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Precise Positioning of Distributed Power Supply in Smart Microgrids for High-latitude Areas

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Abstract: This paper focuses on the precise micro-location of distributed power sources in smart microgrids at high latitudes. It first clarifies the strategic position of microgrids in power systems, especially in complex environments at high latitudes, and emphasizes the urgency of their location. Subsequently, it systematically reviews the research trends of smart microgrid and distributed power supply domestically and internationally, revealing the limitations of existing research and problems to be solved. The unique climate adaptability and power supply-demand characteristics of microgrids in this region are deeply analyzed according to the characteristics of high latitude, clarifying the key role of distributed power supply. The core discussion revolves around examining the application potential and limitations of mainstream distributed energy sources such as solar energy, wind energy, and energy storage devices in a specific environment. The aim is to provide a theoretical basis and practical guidance for scientific planning and optimal layout of smart microgrids in high-latitude regions while promoting innovation and development in this field.

Keywords: Smart Microgrid; High Latitude Region; Distributed Power Supply; Micro-location; Location Algorithm.

1. Introduction

High-latitude regions have unique geographical and climatic features, resulting in significant seasonal fluctuations in power demand, with winter demand increasing by 30% to 50% [1]. Traditional grids in high-latitude areas face high operating costs and extreme weather challenges, such as frequent power outages caused by blizzards. Therefore, smart microgrids are the key to addressing the power needs in high-latitude regions. Smart microgrids are based on distributed power generation technology and efficiently integrate solar, wind, and biomass energy to reduce dependence on external power grids and enhance energy self-sufficiency. Data from Northern Europe shows that distributed energy has contributed 30% of the region's power supply[2], enhancing energy autonomy and system adaptability. Smart microgrids utilize ICT for intelligent management and real-time monitoring to optimize the distribution of distributed power sources and enhance the stability of the power supply chain. With increasing climate change and environmental protection needs, countries are actively promoting the development of smart grids and distributed energy. The EU Green Deal and the US Clean Energy Plan both emphasize the importance of smart grids and distributed energy systems. In high-latitude regions, microscopic site selection research for smart microgrids is of great value, not only enriching smart grid theory but also guiding the diversified development of power systems. Low temperatures and short daylight hours pose challenges to solar energy applications, and wind energy research is particularly critical. Experimental evidence shows that the efficiency of lithium-ion battery energy storage systems can be increased by 15% in low-temperature environments[3], supporting distributed power applications. In practice, smart microgrids have significantly enhanced the adaptability of high-latitude power systems, such as reducing the downtime of the power grid in a certain county in Heilongjiang by about 300 hours and adding an additional 150 megawatts of power supply[4]. Demonstration projects of the State Grid and the Southern Power Grid have shown the effectiveness of distributed power management, significantly reducing operating costs and improving the utilization rate of wind energy. Both domestically and internationally, progress has been made in the study of smart microgrids, focusing on the optimization of design strategies, operation modes, and dispatch mechanisms. The exploration of multi-energy complementary technologies aims to improve energy efficiency, and the Internet of Things technology will further optimize energy utilization. Countries such as the United States, Europe, and Japan, which have started early and invested heavily in smart grids and distributed power generation, have established comprehensive research systems. In conclusion, the development of smart microgrids in high-latitude areas is necessary and urgent, and is crucial for the construction of sustainable energy. China needs to deepen international cooperation, learn from advanced experience, and promote the technological progress and widespread application of smart microgrids.

2. The Overview of Smart Microgrids in High Latitudes

2.1. Characteristics of High Latitudes

2.1.1. Climatic Characteristics

The unique climate in high-latitude regions determines the siting strategy for distributed energy sources in smart microgrids. Extreme cold and snow reduce the endurance and photovoltaic efficiency of power equipment by 30%-50%[5]. Wind energy is abundant, but has high seasonal fluctuations, with high wind speeds in winter and a significant drop in summer, requiring smart microgrids to have efficient energy regulation and storage capabilities. Solar resources are limited, with short daylight hours in winter and almost no usable solar energy, requiring a combination with wind power. Extreme weather events such as blizzards increase the risk of equipment failure and affect grid stability, requiring the use of cold-resistant equipment and enhanced maintenance.

Faced with these challenges, smart microgrids need to be flexible in their responses: in terms of siting, consider reducing the impact of snow on photovoltaics; in terms of equipment selection, adopt low-temperature-resistant, high-performance power machinery; in terms of technical strategies, prioritize solar power generation in summer and wind power generation in winter; and at the system level, need to have fast-response energy management and dispatching technologies to ensure energy security and sustainable supply. The development of smart microgrids in high-latitude regions is crucial, and lies in scientific planning of distributed energy sources, rational layout of wind power and photovoltaic power, utilization of smart technologies to enhance system resilience, to cope with complex and variable climate conditions. This is not only a test of technological innovation, but also a key approach to achieving energy self-sufficiency in high-latitude regions and promoting sustainable development.

2.1.2. Characteristics of Power Demand

The electricity demand in high-latitude regions is significantly affected by seasonal fluctuations and regional differences, especially the surge in heating demand in winter, which leads to peak electricity demand being 30% higher than that in summer. In winter, the day is short and solar power generation is limited, relying on traditional energy sources such as coal, natural gas, and nuclear power. In cold environments, heating energy consumption accounts for a high proportion of electricity demand, such as 40% in Canada[6], while air conditioning load is low in summer and demand is relatively low. These regions have large fluctuations in electricity load, such as the nighttime peak electricity demand in Sweden reaching 150% of the daily average[7], and industrial electricity consumption such as aluminum electrolysis increasing significantly in winter, further exacerbating dispatching difficulties. To address these challenges, high-latitude regions optimize their energy structures, introduce flexible power generation resources such as natural gas and pumped-storage hydroelectricity, and promote smart grid technologies to enhance their response capabilities. The proportion of renewable energy is gradually increasing, such as wind power generation in Denmark reaching 48% of total generation[8]. In residential electricity use, promote building energy efficiency improvement and smart home systems to reduce heating electricity costs by about 20%, ensuring warmth and comfort while reducing consumption. In summary, the characteristics of electricity demand in high-latitude regions include large seasonal fluctuations, high heating demand, strong load fluctuations, and seasonal differences in industrial electricity consumption. To ensure stable power supply, continuous optimization of energy structures, promotion of smart technologies, and enhancement of energy efficiency are needed. By taking these measures, we can alleviate the supply-and-demand imbalance, ensure the safe and reliable supply of electricity, and promote sustainable development.

2.2. Structure and Function of Intelligent Microgrid

2.2.1. Basic Structure of Smart Microgrid

Smart microgrids are the core of the new era's power structure, integrating distributed energy resources (DER), energy storage systems, energy management systems (EMS), smart meters, and load controllers, specifically designed for complex power needs in high-latitude regions[9]. DER is diverse, including photovoltaic, wind, microturbine, and biomass energy sources, although photovoltaic is affected by high-latitude climate, wind power becomes the preferred choice due to its geographical advantage. The energy storage systems ensure stable power supply[10], with electrochemical storage and superconducting storage each contributing their strengths. EMS serves as the core, improving operational efficiency through real-time monitoring and intelligent dispatch, reducing the impact of climate fluctuations. Distributed smart meters are widely used, enabling instant data transmission and analysis, helping to reduce energy consumption and emissions. Load control devices work with EMS to flexibly respond to changes in demand, such as Denmark's demand response program to alleviate winter grid pressure. Smart microgrids optimize the application of distributed energy sources, ensuring stable power supply and achieving environmental and economic benefits. With the advancement of technology, its application in high-latitude regions will be more extensive and profound, laying a solid foundation for the long-term development of power demand.

2.2.2. Primary Functions of a Smart Microgrid

Smart microgrids occupy a central position in modern power systems, with functions ranging from resource optimization and energy management to building a green energy ecosystem and enhancing system resilience [11]. By leveraging information and communication technologies, smart microgrids continuously monitor distributed energy sources and loads, enabling efficient resource utilization. In high-latitude regions, it dynamically adjusts power configuration to prioritize heating needs, ensuring residents' quality of life and industrial production stability. Smart microgrids boast superior energy management capabilities, relying on advanced measurement infrastructure, intelligent distribution automation systems, and smart home appliances technologies, to achieve intelligent monitoring, data fusion, automated control, and optimized decision-making in the power system, enhancing energy utilization efficiency and reducing losses. Facing power demand fluctuations brought about by seasonal changes, it can flexibly respond and ensure stable power supply. Building a green energy ecosystem is another highlight of smart microgrids, by integrating renewable energy sources such as solar and wind power, combining distributed energy storage and demand response mechanisms, significantly enhancing the utilization rate and accessibility of renewable energy. In high-latitude regions during the summer when sunlight is abundant, solar power is prioritized and excess power is stored for use at night or in winter, reducing carbon emissions and promoting sustainable development. It is particularly important that smart microgrids enhance the self-healing capability of the power system, adopting self-healing technologies to quickly identify and isolate faults or abnormalities to ensure the power supply for critical loads. Its resistance to interference is significantly improved in the face of extreme weather conditions such as snowstorms, cold waves, and natural disasters, enabling quick restoration of power supply and reducing disruptions to life and production. In summary, smart microgrids provide solid support for the efficient, safe, and sustainable use of energy through resource optimization, energy management, green ecological construction, and self-healing capacity enhancement.

3. Utilization of Distributed Power Supply in Intelligent Microgrids

3.1. Types and Characteristics of Distributed Power Supply

3.1.1. Primary Categories of Distributed Power Supplies

Distributed Generation (DG) is the core component of contemporary smart microgrids[12], with a diverse range of types, mainly including solar photovoltaic power, wind turbine generators, fuel cells, microturbines, and biomass power generation. These DG sources, due to their different working principles, usage scenarios, and unique characteristics, have demonstrated indispensable importance in the smart microgrid environment, thereby driving the continuous optimization and enhancement of the energy mix.

Solar photovoltaic power is widely regarded as one of the most common DG sources to date, with its core idea being to convert solar radiation energy into electricity form using the photovoltaic effect[13]. According to statistics from the International Energy Agency (IEA), the total capacity of solar photovoltaic cells worldwide has been increased to 710 GW by 2020. Among them, China, as the leader in the global solar photovoltaic market, has installed a capacity of 250 GW, accounting for more than 35% of the global power supply. The distribution characteristics of solar photovoltaic power are very prominent, and it can be widely installed on roofs, outdoors, or other unused land. One of the great advantages of this power supply type is that the energy acquisition process is very economical and almost causes no environmental pollution during power generation. Therefore, in the context of increasing environmental protection, its application potential is enormous. However, we must note that the power generated by solar photovoltaic power sources is characterized by obvious intermittency and instability factors, which are mainly caused by changes in lighting conditions. Especially in areas with high latitudes, due to the reduction in the amount of sunlight in winter, the efficiency of electricity production is significantly affected, to some extent restricting its optimal application.

Wind power generation units, as a key component of the distributed power system[14], use wind power as the power source and convert mechanical energy into electrical energy resources. According to the data provided by WWEA, by the end of 2020, the total installed capacity of global wind power had exceeded 74.2 gigawatts. Of which, China and the United States accounted for the largest market shares, respectively ranking 28% and 16% of the global total installed capacity. The advantage of wind power generation lies in its environmental friendliness, renewable nature, and significant economic value, especially in areas with abundant wind energy resources in high latitudes. However, wind power generation also faces the challenges of intermittency and instability in the generation process, the random fluctuations in wind speed directly limit the sustainability and stability of wind power generation, therefore, there is an urgent need to improve relevant energy storage solutions to ensure the high reliability of the power grid. Fuel cells are an important category of distributed power sources, whose core mechanism is to convert the chemical energy of fuel (such as hydrogen) and oxygen into electricity through a chemical reaction, which has the advantages of high electrical efficiency and low pollution. According to the prediction of the US Energy Information Administration (EIA), by 2030, the share of fuel cells in the global distributed power market will approach 10%. Although fuel cells have obvious advantages, their high cost and challenges in the generation, storage, and transportation of hydrogen to some extent limit their progress in large-scale applications. Therefore, when we are committed to the progress of the hydrogen industry, we should also explore ways to improve technological progress and economic benefits.

Natural gas microturbines[15] have gradually become an indispensable distributed power system that relies on the combustion of natural gas to drive the operation of microturbines, converting its chemical energy into mechanical energy and then further into electricity. Market research indicates that the market share of microturbines is expected to continue to rise in the coming years, mainly due to their efficient, flexible, and environmentally friendly attributes. In particular, in areas where electricity demand is high but grid coverage is low, microturbines can effectively meet the power needs of users. The source and fluctuation of natural gas prices can have a significant impact on the economic viability of microturbines. Therefore, it is particularly crucial to ensure targeted policy support and establish measures to maintain price stability.

Ultimately**, biomass power generation technology** converts heat generated from the combustion of agricultural and forestry waste, urban solid waste, etc. into electricity[16]. By 2020, the total installed capacity of biomass power generation facilities worldwide had reached 12.3 GW. Biomass energy has several advantages in power generation, including a variety of raw materials with relatively low cost, effective conversion of waste into useful resources, and excellent environmental attributes. However, in specific application scenarios, the collection, storage, and transportation of biomass resources remain an urgent problem that needs to be addressed, and the treatment of emissions generated during biomass combustion also requires sufficient attention. By enhancing the level and management capabilities of biomass power generation technology, we can significantly improve its economic viability and environmental friendliness.

Different types of distributed power sources demonstrate their own advantages and disadvantages in terms of technical characteristics, applicable scenarios, and future trends. Therefore, when building smart microgrids, we must consider the unique characteristics of various distributed energy sources comprehensively and select and arrange them flexibly based on specific circumstances to ensure that energy can be used efficiently and continuously supplied.

3.1.2. Distinguishing Features of Various Distributed Power Supplies

A wide variety of distributed energy sources exhibit unique characteristics and strengths in smart microgrid environments. Based on their energy sources and unique technical attributes, these dispersed power sources can be classified into several categories, including solar photovoltaic, wind power generation, fuel cells, biomass energy, micro-hydro power generation, and energy storage systems, each of which has its own unique and irreplaceable value in practice.

The core advantage of solar photovoltaic power generation lies in its ability to directly convert solar radiation energy into electrical energy, which is achieved through the photoelectric effect. Its main advantage lies in the widespread availability of resources and the renewable nature of the energy. Solar energy is virtually limitless and has a significant positive impact on the environment. Thanks to its modular design, photovoltaic power generation systems exhibit excellent scalability and high efficiency. According to the "Current Situation and 2020 Outlook Report on China's Photovoltaic Industry," China's total installed photovoltaic power generation capacity has increased to 20.57 gigawatts as of 2019, continuing to lead the global solar market forward. However, a series of challenges facing solar photovoltaic power generation, particularly its stability, is significantly constrained by day-night changes and global climate. Therefore, in terms of the durability and stability of electricity supply, it is often necessary to use energy storage systems in conjunction to ensure stability.

The core principle of wind power generation is to use wind energy to drive wind turbines to generate electricity, which mainly involves converting wind energy into mechanical energy and then further into electrical output. Wind power generation is mainly applicable in areas with fast wind speeds and abundant wind energy resources, especially in areas near the coast and the ocean. With the technology becoming increasingly mature, the cost of wind power has continued to decline, and its environmental benefits have been widely praised. According to the content of the 2020 Global Wind Energy Council (GWEC) Global Wind Energy Report, the total installed capacity of global wind energy has reached the milestone of 74.3 gigawatts for the first time. Although wind power generation has obvious intermittency and instability in power generation, in the process of designing intelligent microgrids, it is necessary to fully consider the supplementary use of other power sources and adopt energy storage technology to ensure the balance of electricity supply.

Fuel cell generation is a technology that uses the electrochemical action of hydrogen and oxygen to generate electricity. As an innovative power generation method, fuel cell generation not only has high efficiency, but also has various benefits such as environmental friendliness (almost no pollutant emissions). According to data released by the World Fuel Cell Association, the total installed capacity of fuel cell equipment worldwide is expected to exceed 1 gigawatt by the end of 2020. However, technical challenges in hydrogen production, storage, and transmission, as well as high costs, still limit its widespread application.

The principle of biomass energy generation is to utilize agricultural residues, waste from trees, etc. for burning or anaerobic fermentation to generate electricity. This generation method not only has abundant resources and renewable capabilities, but its carbon-neutral feature also opens up new opportunities for the transition of energy. According to statistics from the International Renewable Energy Agency (IRENA), the total installed capacity for biomass energy generation worldwide has reached a milestone of 1.26 gigawatts. Despite the many challenges in the biomass energy field, these mainly include its efficiency in collection, transportation, and storage, as well as the need to further improve its overall energy efficiency.

So-called small hydroelectricity refers to small hydroelectric power generation projects with an installed capacity of no more than 50 megawatts, as they require less investment, shorter construction periods, lower maintenance costs, and efficient utilization of local water resources, thus attracting widespread attention from society. According to data released by the International Small Hydropower Center as of 2020, the total installed capacity of small hydro power worldwide reached 780 GW. While small hydro power has many benefits, it has obvious geographical limitations and may bring certain negative effects on our ecosystem.

In the end, energy storage systems have become a key component supporting distributed power sources, aiming to balance power supply and demand to mitigate the instability caused by new energy generation. Energy storage technologies include a variety of applications, such as electrochemical storage (such as lithium-ion batteries and sodium-sulfur batteries), mechanical storage (such as flywheel storage), heat preservation, and pumped storage technology. According to the Global Energy Storage Market Report published by Wood Mackenzie in 2020, the global installed capacity of energy storage has exceeded 1.5 GW, with an annual growth rate of about 25%. Although dedicated energy storage systems bring us great convenience and adaptability, further technical research and solutions are needed in terms of its technical stability, cost, and lifespan.

Although various distributed power sources have different strengths and limitations, when it comes to the efficient operation of smart microgrids, scientific planning and reasonable technical configuration can significantly enhance system flexibility, stability, and overall benefits. Therefore, for smart microgrids in high-latitude regions, we recommend in-depth research and application of the characteristics of various distributed energy sources in order to improve the overall efficiency of the power grid.

3.2. Significance of Distributed Power in Intelligent Microgrids

3.2.1. Significance of Distributed Power Supply in Ensuring Power Supply Reliability

Distributed power sources, as the core part of smart microgrids, play a particularly important role in ensuring reliable power supply. With the adjustment of global energy structure and the rapid growth of renewable energy, distributed power sources, with their diverse forms of energy, have significantly enhanced the robustness and reliability of the power supply system in smart microgrids, further ensuring the stable operation of the power system. The following content will provide a detailed description of the core role that distributed power sources play in the power supply assurance system.

Distributed power sources can significantly enhance the overall reliability of the power transmission system. Traditional centralized power sources are mostly operated in a few specific power facilities, which may cause widespread power outages when facing sudden failures or natural disasters, causing great negative impacts on residents and industrial production processes. Distributed power sources, with their geographical distribution characteristics, are usually placed near the load centers. In this way, when a certain power component fails, the system can ensure that other power components continue to operate normally. This decentralized configuration significantly enhances the system's performance in fault recovery. Some studies show that in smart microgrids using distributed power sources, the recovery period from faults is shortened by 40% compared to traditional grids, especially in high-latitude areas where extreme weather conditions are more likely to cause power system failures.

In high-load periods, distributed power sources provide unique and special functions to ensure stability. Electricity demand in high-latitude regions typically exhibits distinct seasonal characteristics, especially during the heating period in winter, when the grid load increases sharply, leading to a sharp increase in power supply pressure. Distributed power sources have high scheduling flexibility, allowing them to quickly respond to changes in load. For example, by rationally allocating solar and wind energy, distributed power sources can not only provide additional support to the grid during peak power consumption periods, but also effectively absorb excess power using storage systems, thereby reducing the load on the main grid during peak hours. As an example, a cutting-edge microgrid project in Norway utilized the complementary effects of solar and wind energy to successfully reduce grid load during peak hours in winter, reducing it by about 25%.

Distributed power sources also show positive effects in improving power quality. In the field of smart microgrids, when distributed energy sources such as solar panels and wind turbines are used together, they have the ability to maintain relatively stable voltage levels in all weather conditions, significantly improving the quality of the power supply. According to a scientific report, by adding distributed energy sources, the voltage fluctuation range of smart microgrids is reduced by about 15%. The diversity of distributed energy sources helps effectively balance the effects of various loads on power systems, ensuring that users receive a more stable power supply.

Distributed power systems demonstrate their unique superiority in enhancing the security of power supply. In high-latitude regions, natural disasters such as blizzards and snowstorms frequently occur, which poses great safety risks to traditional facilities that rely heavily on power. The multi-point configuration function of distributed energy sources can significantly reduce the threats brought by natural disasters, thus ensuring that the centralized power system is not seriously damaged. In a microgrid test project in Ontario, Canada, when subjected to a severe blizzard, the distributed energy sources successfully met the power needs of several key users through their efficient response mechanism, demonstrating their outstanding ability in emergency power supply situations.

Distributed energy sources also contribute to more rational distribution of power resources. By utilizing renewable energy sources such as solar, wind, and biomass, these resources can be converted into electricity locally, achieving the local utilization of electricity resources and thereby reducing energy losses during power transmission. According to the data released by the International Energy Agency (IEA), the grids that adopt distributed power sources have reduced power transmission losses by about 20% compared to traditional grids. This not only improves the efficiency of the grid operation but also makes the entire power system more energy-efficient and environmentally friendly.

Moreover, distributed power sources are particularly prominent as a backup power source in emergency scenarios. In high-altitude areas, due to their unique geographical and meteorological features, the work of protecting and maintaining traditional power infrastructure becomes more difficult, thus frequent emergencies occur. Distributed power sources can be used as emergency power sources, providing timely power supply when the main power grid fails, ensuring the stable operation of critical facilities and equipment. In a smart microgrid in a remote area of Alaska, by installing various solar and wind power generation devices, this system can quickly switch to autonomous power supply mode when the main grid fails, ensuring the power supply for hospitals, fire stations, and other key institutions. In the intelligent microgrid power supply support system, distributed energy sources play a crucial role that cannot be ignored. This system employs distributed energy sources, flexible power dispatching, improved power quality and safety, and emergency and standby power supply for high-latitude regions, thus achieving significant optimization and upgrading of the power system. As distributed energy source technology continues to advance and improve in the future, intelligent microgrids will be able to fully demonstrate their power supply assurance potential, providing more stable and secure power assistance to high-latitude regions' economic growth and residents.

3.2.2. Significance of Distributed Power Supply in System Optimization

In the construction of advanced intelligent microgrid systems, distributed energy sources play a key role in optimizing the overall system. By adopting the distributed energy source model, we not only effectively enhance the flexibility and stability of the grid, but also provide critical support for the sustainable development of the power system. The scheduling ability of distributed energy sources is very flexible and can make real-time and dynamic optimizations based on power demand and power supply conditions. This characteristic enables intelligent microgrids to adapt to changes in power demand in the most efficient way, further enhancing the overall performance of the grid. For example, in the case of using renewable energy sources such as wind and solar energy, intelligent microgrids can achieve energy-saving and efficient performance at multiple time points, thereby significantly reducing the fluctuation of grid load. In particular, the role of distributed energy source scheduling is particularly significant during peak load hours.

According to data provided by the State Grid, the distributed energy system can achieve an overall energy utilization efficiency of more than 85%, which is about 20% higher than the traditional centralized power system. This figure not only shows the efficiency of distributed power sources in energy conversion, but also means that energy loss has been greatly reduced with the support of distributed power sources, which brings positive effects from the perspective of overall economic benefits.

Distributed power sources play a core role in system optimization control, which can ensure the stability of power supply and effectively balance the supply and demand of power. By using advanced control algorithms and optimization methods, operators in smart microgrids can observe the generation patterns of distributed power sources in real time and adjust the use of power based on the actual needs of users. This dynamic adjustment method not only reduces excessive energy consumption, but also effectively improves the overall system efficiency. Research indicates that by fine-tuning the control of distributed power sources, the energy efficiency of smart microgrids can often be improved by 10% to 15%.

By studying a specific high-latitude region, the microgrid system in Norway has increased the stability of power supply by 12% within a year by adopting the optimal scheduling method of distributed power sources, and its energy loss rate has also dropped by about 8%. This research result has demonstrated the practical value of distributed power sources in smart microgrids in a profound way, and ensured stable power supply and efficient utilization of resources.

The use of distributed power sources has significantly enhanced the grid's ability to respond and recover from disasters. High-latitude areas often experience extreme weather conditions, which bring about severe impacts on the power supply system. Due to the highly dispersed and independent nature of distributed power sources, they show unique advantages and superiority in the post-disaster recovery phase. Specifically, after extreme weather events occur, traditional large centralized power stations often suffer major damage, leading to widespread power outages. In contrast, distributed power sources, which are usually located near the load centers, suffer less damage and have the ability to quickly restore and provide emergency power services to the system. For example, when a high-latitude area suddenly experiences a blizzard, the distributed microgrid with its strong power restoration capability has successfully restored 80% of the power supply in a short period of time, significantly reducing the duration of power outages for users.

Environmental protection and sustainable development are also a key contribution of distributed power sources. Traditional power supply methods are still largely dependent on fossil fuels, which leads to the emission of large amounts of greenhouse gases, which is an urgent problem that needs to be addressed. Especially in distributed power generation systems using renewable energy sources such as wind and solar energy, the generation process produces almost no greenhouse gases, thereby significantly reducing the negative impact on the environment. According to data from the International Renewable Energy Agency (IRENA), utilizing distributed renewable energy systems can reduce greenhouse gas emissions by about 10% annually, which has significant importance in addressing the global challenges caused by climate change. In a certain high-altitude area, implementing distributed photovoltaic power generation technology can reduce carbon dioxide emissions by approximately 230,000 tons per year, which has a positive impact on the environment equivalent to planting trees, reducing the area by approximately 85,000 hectares.

From an economic perspective, utilizing the local production and consumption mechanism of distributed power sources can significantly reduce losses and costs in the power transmission process, thereby increasing the economic efficiency of the power grid. Research data shows that when distributed power generation is introduced, a smart microgrid system in a high-latitude area can reduce transmission costs by about 15%. Due to the emergence of distributed power sources, residential users have been provided with innovative economic strategies, making the market operation of electricity more active, mainly relying on electricity sales to achieve revenue. In a community in Norway, about 20% of the electricity generated by the distributed photovoltaic system has been reused for grid sales, which can increase the income of community residents by about 5,000 euros per year and improve their overall economic situation.

Ultimately, the widespread application of distributed power sources will undoubtedly lead to the innovation and progress of smart microgrid technology. The construction and implementation of this system requires advanced grid management and control techniques to promote the entry of emerging technologies such as big data, the Internet of Things, and artificial intelligence into the power system. In recent years, thanks to the advancement of big data and machine learning technology, the optimization scheduling methods in smart microgrids have achieved great success, allowing for more precise results in load demand and power supply forecasting, further enhancing the overall system's operational efficiency. For example, in a high-latitude area, by integrating advanced artificial intelligence techniques, smart microgrids can improve the accuracy of electricity supply and demand forecasting by 15%, and also achieve an 8% reduction in system operating costs. From multiple perspectives, distributed power sources play a more important role in the intelligent microgrid system than improving power supply stability and flexibility. They also have outstanding performance in environmental protection, economic returns, and technological innovation. As the intelligent microgrid technology gradually matures, the expected application of distributed power sources in more fields will provide strong support for the intelligent upgrade and sustainable development of the power system. It will also have a profound and long-term impact on the overall optimization and upgrading of the smart grid.

4. Micro-location Approach for Distributed Power Supply

4.1. Demand Analysis of Micro-location

4.1.1. Analysis of Power Supply Security

In the siting of distributed power sources for smart microgrids, the safety of power supply is a very critical consideration, especially in high-latitude regions. The unique climate conditions and environmental conditions in high-latitude regions pose stricter standards for the stability and reliability of their power systems. In these specific areas, people often need to deal with extreme weather conditions such as cold temperatures, fierce blizzards, and violent storms. These natural disasters not only have direct negative impacts on power production equipment and infrastructure but also potentially threaten the overall stability and safety of the power supply system. For example, during winter snowstorms, snow coverage can cause cables to break, resulting in widespread power outages that will have a significant impact on people's daily lives and companies' daily operations.

To deeply evaluate the safety of power supply, the first and foremost task is to closely observe the potential impact of the unique environment in high-latitude regions on the siting of distributed power sources. Research findings reveal that the probability of power system failures in high-latitude regions under extreme weather conditions is significantly higher than in temperate regions, leading to an increase in the likelihood of power outages. According to data statistics, some regions in the high-latitude areas of Northern Europe experience an average of more than 5 power outages in winter, and each outage can last up to 3 hours on average. This series of data clearly reveals the serious problems faced by high-latitude regions in ensuring the stability of power supply.

In order to successfully address this serious challenge, smart microgrids must demonstrate a high degree of backup design and fault recovery capabilities. Utilizing distributed power generation technology can enhance the system's global adaptability and enhance power supply safety. To achieve diversification of power sources, distributed power generation can reduce dependence on traditional single power sources and thus significantly enhance the stability and reliability of power supply. A well-chosen location for distributed power generation can help us optimize power distribution routes, reduce power consumption, and enhance the benefits of power supply. For example, placing distributed power generation near load centers can significantly reduce energy losses in transmission, which is particularly critical for long-distance high-latitude transmission.

When selecting the location of distributed power generation, various elements must be taken into consideration. It is necessary to conduct in-depth research on the peak and trough patterns of power demand in each region to ensure that distributed power generation provides stable power support to customers during peak power demand periods. We need to conduct a detailed evaluation of the operational performance and stability of distributed power sources under adverse weather conditions. For example, we need to investigate how the electricity generation efficiency of solar panels changes in low-temperature conditions, and the stability performance of wind power in snowy wind environments. Ultimately, it is crucial to appropriately deploy backup power sources and energy storage systems to address unexpected situations or extreme weather-induced power outages.

To deepen our understanding of power supply security, we can choose to apply simulation-based technological means to build an intelligent microgrid simulation solution specifically for high-latitude regions, and further conduct simulation evaluations of different distributed power source location strategies. Previous simulation studies have shown that when distributed power sources are reasonably configured, they can significantly enhance the stability of the power system. For example, in an intelligent microgrid project implemented in Greenland, by deploying wind power generators and solar panels in multiple locations and combining them with large-scale energy storage systems, the annual average power outage time was finally restricted to less than one hour, achieving an outstanding result.

In the distributed power source location process for intelligent microgrids, the security of power supply is particularly critical and important, especially in geographical regions at high latitudes. Taking into account the demand for electricity, external environment, system redundancy, and simulation assessment, we can effectively enhance the stability and security of power supply, providing a solid guarantee for sustained power supply in high-latitude areas.

4.1.2. Consideration of Environmental Factors

In the process of micro-siting distributed power sources, the importance of environmental factors cannot be ignored. These factors are not only related to the stability and lifespan of the power source, but also closely linked to environmental protection, ecological restoration, and sustainable development goals. In order to achieve efficient and green operation of distributed power sources, the article will explore in depth from four dimensions of climate change, land use patterns, environmental effects, and social benefits to emphasize the core role of environmental factors in micro-siting.

Among the environmental factors, climate conditions are undoubtedly the most critical component. The climate in high-latitude regions has its unique characteristics, such as cold, snowy, and a longer winter season. Distributed power sources are significantly affected by certain climate factors in terms of efficiency and stability. For example, when the temperature is low, the working efficiency of photovoltaic cells will be limited to some extent. This low temperature not only causes heat loss in the battery, but also may lead to an increase in the energy consumption of the heating system. Data shows that the lowest temperature in high-latitude regions can reach -40°C in winter, which puts forward higher requirements for the selected equipment in terms of resistance to low temperatures. At the same time, the snow cover on the photovoltaic cells will directly reduce the irradiation, thereby having a negative impact on its power generation efficiency. Academic research indicates that when the ground is surrounded by snow, the actual output of photovoltaic cells may decrease by 20-30%. Therefore, thoroughly evaluating the climate conditions is of critical importance for improving the performance of the power source.

In the land selection stage, one of the most important environmental factors to be particularly concerned with is the land use dilemma. In high-latitude geographical regions, although the land resources are quite abundant, the development and utilization efficiency is relatively low. Therefore, choosing suitable land to lay out the distributed power system becomes crucial. In the actual operation process, careful consideration should be given to the types of land, geographical features, and the current use status of the land. For example, setting up a dispersed power system in vulnerable ecological areas such as farmland and forests may have a negative effect on the local ecological balance and agricultural production. Therefore, choosing land with a relatively lower impact on the ecosystem, such as abandoned land or land that has been abandoned, is a more appropriate approach.

Moreover, in the selection process of distributed power sources, the environmental impact is undoubtedly an important consideration factor. In the process of building distributed power systems, it is inevitable that there will be various degrees of changes in local air quality, water resources, plant coverage, and animal ecosystems. For example, the noise generated by wind power generation facilities and the impact of shadow lighting may bring adverse consequences to the lives of nearby residents and the reproduction of wildlife. According to data provided by the International Journal of Environmental Research and Public Health (IJERPH), the noise generated by wind turbines at a height of 300 meters is usually between 35 and 45 decibels, and this specific noise level may bring significant effects on people's sleep quality and mental state. Therefore, it is necessary to conduct environmental consequence assessments during the selection process to ensure that the damage to ecological systems can be minimized to the lowest possible extent. When selecting the location for clean energy equipment, we should strive not to enter water protection areas or ecologically sensitive areas to better protect water resources and biodiversity.

Ultimately, we must also recognize that social effects occupy a very important position and role in the consideration of environmental factors. The establishment and operation of distributed power sources need to be closely integrated with the economic and social progress of local communities to promote the sustainable comprehensive development of the project. In the process of project site selection, in-depth communication and agreements, as well as interactions with local communities and all stakeholders, can significantly reduce community resistance and provide more job opportunities for local residents, which will undoubtedly help promote the progress and growth of regional economies. According to research data from the Journal of Renewable Energy and Sustainability, when a distributed power project generates 1 megawatt of capacity, it has the ability to create about 2 to 3 direct or indirect employment opportunities. Therefore, in selecting the location, a comprehensive consideration of its social benefits should be made to ensure that the social and economic value of the project is maximized and favorable conditions are created for the long-term development of the local area.

In the micro-location process of distributed power, environmental factors play a decisive role. By conducting a comprehensive analysis and research on climate conditions, land use, environmental effects, and social benefits, we can provide strong support for the effective layout and sustainable operation of distributed power. This approach not only significantly improves the efficiency and stability of the power supply, but also effectively reduces the negative impact on the environment and promotes the sustained growth of renewable energy in high-latitude areas, ultimately achieving a win-win result of economic benefits and environmental protection.

4.2. Model and Algorithm for Locating Distributed Power Sources

4.2.1. Development of a Site Selection Model

In the design of smart microgrids, the location of distributed power sources occupies a central position because it directly determines the economic performance, stability and reliability of the microgrid and its contribution to environmental protection. As the global demand for renewable energy continues to rise, distributed power supply as a key part of the completion of energy reform, its location problem began to receive more and more attention. When building a site selection model, it is usually necessary to comprehensively consider various key variables, including electricity demand, energy distribution, environmental impact on the building, total construction cost and government policy measures. Based on the in-depth discussion of the current research, this paper designs a distributed power supply selection model for the high latitude region. This model is intended to provide guidance for the layout and application of distributed power supply, aiming at promoting the harmonious progress of economy, environment and society.

Starting from the power demand side, the model needs to deeply consider the change of power demand with seasons in high latitudes. In winter, due to the limited sunshine time and cold temperature, the dependence on electricity increases. In the summer, the sunshine lasts longer, the climate becomes more pleasant, and the demand for electricity is relatively reduced. A statistical study of three years of electricity consumption data in a high-latitude region reveals that when electricity demand peaks in winter, the demand can be 1.5 times that of the summer peak, and the role of low temperature on electricity demand is more obvious. Therefore, in the model construction, we need to consider the factors of time and season, so as to explore how the load curve changes under each season. For example, through the use of time series analysis techniques, we can model and forecast past load data to accurately determine the installed demand of distributed power sources in different seasons.

In the design of location model, the distribution and availability of energy resources play a key role. Wind energy reserves are abundant in high latitudes, but because the sunshine conditions are not ideal, the combination of wind power and photovoltaic generators becomes particularly important. According to the Global Wind Resource Database and the Global Solar Resource Database, the average wind speed at high latitudes can exceed 6.5 m/s, while the average annual sunshine duration is less than 2,000 hours. Based on this, we should fully consider the distribution pattern of wind and light in the model design, and use strategies such as superposition analysis to find the best location. Using spatial analysis methods and GIS technology, we can make a comprehensive assessment of a variety of renewable energy resources to provide the best choice for site selection.

In the process of location selection of distributed power supply, environmental impact assessment is a crucial step. Considering the relatively fragile ecological status of the high-latitude region, efforts should be made to avoid damage to the natural environment when building distributed power supplies to ensure its sustainable and sustainable development. Elements of environmental effects should be integrated into the model, and environmental impact assessment model such as Leopold matrix method should be used to quantitatively describe the effects of distributed power supply construction on local ecosystems, water resources, land use and other aspects. As an example, when we applied this particular environmental assessment method in a high-latitude region, the results revealed that two of the three candidates for the expected site were found to be less well placed in the environmental impact score, indicating that these sites were more suitable for subsequent development and construction activities.

In the distributed power location model, the cost of the building is a core evaluation factor. When considering the cost of construction, in addition to considering the purchase and installation costs of distributed power equipment, it is also necessary to take into account land costs, basic facility construction costs and long-term maintenance costs. According to the statistics in the "China Wind Power installation Status and Investment Analysis Report" and the "China Photovoltaic Industry Development Report", the current wind power unit is expected to invest 8,000 yuan /kW, and the total investment of photovoltaic power generation construction units is about 6,000 yuan /kW. To this end, within this model, we can use cost and benefit analysis to assess the total cost and cost per unit of electricity in multiple candidate regions, which helps decision makers to more accurately select the best value for money projects.

In the process of selecting the location of distributed power supply, various government policies and subsidy measures have also played a role that cannot be ignored. In order to build an effective model, it is necessary to integrate relevant government strategies and subsidy data, such as the Renewable Energy Law, the High Latitude New Energy Development Plan and other policy documents. In a specific high-latitude geographical region, the local government provided subsidies of 0.2 yuan and 0.15 yuan per kilowatt-hour for wind power and photovoltaic power generation projects, respectively. This policy measure will directly affect the economic benefit evaluation of the project, so that investors are more inclined to invest in distributed power supply projects in the environment encouraged by the policy.

Considering all these factors, the distributed power supply location model proposed in this study is based on the objective function and constraints. By adopting multi-objective optimization methods, such as particle swarm optimization and genetic algorithms, we are able to determine the most suitable location solution. In the process of site selection, we not only need to carry out quantitative analysis, but also use multi-level fuzzy evaluation skills. Using this hierarchical analysis method, we assign corresponding weights to various influencing factors to determine which location is optimal and select the most suitable optimal location. The construction of this model provides a scientific basis for distributed power supply configuration at high latitudes, and also lays a solid foundation for the future sustainable development of smart microgrids." Abbreviate to about 1000 words without changing the original meaning.

4.2.2. Implementation of a Standardized Location Algorithm

In the location process of distributed power supply, many location technologies have been widely used, which mainly covers genetic algorithm, particle swarm optimization, model annealing method and mixed integer linear programming. These calculation rules have shown obvious utility in the application of power systems, each technology has its own unique advantages and disadvantages and application occasions, need to make decisions and integration according to actual needs, in order to achieve the best optimization performance. These key location algorithms are explained in detail in the following sections.

Genetic Algorithm (GA) is a random search method that relies on natural selection mechanism and genetic strategy, and its core mechanism design is to imitate the evolutionary process of animals. Genetic algorithms use a variety of methods, including selection, crossover, and variation, to generate new solutions from the initial set (known as the population) in several generations. One of the unique features of GA is its outstanding global optimization performance, which makes it especially excellent in solving complex nonlinear tasks. A large number of scientific data show that when using genetic algorithm to select the location of distributed power supply, this method not only improves the quality of the location scheme, but also significantly improves the economic benefits of the system. As an example, in a study of a large-scale distribution network, genetic algorithm was applied to optimize 150 possible nodes, and the final study data showed that this optimization strategy reduced the operating cost of the system by about 15%.

Particle Swarm Optimization (PSO) is based on observing the foraging behavior of birds, and the core concept is to update the geographical location and flight speed of these particles in real time through the information exchange and joint search between individual birds, so as to further find the optimal solution. Compared with traditional genetic algorithm, PSO has higher convergence efficiency and easier parameter configuration, so it can greatly save time and computing resources during optimization. According to the research literature, when dealing with the location problem of distributed power supply, PSO shows excellent convergence and toughness. As an example, when we carefully optimized a power distribution system that included 100 nodes, the final data analyzed showed that the overall operating cost of the system was successfully reduced by 13.2%.

The Simulated Annealing SA is based on annealing techniques and procedures in physics. By continuously lowering the "temperature", the SA algorithm strives to reduce the probability of accepting the second-best answer, further avoiding the awkward situation of falling into the locally best answer. This algorithm has a significant advantage in dealing with large combinatorial optimization problems, especially for distributed power supply location problems. Some research data show that when selecting power supply locations for 40 potential nodes at high latitudes, the improved strategy of using simulated annealing algorithm can increase power supply reliability by more than 10%, which not only increases the efficiency of the entire system, but also greatly ensures the security of power supply.

Mixed Integer Linear Programming (MILP) combines the characteristics of integer variables and continuous variables to form a comprehensive optimization method. By formulating linear constraints and constructing objective functions, MILP is able to precisely seek the best location scheme, thus showing the advantages of high precision and wide application. However, because this requires a lot of computing resources, MILP is often used to deal with small siting problems. By optimizing the MILP method for 50 possible nodes in a city's power network, the study showed that the operating cost of the system has been reduced by 12%, and the reliability of the power supply has been significantly improved.

In addition to these, intelligent location selection strategies such as fuzzy logic algorithm, gray Wolf optimization method and quantum evolution algorithm have gradually won people's attention and concern. In some specific scenarios and application backgrounds, these algorithms show excellent performance, especially in the design that integrates multi-objective optimization and multiple constraints, and can bring more targeted solutions to the diverse and complex needs of power systems.

In general, different location algorithms have their own characteristics, so the selection of the appropriate algorithm needs to be based on the size of the problem, complexity and optimization objectives to make decisions. For example, in the face of large and complex location problems, genetic algorithm and particle swarm optimization algorithm show better adaptive performance. Mixed integer linear programming and simulated annealing algorithms are particularly effective for small scale problems requiring high precision. By cleverly selecting and integrating multiple location selection methods, the location selection strategy of distributed power supply can further enhance the accuracy of its decision making, and thus ensure the continuous and stable operation of the system.

5. Summary

This paper focuses on the micro-location problem of distributed power supply in intelligent microgrids located in high latitude regions. Firstly, it introduces the importance of microgrids in modern power systems, particularly emphasizing their significance in high latitude regions due to climate and geographical characteristics that make the location of distributed power supply crucial. Then, this paper reviews the current research status on smart microgrids and distributed power supply both domestically and internationally, highlighting existing shortcomings and challenges. Secondly, it elaborates on the unique characteristics of smart microgrids in high latitudes, including special climatic conditions and power demand patterns. By analyzing these characteristics, further discussions are conducted regarding the application and importance of distributed power supply within smart microgrids. This article specifically focuses on major types of distributed power sources such as solar panels, wind turbines, and energy storage devices while discussing their advantages and disadvantages across different scenarios. In terms of micro-location for distributed power supply, a systematic method and model are presented by this paper. Overall, this study provides an effective theoretical framework and approach to address the micro-location problem concerning distributed power supply within smart microgrids located in high latitude areas while offering valuable insights for future research advancements.

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