Proceedings of the 3rd International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/140/2025.21548

A Review of Research on Dispatching Optimization of Source-Grid-Load-Storage Synergistic Distribution Network

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Abstract: In recent years, the installed capacity of renewable energy such as wind power and photovoltaic has increased significantly worldwide. However, with the increasing demand for electricity, the problems of instability and volatility of new energy power generation have become more and more serious. This paper first briefly analyzes the development model and technical characteristics of "source-grid-load-storage" integration and focuses on the operation of the distribution network. Then, it analyzes the current difficulties in distribution network optimal dispatching and summarizes in detail the connection between them. By reviewing the research achievements at home and abroad, it points out the solutions to the current distribution network optimization problems and the coordinated optimization effect between "source-grid-load-storage" and the distribution network. Meanwhile, combined with the current research on the "source-grid-load-storage" integration construction and distribution network, this paper clarifies the development trends and strategies of the future new energy power system. Finally, this paper summarizes and looks forward to the development of high-proportion new energy in the future.

Keywords: a high proportion of new energy, power systems, integrated development of source-grid-load-storage, distribution networks, scheduling optimization

1. Introduction

In recent years, the proportion of renewable energy power systems in the global energy mix has been increasing. China's new energy development, represented by wind power and photovoltaic power generation, has achieved remarkable results, with the proportion of power generation steadily increasing and the cost also declining rapidly [1]. However, with the gradual transformation of power generation structure, the volatility and instability of new energy power generation are also affecting the stability and security of the power system.

In February 2021, China issued the "Guiding Opinions on Promoting the Integrated Development of Power Source-Grid-Load-Storage and Multi-Energy Complementation", emphasizing that the integrated development of source-grid-load-storage and multi-energy complementation is an inherent requirement for the power industry to adhere to the concept of system and an objective need to achieve high-quality development of the power system. The coordinated and interactive development among source, grid, load, and storage is crucial for promoting the real-time power balance of the new power system and ensuring the reliable power supply. In the context of large-scale integration of new energy and the increasing demand for electricity, the optimal dispatching of the distribution network can

DOI: 10.54254/2755-2721/140/2025.21548

reduce peak loads and network losses, thereby improving the economy of the distribution network [2].

This paper studies the components and advantages of source-grid-load-storage and the dispatching difficulties of the distribution network, summarizes the role of "source-grid-load-storage" in optimizing the dispatching of the distribution network, further clarifies the future optimization direction of the distribution network, provides useful references for the efficient utilization and intelligent development of new energy, and finally looks forward to the development of the high-proportion new energy power system.

2. Development Status of Source-Grid-Load-Storage Integration

2.1. Composition of Source-Grid-Load-Storage Integration

"Source-grid-load-storage" integration refers to the organic combination of energy sources, power grid systems, power loads, and energy storage networks to form an energy system that integrates integration, integration, and complementarity, so as to achieve high-efficiency and energy-saving energy supply and demand requirements [3-4].

In the current situation of large-scale new energy grid connection, through technological innovation and optimal allocation of systems, the optimal utilization and coordinated development of energy can be realized. In the future, the development of new energy grids needs to optimize the integration of resources on the power supply side, the grid side, the load side and the energy storage network, and fully improve the regulation capacity of the power grid, and there will be more coupling between the power system and other energy-related systems, as shown in Figure 1.

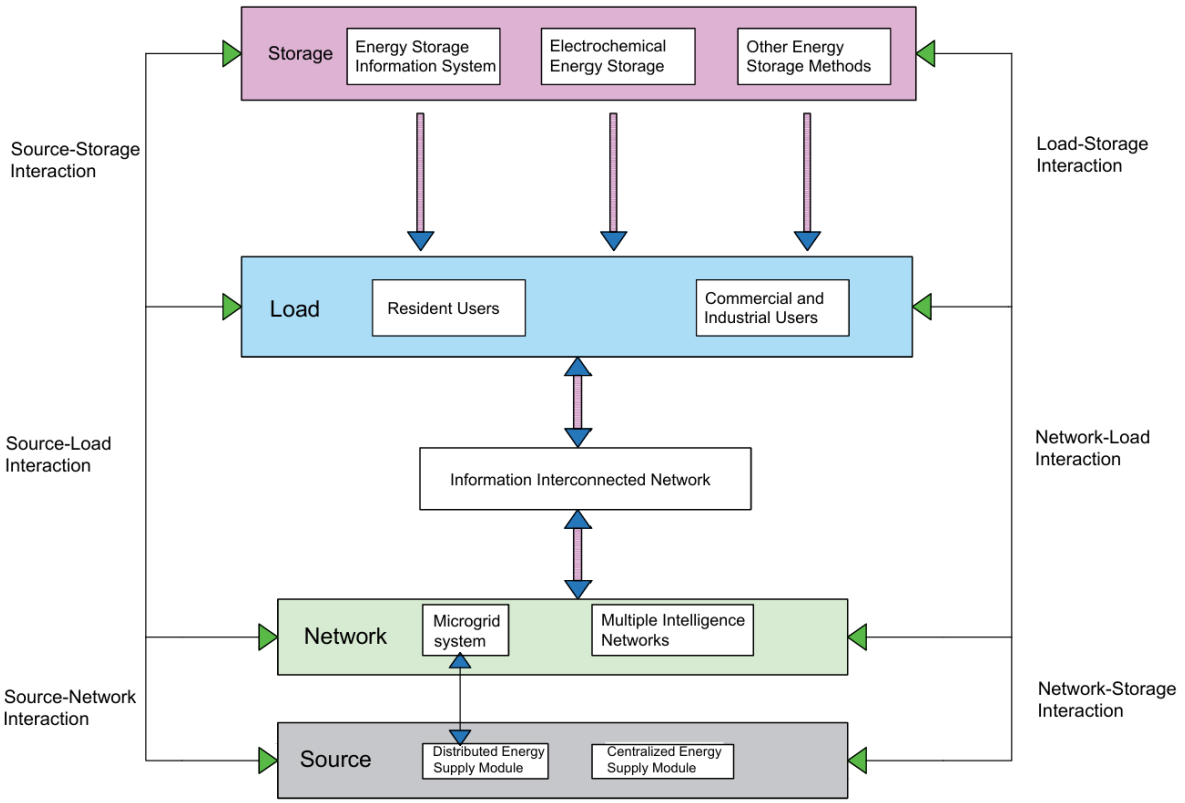

Figure 1: Architecture of the source-grid-load-storage coordination optimization model.

DOI: 10.54254/2755-2721/140/2025.21548

Figure 1 well reflects the coupling relationship among power systems, and then we can introduce the technical characteristics of the "source-grid-load-storage" integration construction.

2.2. Technical Characteristics of Source-Grid-Load-Storage

2.2.1. Real-time and Extensiveness

Under the role of the information platform, the collection, processing, analysis, and feedback of energy-related information through big data can help us monitor and predict the new energy power system in real time, coordinate various energy sources and resources in a certain area according to local conditions, and then obtain the operating status and future trends of the new energy power system [5-6].

Regarding this, Ref. [7] points out that the new power system will realize the full-factor interaction of source, grid, load, and storage through artificial intelligence technology. Ref. [8] explores and constructs a multi-dimensional network relationship with horizontal cross-connections centered on the power grid and vertical "cloud - tube - edge - end" expansion in various fields based on the 5G + cloud-edge-end collaboration technology, which has research value. It can be seen that the introduction of the information platform and the construction of the energy Internet will be one of the paths for power grid optimization.

The "source-grid-load-storage" integration construction also involves multi-energy flow complementation technology.

2.2.2. Multi-energy Flow Complementarity and Coordinated Control Technology

The multi-energy flow complementary technology is embodied in the mutual coupling of the multi-energy Internet, which is the research basis for the planning, scheduling, control and interaction of multi-energy systems. The optimal values of the optimization variables can be calculated by using the planning optimization algorithm to set the planning objectives and constraints of the multi-energy complementary system, which provides an important basis for evaluating the reliability and safety of the system [9-10]. This provides a more economical solution for the optimal dispatching of the distribution network, and some literatures have analyzed this.

Ref. [9] summarizes the static energy hub (EH) model and the steady-state mixed power flow model for multi-energy flow hybrid modeling, in which the static EH model uses the energy vector $P = [P_a, P_b, \dots P_n]^T$ as the input variable and the load vector $L = [L_a, L_b, \dots L_n]^T$ as the output variable to form the energy conversion matrix C of a certain region, and obtains the multiple-input multiple-output power conversion formula:

$$L = CP \tag{1}$$

$$C = \begin{bmatrix} C_{aa} & \cdots & C_{na} \\ C_{ab} & \ddots & C_{nb} \\ \vdots & & \vdots \\ C_{an} & \cdots & C_{nn} \end{bmatrix} \tag{2}$$

$$C_{ij} = \sum_{n=1}^{N} (v_{i,n}(t) \prod_{m=1}^{M} \eta_{n,m}^{j}(\Theta, t)) \tag{3}$$

In the formula: C_{ij} is the coupling coefficient between i energy and class j, and $v_{i,n}(t)$ is the scheduling parameter, and $\eta_{n,m}^{j}(\Theta, t)$ is the conversion efficiency of the energy conversion unit n in the m link production load j.

Although the above formula can reflect the static relationship of energy during conversion and transmission, it cannot describe its complex dynamic performance. In response, Ref. [11] establishes

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a typical component model of the multi-energy collaborative integrated energy system and a multi-energy flow coupling calculation method based on the fragmentation problem of traditional energy planning, which better solves the dynamic optimization of the integrated energy system. At the same time, Ref. [12] summarizes the coupling and difference characteristics of multi-energy flows and points out the time scale differences and stability problems of the integrated energy system, as well as the current unpredictability of the integrated energy system.

The application of multi-energy flow complementary technology is not only reflected in the construction of integrated energy system (IES) and its static and dynamic analysis, but also in the ability to collect and process information, so as to better realize multi-energy metering and monitoring. In the future, we will make full use of energy Internet technology, digital twins, virtual power plants, etc., and apply them to multi-energy flow systems to promote the development of integrated energy systems in the direction of digitalization and intelligence.

3. Analysis of Dispatching Problems in China's Distribution Network

In 2023, China's new installed capacity of new energy power generation will reach 290 million kilowatts, accounting for 15.6% of the total power generation, officially entering the stage of high proportion of new energy predicted by the International Energy Agency and other institutions, which also means that the characteristics of new energy power generation will be further highlighted [13].

Photovoltaic and wind power generation are often affected by factors such as seasons, temperatures, day and night, and cloud cover, with strong randomness and uncertainty, making it difficult for a large number of installed power generation equipment to work efficiently, bringing challenges to the operation and dispatching optimization of the distribution network [14]. Taking East China of China as an example, it is statistically estimated that there are more than 400,000 distribution substations and more than 3,000 new energy power stations and other large numbers of new energy facilities in this region. The complexity is much greater than that of conventional energy sources such as thermal power, and the difficulty of consumption and economic operation management of the distribution network also increases [15].

3.1. Economic Difficulties in Distribution Network Dispatching Optimization

The difficulties encountered in the economic benefits of distribution network dispatching are the planning problems of input and output and the load characteristics on the user side. It is difficult to accurately predict and model under the influence of new energy consumption levels, with strong uncertainty. However, many current planning schemes do not consider the problem of unequal input and output in the analysis process.

In response, Ref. [16] proposes a distribution network input-output benefit evaluation and prediction method based on the equal measurement mode. Based on the cost-efficiency formula (4), a comprehensive evaluation model of distribution network input-output benefits is constructed, which solves the problem of unequal input and output benefits of traditional evaluation methods.

$$CE = SE/LCC \tag{4}$$

In the formula: CE is the input-output benefit value; SE is the output benefit value; LCC is the input cost value.

On this basis, Ref. [17] proposes a master-slave game economic model, considering the uncertainty of new energy consumption and DR for the load characteristics on the user side, realizing the optimization of economic and environmental benefits. However, the price-based DR itself is also difficult to overcome its uncertainty problem.

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Research shows that through scientific planning of new energy layout, overall planning of source-grid-load-storage, fully flexible integration of resources, improvement of their interactivity and dynamic adjustment performance, and further exploration of the interaction potential of "source-grid-load-storage". It can be ensured that the distribution network system can still achieve flexible dispatching, safe operation, and power mutual assistance among regions under the disturbance of the volatility of high-proportion new energy generation.

4. Dispatching Optimization of Source-Grid-Load-Storage Cooperative Distribution Network

In view of the optimization problem of the distribution network in the current power grid system, it is necessary to comprehensively consider the factors such as the spatio-temporal scale, the stability of the power grid itself, and the prediction accuracy. This paper combines the construction advantages of the integration of "source-grid-load-storage" with the pain points and difficulties of the distribution network, and makes use of the advantages of "source-grid-load-storage" itself in terms of multi-energy flow interaction, information platform establishment, and integrated energy system management, so as to establish the connection between the coordinated development of source-grid-load-storage and distribution network, and dig deep into the role of distribution network dispatching optimization.

4.1. Optimization Requirements for Distribution Networks

Improving the optimal scheduling of the distribution network refers to the establishment of a synergistic relationship between the "source-grid-load-storage" and the distribution network at the level of spatio-temporal scale, and comprehensively considering the economy and environmental protection of the system operation, so as to not only improve the energy utilization rate, but also reduce the operation cost of the distribution network and the problem of new energy consumption.

4.2. Research Status of Distribution Network Optimization

Ref. [18] proposes a comprehensive optimization design method for power system considering source-grid-load, establishes an opportunity constraint optimization model, and realizes the economic operation and full utilization of distributed generators by reasonably arranging the power output of controllable distributed generators, optimizing the network topology, and adjusting the response load. In Ref. [19], a coordinated operation and scheduling method of active distribution network considering source-grid-load-storage is proposed, and a multi-time-scale day-ahead intraday optimal scheduling model is established, and the objective function is shown in equations (5) and (6).

$$minf_2 = \sum_{t=1}^{H} \alpha \left(P_{DD,ref}^{t} - P_{DD}^{t}\right) \tag{5}$$

$$minf_3 = \frac{\sum_{t=1}^{H} P_{RES}^{t}}{\sum_{t=1}^{H} P_{WT}^{t} + P_{PV}^{t}} \tag{6}$$

This literature predicts the output of new energy and the load amount based on historical data and the weather forecast of the dispatching day. Then, the imperialist competitive algorithm is used to solve, and the optimal dispatching results are obtained, as shown in Figure 2.

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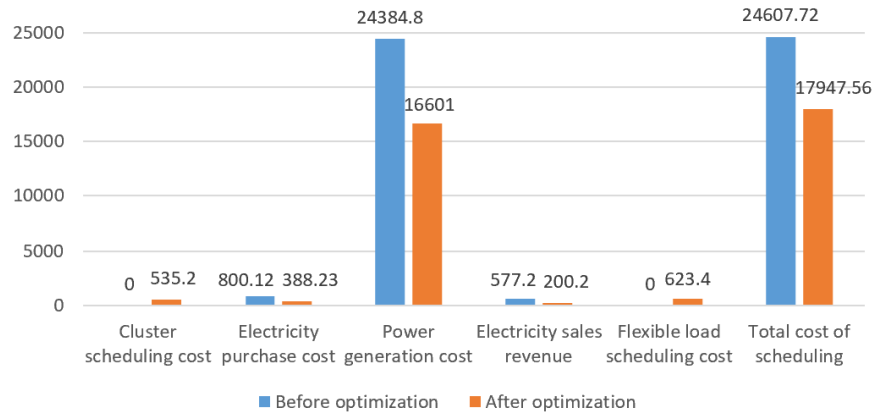

Figure 2: Comparison of cost parameters before and after optimization.

This histogram reflects the optimization of the operation cost of the distribution network under long-time scale and multi-element coordinated dispatching. Then, the literature analyzes the trend of peak shaving and valley filling from the perspective of the load curve, and further obtains the new energy consumption situation before and after optimization as shown in Table 1.

Table 1: Consumption of new energy.

Mode	Before optimization	After optimization
Consumption of new energy	87.21%	96.31%

The above data prove the role of the coordinated development of "source-grid-load-storage" and the distribution network in improving the economic benefits of the distribution network and realizing the optimal dispatching of the distribution network.

Ref. [20] comprehensively considers the interactive optimization of "source-grid-load-storage", establishes a multi-objective optimal dispatching model for a multi-voltage level DC distribution network with photovoltaic, and uses the simulation results of examples to prove the economy of the coordinated optimization for the operation dispatching of the distribution system.

In conclusion, by redesigning the coordinated optimization system of the distribution network and "source-grid-load-storage", establishing day-ahead and intra-day dispatching models, and taking into account various influencing factors such as the influence of the time scale level, the economy of distribution network dispatching can be realized, and the new energy consumption level can be improved at the same time.

5. Conclusion

The "source-grid-load-storage" integration construction aims to promote the further development of high-proportion new energy in China and the structural adjustment and optimization of related industries. Through optimization at the space-time scale level, intelligent development, and multi-energy complementation technology, the problems encountered in the current power system, especially in the distribution network dispatching optimization, can be solved.

This paper focuses on the development background of high-proportion new energy, analyzes the technical characteristics and unique advantages of the "source-grid-load-storage" integration construction, discusses the current optimization difficulties of distribution network dispatching, and summarizes the optimization role of "source-grid-load-storage" for the distribution network based on relevant domestic and foreign research, including the improvement of consumption level, the optimization of distribution network dispatching, and intelligent development. It breaks through the

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limitations of the insufficient regulation ability and poor stability of the old distribution network, and provides a reference direction and value for the future development of the distribution network and even the power system.

To sum up, as a key bridge, "source-grid-load-storage" has played an important role, and will further radiate to the entire power system to form a complete form of energy Internet, give full play to its advantages of multi-energy complementarity and information platform, and finally establish a comprehensive energy management system to help achieve the "double carbon" goal and bring more far-reaching impact to the development of new energy.

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