data for each province in China, converting it into output data. The study constructed extreme weather scenarios under sustained low-output conditions and analyzed their spatiotemporal characteristics, combining adequacy methods to assess the impact of various sustained low-output scenarios [7]. This research transformed meteorological factors into output data, providing a quantitative analysis of the impact of extreme weather on the adequacy of new power systems. However, specific optimization measures still require further research.

Regarding the optimization configuration of reserve capacity in power systems, one study established prediction error models for wind power, photovoltaic power, and load output based on a new energy system. Building on the participation of conventional units in providing reserve capacity, the study proposed an optimization configuration method involving flexible loads and energy storage, constructing a source-load-storage multi-reserve system and establishing a reserve optimization model considering new energy reserves [8]. This optimization configuration method can achieve coordinated reserve optimization for multiple types of energy, improving the system's economic efficiency. However, it did not consider the uncertainties under extreme weather conditions or the optimization configuration of reserve capacity in such scenarios. Another study proposed a power system optimization dispatch method based on large-scale wind power and solar thermal power plants. It first established a dispatch operation model for solar thermal power plants with thermal storage and electric heating, then considered factors such as thermal power units, solar thermal power plants, and electric heating providing reserve capacity and system safety constraints to establish an optimization dispatch model [9]. This study improved the operational flexibility of solar thermal power plants and the economic efficiency of system operation, providing new insights for further optimization dispatch research.

3. Modeling and analysis

3.1. Evaluate the extreme weather impacts

By assessing the impact of extreme weather on various components of the power system, the system's vulnerabilities under different types of extreme weather can be identified, allowing for targeted strengthening measures. Additionally, assessing the impact of weather on power load fluctuations and changes in power output can help analyze the required reserve capacity under different extreme conditions, enabling rational allocation of power resources across regions and improving the overall operational efficiency and reliability of the power system.

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3.1.1. Analysis of meteorological data

Collect historical meteorological data and real-time weather forecast information, including the type, intensity, and impact range of extreme weather events, such as typhoon paths, wind speeds, rainfall, or the temperature drop and duration of cold waves, to accurately predict their impact on various components of the power system.

3.1.2. Assessment of the probability of equipment failure

Assess the failure probability of various components of the power system (e.g., transmission lines, transformers) under extreme weather events. When an extreme weather event (e.g., typhoon or ice storm) passes through a region, the damage intensity to the power system in that region varies over time and geography, and the failure probability of system components is related to the damage intensity of the weather. Typically, the damage intensity of extreme weather is related to its disaster-causing factors (e.g., wind speed or ice load). The failure probability of a component can be represented by a vulnerability curve, mapping the intensity of extreme weather to these vulnerability curves at each simulation step to obtain the failure probability of system components under different extreme weather events. This paper references a study on the framework for assessing the failure probability of power system components considering the spatiotemporal impact of extreme weather, as shown in Figure 1 [10].

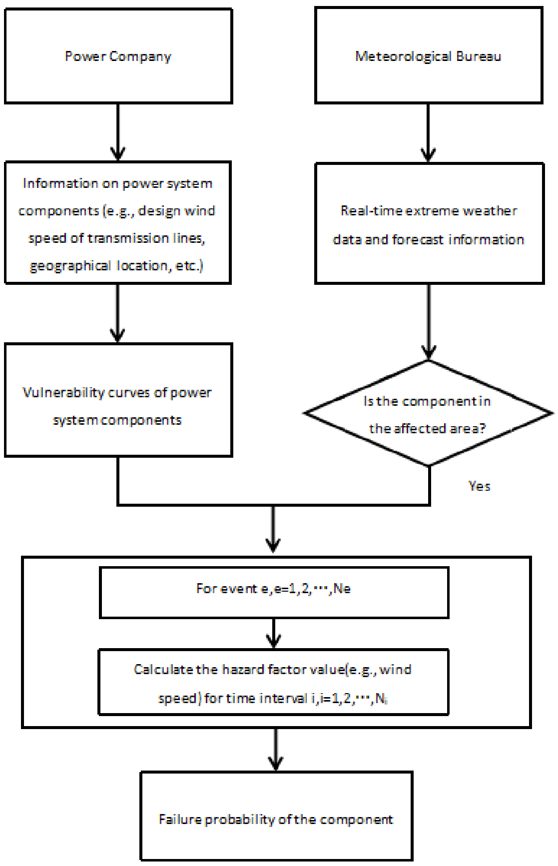

Figure 1: Flow chart of the evaluation of the probability of failure [10]

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3.1.3. Forecast of load change

Consider the impact of extreme weather on user electricity consumption behavior, such as a significant increase in air conditioning load during high temperatures or a surge in heating equipment usage during cold waves, to predict changes in power system load trends and peak demand. Existing literature proposes a short-term load forecasting model based on a tensor low-rank completion algorithm for extreme weather scenarios, where data is sparse and highly random. The model uses an improved heat index and temperature to filter data, proposes a tensor-based load data model to complete missing data, and selects input features through Pearson correlation analysis to construct a short-term load forecasting model based on Long Short-Term Memory (LSTM) networks and Rough Set Theory (RST) [11].

3.2. Determine the standby capacity requirements

3.2.1. Reliability-based calculation

Based on power system reliability standards, such as power supply reliability indicators and loss of load probability, combined with equipment failure probability and load changes, calculate the required reserve capacity to ensure that even if some equipment fails during extreme weather, power supply reliability can be maintained through reserve capacity. Existing literature reviews methods used by large power grids worldwide to determine operating reserve capacity and their characteristics, analyzing the advantages and disadvantages of various assessment methods from the perspective of grid reliability assessment. A series of reliability indicators derived from probabilistic methods can guide grid operators in reasonably reserving and allocating grid reserve capacity, outlining specific implementation methods and steps for grid reserve capacity reliability research [12].

3.2.2. Multi-scene analysis

Consider different extreme weather scenarios and load growth scenarios for multi-scenario simulation and analysis. For example, simulate the operation of the power system under different extreme weather conditions (e.g., typhoons, heavy rain, high temperatures) and different load levels (e.g., peak load, low load) to determine the maximum reserve capacity requirements for various possible situations [13].

3.3. Optimize the standby capacity configuration and scheduling

3.3.1. Optimization of the configuration

Configuration optimization requires reasonable arrangements of reserve capacity for various types of generating units. Traditional thermal, hydro, and gas units need to consider their output characteristics, regulation capabilities, and start-up times. Due to the high uncertainty of renewable energy output, energy storage systems should be integrated to provide stable reserve support. Analysis should be conducted on multi-source data fusion of resources, meteorology, environment, and the grid, renewable energy resource assessment, power prediction under extreme weather, power balance, energy balance, and optimization dispatch [14]. On the grid side, strengthen the construction and maintenance of transmission networks, rationally plan the layout of transmission lines to avoid over-concentration in areas prone to extreme weather, and enhance grid disaster resilience by adopting double-circuit lines, ring network structures, etc., to improve transmission capacity and flexibility. Additionally, sufficient emergency repair equipment and materials, such as mobile substations, temporary transmission lines, and repair vehicles, must be equipped to restore

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power supply promptly in case of equipment failure. Load-side reserve can be achieved through demand-side management measures, guiding users to adjust their electricity consumption behavior and reduce peak load demand. For example, implement time-of-use pricing, interruptible load contracts, etc., to encourage users to reduce unnecessary electricity consumption during extreme weather, thereby alleviating power supply pressure on the system and indirectly reducing reserve capacity requirements. Meanwhile, promotes the application of distributed energy and microgrids, enabling partial loads to achieve self-sufficiency during extreme weather and reducing reliance on the main grid.

3.3.2. Scheduling and optimization

Before the onset of extreme weather, adjust the power system's operation mode and reserve capacity configuration based on forecast results, such as increasing the output of generating equipment in advance, raising grid voltage levels, optimizing power flow distribution, transferring some critical loads to backup power sources, or implementing load shedding measures to mitigate the impact of extreme weather on the power system. Establish a real-time monitoring and control system to monitor and analyze the operating status of the power system, equipment health, and meteorological conditions in real-time. Adjust the deployment and allocation of reserve capacity based on real-time data, prioritizing power supply for critical users and key areas. In case of equipment failure or sudden load changes, quickly activate emergency plans mobilize backup power sources and repair resources to restore power supply. Strengthen coordination and cooperation with other related industries, such as meteorological departments, transportation departments, and communication departments, to share information resources and jointly address the impact of extreme weather. For example, collaborate closely with meteorological departments to obtain more accurate weather forecasts, coordinate with transportation departments to ensure timely delivery of repair personnel and materials, and work with communication departments to ensure smooth communication for the power system [13].

4. Discussion

Traditional methods for determining reserve capacity are mostly deterministic and struggle to adapt to the volatility and uncertainty brought by large-scale renewable energy integration. Models often consider only one or a few uncertainty factors, failing to comprehensively and accurately reflect the complex realities of actual systems, leading to suboptimal reserve capacity optimization results. Under extreme weather conditions, how to fully leverage the peak regulation role of thermal, hydro, and pumped storage power, and shift from "source follows load" to "source-load interaction," strengthening emergency reserve capacity configuration and dispatch, remains to be studied. Currently, virtual power plants, as an emerging power system regulation tool, can integrate a large number of scattered adjustable power loads to participate in grid dispatch, effectively achieving peak shaving and valley filling, providing frequency regulation, voltage regulation, and reserve power auxiliary services, enhancing grid security. While commercialized abroad, virtual power plants are still in the early stages of development in China, with vast potential for growth [15].

Based on existing research, further studies can be conducted in the following areas: deploy a comprehensive power equipment risk monitoring and early warning prevention system, strengthen real-time monitoring and analysis of equipment operating status, combine meteorological trends to predict equipment limits, and adjust operation modes and reserve capacity deployment promptly. Explore new optimization algorithms and technical means to improve the solving efficiency and accuracy of reserve capacity optimization models. Promote the complementary integration of various types of power sources and energy forms, leveraging their respective advantages to enhance

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the flexibility and stability of the power system, reduce reliance on a single energy form, and strengthen cross-regional coordination and mutual support to better meet reserve capacity demands under extreme weather conditions.

5. Conclusion

This paper summarizes the method of optimal configuration and scheduling, which provides the thinking of rapid configuration and scheduling under the consideration of new energy access and can further promote the given and sustainable development of new energy. This paper does not analyze through specific examples verify the reliability. It will be further studied in the future. According to the summary of this paper, we can see that the current domestic and foreign researchers in the theoretical framework and applied research are putting forward many valuable ideas and conclusions. The future research can strengthen interdisciplinary research cooperation, such as combining with weather model and power system model, studying the occurrence of extreme weather and transmission mechanisms, so as to achieve more accurate standby capacity configuration and provide more comprehensive and deeper support for the optimization of standby capacity.

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