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Analysis of the current status of research on optimal scheduling and demand-side response for active distribution networks

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Abstract: *Traditional energy sources are experiencing a crisis as a result of the growing global economy. In contrast, green energy sources, like wind energy, are supported by national policies and are gradually gaining public attention. However, because of their stochastic characteristics and intermittent power generation, which compromise power grid security and scheduling capabilities, green energy sources lead to problems with polished wind abandonment. Because of its initiative and flexibility, active distribution network technology has emerged as a viable solution to classic active distribution network difficulties. This has led to a great deal of in-depth research being conducted by both domestic and international experts. In addition to introducing demand side management (DSM) level response relevant areas for analysis, this paper also discusses the current state of domestic and international research on optimisation algorithms for active distribution grids.*

Keywords: *Active distribution network, Distributed energy storage, Demand side response, Economic optimal dispatch*

1. Background and significance of the study

The world economy is expanding quickly, yet pollution is causing traditional non-renewable energy sources to disappear. Economic growth and the resolution of the energy issue will result from the grid's ability to absorb and utilize wind, solar, and other renewable energy sources to lower pollution levels in the environment.

Because of its size, our nation has an abundance of renewable energy sources. With the state's unwavering backing, the production of wind and photovoltaic power has steadily replaced the loss of thermal power in recent years. The "China Wind Power Development Roadmap 2050" plan states that installed wind power capacity will reach 200 million, 400 million, and 1 billion kilowatts by 2020, 2030, and 2050, respectively. Wind power will also become one of China's five major energy sources, making up 17% of the country's total energy by that time. There was a 22 percent increase in installed wind power capacity from the previous year to 25.74 million kilowatts. Regarding the wind power structure, by the end of 2019, the nation's installed wind power capacity amounted to 210 million kilowatts. Of that total, 204 million kilowatts, or 97%, were accounted for by installed onshore wind power, while the remaining 5.93 million kilowatts, or 3%, were accounted for by installed offshore wind power. In 2021, photovoltaic power generation—another massive source of renewable energy—will add approximately 29 gigawatts annually, accounting for more than half (almost 55%) of all newly built PV capacity for the first time in history. In the meantime, the new PV distribution will see annual domestic PV installations surpass 10 GW for the first time in 2020 and 20 GW for the first time in 2021, with a strong momentum up to about 215 GW. It is anticipated that photovoltaic and wind power generation will eventually replace current decentralized power generation power companies as their primary sources of power. While it is true that these power sources have wide distribution, are user-friendly, and can supply power quickly, they also have certain drawbacks, such as unpredictable and intermittent power generation, difficulty adjusting in real time, and other issues that will negatively impact power grid scheduling and operational stability. Wind turbines are subject to significant weather and wind speed variations, making them susceptible to short-term fluctuations in power generation. In addition, during the day, power generation during the load peak is small, but during the night, power generation is large. This defies the principle of power system peaking, as the active distribution network is tested for wind power dissipation and load shaving to fill in the valley ability. And how to maximize the use of renewable energy sources, improve the use of light and wind energy, and boost the power system's reliability in all operational elements and capacity

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scheduling has emerged as a critical issue that requires immediate attention.

And China is using active distribution network technology research and implementation as a breakthrough point for reform in order to address the existing issue and advance power reform. By contrast, the traditional distribution network can only meet the bare minimum requirements for power transmission, from the power generation network to the point of power consumption. The entire process follows a predetermined protocol; in other words, if the supply of electricity exceeds the demand or falls short of the supply, electricity will be lost. Second, the grid's stable operating structure will be severely impacted by the parallel connection of a significant number of large-scale intermittent distributed energy (DG) units. It may even cause the current to reverse, ruining the grid's structure. To summarise, the active distribution grid, which has emerged as a technological breakthrough for the realisation of the new power, is a technological advancement that satisfies the requirements for the use of the new power. Figure 1 illustrates the characteristics of the active distribution grid.

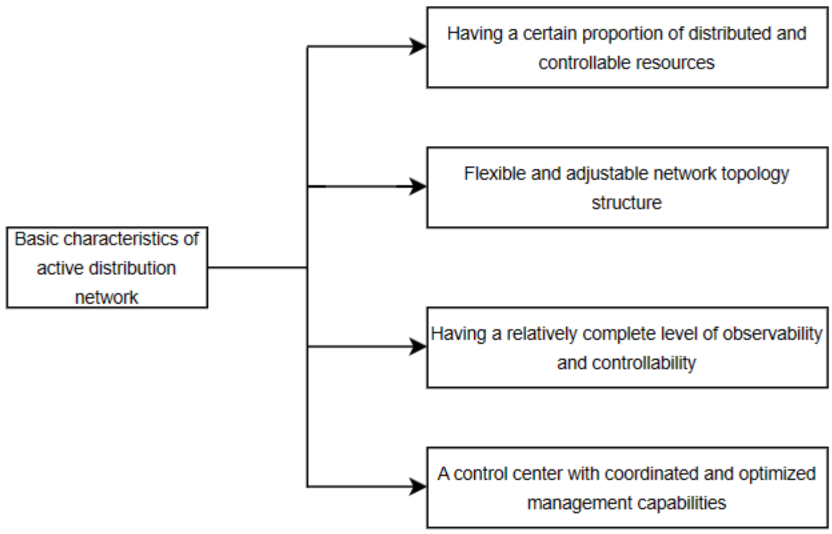

Figure 1: Structure of the basic features of the active distribution network

Intelligent distribution management is beneficial to the grid's peak and prevents anti-peak issues from occurring from access to distributed generation (DG), energy storage, loads, and other controllable units when managed by an Active Distribution Network (ADN). Concurrently, similar to large-scale distributed generation (DG) into the grid when the grid's operation and maintenance issues will be a strong guarantee, and increase the use of DG, so that DG can become an ADN deployment of the balance of supply and demand of controllable resources, thereby improving the power system's own deployment capacity and laying the groundwork for future renewable energy development.

The original distribution model of the distribution network, which allows users to only accept the deployment of the power system but not feed back into it, is used to supply power to a single demand side under the traditional generation-distribution-demand-side model. This model concentrates on large-scale power generation on the part of the generation network. Such a paradigm does not allow the user to input back to the power system; instead, the user can only accept the allocation made by the power system. During special occasions or holidays, the power generation network can only provide secondary power generation, which has very low economic efficiency, and the regular power generation network to supply power users cannot be consumed, resulting in a waste of power. This is a drawback of this arrangement. Since its inception, the smart grid concept has gained widespread recognition as a means of increasing power utilization efficiency and achieving the dual goals of carbon neutrality and peak carbon emissions. The demand side is virtualized in smart distribution grids as a potent dispatch resource. As more DG sources, including solar and wind power, become available, Demand Side Management (DSM) is evolving to keep up with the developments. Peak shaving and valley filling, which meet the demand side of the power demand while attempting to flatten the load curve as much as feasible, are the primary regulating instruments of Disempower loads can be divided into three categories: shifting, interruptible, and critical loads. These loads have the ability to change from peak to trough hours, which

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lowers the cost of power consumption on the demand side. A key component of demand side management is demand side reaction. Through the use of time response or other incentives, demand side response enables customers to modify their consumption patterns. Then, in order to actively participate in scheduling, demand side response is examined in this research as an alternative to ADN optimization, which is informative for future clean energy grids.

2. Study on Optimal Dispatch of Active Distribution Networks

In order to achieve the highest level of economic efficiency in distribution network operation, the optimal dispatch mode of a traditional distribution network is based on controlling reactive power voltage and adjusting the network structure through the casting of reactive power compensation devices, adjusting transformer joints, and other scheduling modes. However, because the intermittent nature of renewable energy power generation makes it impossible for the traditional distribution network to mitigate the negative effects of its output on the secure and reliable operation of the power grid, these deployment modes only address the symptoms rather than the underlying cause. Thus, the general trend will be the growth of an active distribution network. In order to ensure the safe operation of the distribution network, all forms of distributed generation, energy storage, and other adjustable resources can be used as methods of ADN regulation and control. These resources can also be used to grasp the demand side of demand situations.

On the other hand, when managing the distributed generation and satisfying the demand side of the electricity demand, the active distribution network needs to employ energy storage systems in a flexible manner to minimize power consumption. Fig. 2 below illustrates the energy storage system's fundamental idea:

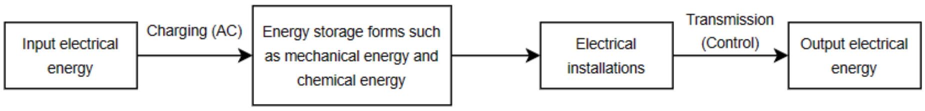

Figure 2: Basic principle diagrams of energy storage system.

In addition, energy storage systems are separated into distributed and centralized categories based on application techniques and distribution network access points.

The majority of the time, centralized energy storage is employed in sites with high power generation; however, due to the high losses and complexity of the transmission process, distributed energy sources (DG) such as wind and photovoltaic power generation are not good candidates for energy storage. In Figure 3, centralized energy storage is displayed.

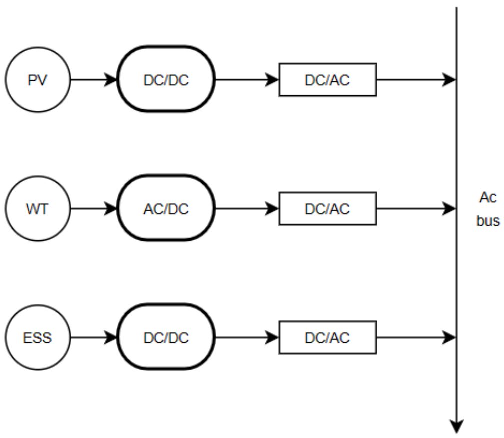

Figure 3: Centralized energy storage grid connection diagram.

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The benefits of distributed energy storage are more obvious; they include distribution flexibility, anytime regulation and independent control, but they are limited to short-term grid voltage and power support. Parallel to the grid is distributed power and energy storage systems, which also serve to reduce the output volatility of distributed power. Additionally, the distributed energy storage grid-connected operator, or IEEE 33 node, is adopted in this research. Fig. 4 depicts the grid link for distributed energy storage:

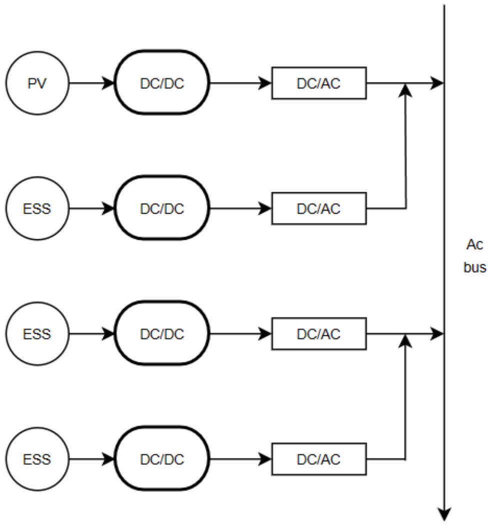

Figure 4: Distributed energy storage grid connection diagram.

In order to reduce the peak load and fill the valley, the energy storage system uses its charging and discharging characteristics to absorb fluctuations in distributed renewable energy. It also plays a crucial role in demand-side load scheduling and the DG grid connection. This utility model increases the rate at which renewable energy is used and also increases the efficiency with which the distribution network operates.

In order to achieve enough energy storage, literature [1] examined battery and thermal network energy storage, suggested a distribution network based on thermal energy storage, and offered a control model for frequency and peak regulation of heating units. In order to accomplish real-time optimization of the peak and valley regulation, literature [2] presented a battery storage system as a controllable load and built a dynamic planning based battery storage system for distribution networks.

The nature of distributed renewable energy generation is stochastic and sporadic. The creation of a smoothing renewable energy generation system is suggested in literature [3]. The capacity optimization of the storage system is selected to accomplish this goal by reducing variations in renewable energy generation. Economic forecasting of power generation within the wind power system and load forecasting for both wind power renewable energy sources are provided by literature [4].

The aforementioned research ignores the demand-side element of resource regulation in favor of scheduling variable units like energy storage devices and renewable energy sources like wind power for distribution network optimization.The active distribution system with demand-side management, whose primary consumers are the industrial park's users, was formally implemented in July 2017 at Jiangsu City's Zhangjiagang Industrial Park. As time goes on, AND optimization and regulation will become more and more important. Future AND optimization will consider demand side response to be a crucial benchmark as times change.

The two-dimensional multivariate nonlinear mixed integer programming solution model that represents the optimization model of the active distribution network can be approached using one of two methods. A possible strategy is to linearize this optimization model. To contact the DG optimal output in the ADN system, a Gurobi solver was selected. Literature [5] employed a second order cone method with tidal flow constraints. The optimal solution was reached through oscillation in literature [6], which employed an optimized Varangian relaxation approach to solve the computation for the entire unit. In order to construct a predictive model of the historical factors and model parameters and estimate the load

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level on the following generation, literature [7] chose fuzzy linear regression. The alternative is to employ artificial intelligence algorithms to solve the issue following self-learning. For instance, literature [8] employed the particle swarm algorithm for distributed cooperative optimization; literature [9] employed the simulated annealing algorithm with branch exchange and literature [10] employed the enhanced NSGA-II algorithm. Algorithms for artificial intelligence can be easily learned, adjusted, self-iterative, and very effective if tailored to the specific circumstances. On the other hand, this paper chooses the trend back generation algorithm for improvement, which is more appropriate for arithmetic example analysis, and the second-order cone relaxation algorithm, which can achieve the global optimal solution traversal and whose optimality seeking ability is higher than the artificial intelligence algorithm.

3. State of the Art in Demand Side Response Research

The user side is configured as a rigid resource in the traditional distribution network's working mode, meaning that it can only receive power supplies and cannot actively participate in the distribution network's optimal scheduling. As a result, the user's ability to meet load demand has a gradual negative impact on the amount of money invested in power generation and distribution, which lowers economic returns. To accomplish full regulation of the active distribution network, demand-side resources are integrated into the resources that are part of the distribution network through the use of the active distribution network. Demand-side management is predicated on the economic advantages and power-consuming behaviors of the user; through pertinent rules, the power sector can assist consumers in modifying their own power-consuming behaviors. The main tenet of demand side management is demand side response, which can be used to transfer and interrupt loads, achieve peak shifting and valley filling, and reduce the pressure on the system power supply during periods of peak electricity consumption. Demand-side response technology has, of course, advanced enough over the course of the last 40 years to the point where it can, in certain cases, replace the supply side in smart grid operations. The two primary types of demand side response that exist now are incentive demand response and hourly price demand response. After extensive development, China has created its own demand-side response techniques, including interruptible load (IL) and time-of-use tariff response (TOU).

Demand response studies based on tariffs and incentives have been explored in the literature. One study [11] considered both supply and demand sides to establish an optimal dispatch model for customer terminals and active distribution networks, aiming to minimize integrated costs. The study used the AHP algorithm to determine weight ratios in the objective function and demonstrated its application in a 44-node system. Another study [12] validated the characteristics of demand response for off-grid trade purchases, highlighting regulatory and trading aspects in the auxiliary market. Literature [13] interpreted criteria for energy demand response in industrial parks, establishing load criteria for industrial users and mapping classified loads for future use.

While previous works have addressed the importance of tariffs and incentives, the control of incentive-based demand response on the user side may not adapt quickly to policy changes and network restructuring in demand response. However, tariff-based demand response can enhance user motivation and provide a demand experience, leading to increased user participation and benefiting the efficient allocation of active distribution networks. Real-time tariff demand response is currently considered the most effective method for demand-side response.

4. Conclusion

In this paper, in view of the single demand-side management and economic dispatching problems of traditional distribution networks, and the impact of green energy polishing and curtailment on the safety and dispatching ability of the power grid, the establishment of a smart distribution network and demand-side management and economic optimization scheduling are proposed to achieve the goals of renewable energy stabilization and economic forecasting. In addition, in order to solve the optimization problem, this paper adopts the second-order cone relaxation algorithm, which can realize the global optimal solution traversal, which is expected to improve the reliability and stability of the electric energy system in practical applications, reduce energy loss, and contribute useful experience and insights to the development of smart grid in the future.

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