

# Overview of Optimized Load Scheduling of Energy Hub under Energy Internet Environment

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**Abstract:** Energy hubs (EH) play a key role in the energy Internet environment, especially in the load optimization scheduling of multi-energy systems. As an input-output port model of multi-energy systems, EH realizes real-time monitoring and intelligent analysis through the Internet of Things, big data and artificial intelligence technologies, promoting the efficient use of energy and the reduction of environmental pollution. This model uses the coupling matrix to describe the conversion, storage and transmission relations between energy sources, which provides strong support for the planning and operation of multi-energy systems. With the development of the energy Internet, the importance of EH is becoming increasingly prominent. By the introduction of EH, the coordinated operation of power, natural gas, heat and other energy systems can be realized, and the flexibility and stability of the system can be improved. Current research focuses on stochastic optimization of energy systems and load optimization scheduling to cope with the uncertainties in energy prediction and price. However, user behavior and demand response still face challenges in energy system planning and scheduling. Future research needs to deeply explore the changes in user behavior and introduce demand response mechanisms to improve the accuracy and effectiveness of energy system planning and scheduling. In the future, the optimal scheduling of energy hub load will develop in the direction of intelligence, self-adaptability and multi-energy collaborative optimization. Using big data, cloud computing and other technologies to achieve higher levels of intelligence and adaptability, in-depth research on the collaborative optimization of various energy sources, to promote the efficient operation of the energy system and green and low-carbon development, to provide strong support for the sustainable development of the energy sector.

**Keywords:** Energy Hub; Multi-energy System; Energy Internet; Demand Response; Optimized Operation.

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## 1. Introduction

With the rapid growth of the global economy and the acceleration of industrialization, energy demand continues to grow, and the complexity of energy supply is becoming increasingly prominent. The traditional energy system is faced with multiple problems such as low efficiency, serious environmental pollution and single energy structure, which makes the energy hub as the key node in the energy system become particularly important.

With the development of energy Internet and the increase of people's demand for comprehensive energy services, the coordinated and efficient utilization of electricity, gas, cold, heat and other energy sources has attracted more and more attention, and energy hubs emerge at the historic moment. Energy hub is a kind of used to describe the energy system of energy supply and load demand coupling relationship between input-output dual port model [1][2], using the coupling matrix to describe the various forms of energy distribution, conversion relationship, without detailed calculation of tide equation, in the optimization of energy system configuration and operation optimization has played an important role in the research. The study on load optimization scheduling of energy hub is to make full use of the flexibility of multi-energy coordination and complementarity, and solve the problem of energy distribution and scheduling by comprehensively considering the energy demand of end users under the condition of meeting the system operation constraints and user load demand.

In recent years, with the rapid development of the Internet of Things, big data, artificial intelligence and other technologies, new ideas and methods are provided for the

optimal load dispatching of energy hubs. Through the introduction of advanced information technology means, real-time monitoring, data collection and intelligent analysis of the operation status of the energy hub can be realized, thus to provide powerful data support for optimal scheduling. At the same time, combined with mathematical planning, artificial intelligence and other optimization algorithms, a more accurate and efficient energy hub load optimization scheduling model can be built, to realize the optimal allocation and efficient utilization of energy resources.

Scholars at home and abroad have carried out detailed research on energy hubs, including the modeling of energy hubs and the application of energy hubs in the planning and operation of multi-energy systems. This paper aims to summarize the research status, methods, challenges and prospects of energy hub load optimization scheduling, analyze the application effect of different methods in energy hub load optimization scheduling, and explore the shortcomings of existing research. Through comprehensive analysis, it aims to provide valuable reference and reference for the research of energy hub load optimization dispatching, and promote the sustainable development and green transformation of energy system.

## 2. Basic Concept and Theoretical Basis of Optimal Load Dispatching in Energy Hub

### 2.1. Definition and Function of the Energy Hub

The Federal Institute of Technology Zurich (ETH Zurich) first proposed the concept [3] of the energy hub (energy hub, EH) in 2007 in the "Future Energy Network Vision" project

study. The energy hub is defined as an input-output port model for describing the relationship between energy, load, exchange and coupling between networks in a multi-energy system. The coupling matrix describing the input energy and output load ports can briefly represent the coupling relations between the conversion, storage and transmission of various forms of energy such as electricity, heat and gas, and play an important role in the planning and operation of multi-energy systems [4].

Energy hub concept from a very simple idea: no matter more energy system between electricity, heat, gas coupling is complex, and all need various forms of energy input, eventually converted into other forms of energy as the output of the system, then can be more energy system abstract as shown in figure 1 the input-output dual port network, the middle of the box analysis for the energy system, using energy hub abstract description [5].

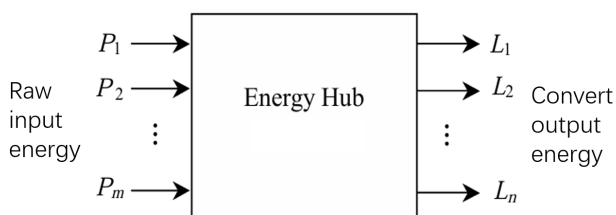


Figure 1. Input-output port model for multiple energy systems

The P vector at the left end of the energy hub represents the original energy input of the multi-energy system, and the L vector at the right end represents the energy output after conversion. Therefore, the energy hub at the mathematical level is a function of an input P to an output L:

$$L = f(P)$$

Where the function  $f()$  can take into account the transmission, conversion, storage and other links of various forms of energy [6].

Because the energy hub modeling method has a high degree of abstraction, so as long as an energy system reasonable modeling, regardless of the size of the system, can be described with the energy hub, such as a single residential user [7-9], commercial buildings (e. g., airport, hospital) [10], factory (such as steel mills, paper mills) [11], conventional generating units (such as hydropower station, CHP, etc.) [12,13], a region or even a national energy system [14], etc.

The basic components of the energy hub are mainly divided into three parts [5]: energy conduction equipment: no energy conversion, can realize direct energy transmission, such as cable, heat network pipeline, gas network pipeline, etc.; energy conversion equipment: realize the conversion and coupling between different energy forms, such as fuel cell, motor, steam and gas turbine, internal combustion engine, electrolytic cell, etc.; energy storage equipment: battery, pumping and storage power station, heat storage device, etc.

## 2.2. Objectives and Principles of Load Optimization Scheduling

Load optimization scheduling is an important optimization problem to support the economic and efficient operation of the energy system. Therefore, various studies on optimized load scheduling of multi-energy systems. Literature [15] establishes a day-ahead load scheduling model for community microgrid, and applies deep learning to load and renewable energy prediction. In the study of Afrashi et al. [16],

a deterministic model for the management of a multi-carrier energy system was proposed to coordinate renewable energy, battery and cogeneration, thus minimizing the energy cost of the energy hub. AkbaziZadeh et al. [17] proposed an energy hub energy management model connecting electricity, gas and heating networks, which takes into account the load of electric vehicle (EV), energy price, renewable energy and energy demand. Heidari et al. [18] proposed a stochastic operation model, including renewable energy, heat and power generation (CCHP) system and ice storage, focusing on the impact of ice storage on the performance and efficiency of energy hubs. A large number of references provide a good theoretical basis for the optimal operation of energy hubs. However, the development of the energy Internet makes the multi-energy systems facing more and more uncertainties. On the one hand, a high proportion of renewable energy is continuously connected to the energy system, and the uncertainty of renewable energy has a great impact on the planning and operation of the energy system by [19]. On the other hand, the implementation of demand response brings inconvenience to users' life or production, which also brings uncertainty to users at different times. Therefore, how to solve the uncertainty in the operation of energy hub and realize the stable operation of system economy is a research hotspot in this field.

## 3. Research Status of Optimal Load Dispatching in Energy Hubs

### 3.1. Research on Single Micro Grid Load Optimization Scheduling

At the present stage, the research on micro-grid load optimization scheduling is mainly aimed at a single micro-grid. The traditional problem of single micro-grid load optimization scheduling is for load management from the perspective of the supply side. From this perspective, the decision maker can achieve the dispatching goal by reasonably arranging the output of the distributed generation unit on the supply side, the charging and discharge power of the distributed energy storage unit and the transmission power between the micro grid and the main grid while meeting the energy demand of the demand side.

Traditional energy systems, such as power systems, natural gas systems, and thermal systems, are mostly planned and operated separately. The lack of coordination between traditional energy systems affects the economical and efficient operation of the whole system [20]. With the development of energy Internet, the coupling of various energy sources (electricity, gas and heat) has been significantly strengthened, and the interaction between power supply, power grid and load has been continuously strengthened by [21]. Therefore, the coordinated operation of multiple energy sources becomes an increasingly urgent task.

For multi-energy micro-grid systems, the supply and conversion of different energy sources can improve the flexibility and stability of the whole system. For example, in the case of power shortage, electricity can be generated by natural gas. In addition, multi-energy systems can improve the energy utilization efficiency of micro-grid systems by coupling different forms of energy.

To effectively model multi-energy microgrid systems, the concept of energy hub (Energy Hub, EH) is proposed as [22]. Energy hub is an input-output two-port model describing the supply, conversion, storage and their coupling relationship of

different types of energy and load requirements in a multi-energy system. It uses a coupling matrix to represent the interrelationship [23][24] between the conversion, distribution and storage of multiple energy sources. Energy hubs have been extensively studied in the planning and operation of multi-energy systems. Literature [25] proposes an energy management model for residential energy hub. The proposed model uses the house as a cold, heat and power generation system, the model uses electric vehicles as a storage unit, and considers distributed power sources such as heat storage and photovoltaic. The results show that participation in demand response projects, the use of heat storage and electric vehicles can increase cogeneration in energy supply and peaking capacity, and help reduce energy costs. Literature [26] proposed comprehensive considering the weather, electricity price and other information of commercial energy hub optimization model, the literature through Monte Carlo simulation, studied the performance of the model under different electricity price and weather conditions and change, the results show that even in the case of electricity price and weather conditions exist uncertainty, energy costs fell significantly.

### 3.2. Research on Multi-microgrid Load Optimization and Scheduling

In the existing research on collaborative scheduling between multiple energy systems, literature [27] studied three typical schemes for managing energy hub clusters on the demand side under the random load prediction framework, namely individual, shared and aggregation. Literature [28] proposes a thermoelectric integrated multi-microgrid hybrid energy sharing framework considering power generation cost, transaction cost, cost of thermal energy inconvenience, load characteristics and power consumption utility. Literature [29] proposes a multi-objective optimal energy flow management model for interconnected multi-energy hubs, aiming to minimize the energy cost, active power loss and natural gas loss of multi-energy hubs. Literature [30] proposes an optimized scheduling model for a multi-residential energy hub system considering battery life. Literature [31] analyzes the performance of multiple residential energy hub load scheduling models under TOU electricity price and dynamic electricity price, and studies the influence of electric energy storage units and renewable resources on the optimization of energy hub load. The results show that the proposed optimization model can reduce the daily cost of the energy hub, and the dynamic pricing scheme can better motivate the energy hub to adjust its daily operation mode.

## 4. Key Technologies and Methods of Load Optimization Dispatching in Energy Hubs

In existing studies, the main methods to deal with energy system uncertainties are stochastic optimization and robust optimization.

In randomized optimization studies, several works have been conducted to address the planning problem of multi-energy systems. Literature [32] proposes an optimal planning model of energy hub to determine the type and capacity of the installed components in the hub, considering the reliability of maintaining power supply and heating, carbon dioxide emissions, and the physical limitations of electricity and gas networks; the model estimates the sensitivity to the

uncertainty of electricity and gas prices using stochastic planning method. Literature [33] proposes a mid-term energy hub management model to minimize the total cost of the system, and the model uses a stochastic planning method to treat the uncertainty of electricity price. Literature [34] uses a two-stage stochastic method to solve the dynamic multi-carrier microgrid planning problem under uncertainty. Literature [35] constructs a new stochastic framework for the planning study of energy systems, reducing the complexity of stochastic models by assessing the relative importance of uncertain sources and discarding sources with minimal impact. Furthermore, some researchers have applied stochastic optimization methods to the operational optimization of energy systems. Literature [36] proposes a stochastic optimization framework for complex microgrids, in which stochastic optimization is performed to retain the up / down regulation capacity for the uncertainty of energy prediction, and then rearrange the initial scheme according to signal requests and economic quotations. Considering the uncertainty of renewable energy, electricity prices and electric vehicle demand, literature [37] proposes an optimization model of random multi-objective grid connection and unbalanced microgrid, which generates three uncertain scenarios using the roulette mechanism. In literature [38], a new stochastic model is proposed for optimizing the CCHP system under energy load and price uncertainty, where a Monte Carlo sampling technique is used to generate a set of probability scenarios with different energy loads and associated energy prices based on a given occurrence probability. Although stochastic optimization is a well-established method to deal with uncertainty, its application requires obtaining the distribution function of uncertain variables, which is difficult to achieve in practice. Moreover, a large number of discrete scenarios generated by stochastic optimization often lead to a large computational amount and a long solving time. Although scenario reduction based on clustering methods can reduce computation, clustering scenarios may not be representative.

Robust optimization has received much attention as another important approach to cope with uncertainty. Robust optimization methods only need to know the fluctuation range of the uncertainty variable, not its probability distribution, and the solution is robust to all uncertainty sets (including worst case). Thus, a large number of robust optimization models have been developed for the planning and scheduling of energy systems. In terms of energy system planning problems, literature [39] proposes a robust optimization model to determine the optimal energy structure, which considers various predicted power load, capacity factor, and energy price uncertainties. Literature [40] proposes a decentralized adaptive robust planning model to address the planning problem of multi-stakeholder integrated energy systems. Moreover, several studies have applied robust optimization to the optimal operation of energy systems. For example, literature [41] proposes the optimal scheduling model for interconnected multi-EH in the presence of electric vehicles, which adopts a robust optimization approach to cope with the uncertainty of electricity price, renewable energy, and power load. For the actual scheduling of island microgrid under source and load uncertainty, literature [42] proposes an adaptive robust optimization model with binary recourse variables.

## 5. The Inadequacy of Existing Studies

### (1) Uncertainty and volatility of renewable energy sources

Renewable energy, such as wind energy and solar energy, has great uncertainty and volatility, which brings great challenges to the optimal load scheduling of energy hubs. Although the existing studies suggest some methods to deal with this uncertainty and volatility, there may be some limitations. For example, prediction methods based on historical data may not accurately predict future renewable energy generation; methods based on stochastic planning or robust optimization may be too conservative or too optimistic. Therefore, how to more accurately predict and manage the uncertainty and volatility of renewable energy sources, is a problem that should be emphasized in the future research.

### (2) Efficiency and practicability of the optimization algorithm

In the optimal scheduling of the energy hub load, the selection and application of the optimization algorithm have an important influence on the quality of the scheduling results. However, the existing optimization algorithms may still have some problems with their efficiency or practicality. For example, optimization algorithms based on mathematical planning may have large computation and long solution time; optimization algorithms based on artificial intelligence or machine learning may require a lot of historical data and training time. Therefore, how to select the appropriate optimization algorithm according to the specific application scenarios and requirements, and improve its efficiency and practicability, is a problem that needs to be concerned about in the future research.

### (3) Research on user behavior and demand response

In the process of load optimization dispatching in the energy hub, the user behavior has a significant impact on the load fluctuation and the power demand. However, existing studies often lack in-depth analysis and modeling of user behavior. User behavior is affected by many factors, such as weather, electricity price, personal habits, etc. The change of these factors will directly affect users' behavior of electricity consumption. Therefore, constructing a model that can accurately reflect the change in user behavior is crucial to improve the accuracy and effectiveness of optimal load scheduling in energy hubs. Demand response is an important mechanism in the power system. By adjusting the electricity behavior of users to respond to the changes of the power system, so as to realize the balance of power supply and demand. However, the demand response mechanism is relatively less used in the study of optimized load scheduling in energy hubs. This is mainly because existing studies often focus on the optimal scheduling of the supply side, while ignoring the management of the demand side. In fact, through the introduction of the demand response mechanism, the electricity consumption behavior of the users can be adjusted more flexibly, so as to realize the optimal scheduling of the energy hub load. In fact, user behavior and demand response are interrelated, and their changes will directly affect the fluctuations of the energy hub load and power demand. Therefore, it is of great significance to construct a comprehensive optimized scheduling strategy that can comprehensively consider user behavior and demand response to improve the effect and efficiency of optimal energy hub load dispatching.

## 6. Future Development Trend of Energy Hub Load Optimization Dispatching

Under the background of energy transformation and the rapid development of smart grid technology, the optimal dispatching of energy hub load is facing unprecedented development opportunities. Future trends will focus more on intelligence, refinement, collaboration and sustainability to adapt to the complexity and variability of energy systems.

Intelligence will become the core driving force of the optimal dispatching of energy hub load. With the help of advanced technologies such as big data, cloud computing and artificial intelligence, energy hubs will realize real-time monitoring, predictive analysis and intelligent decision-making. Through the deep learning algorithm, the system can independently learn and adapt to the change law of energy load, and realize accurate load prediction and optimal scheduling. In addition, the intelligent scheduling algorithm can deal with the complex multi-energy coupling relationship, improve the energy utilization efficiency, and reduce the operating costs.

Refinement will be an important development direction of energy hub load optimization dispatching. With the diversification and personalization of energy needs, energy hubs need to more finely manage various energy resources. By constructing high-precision energy model and load prediction model, the fine management of various energy sources is realized. At the same time, the refined optimization algorithm will develop more reasonable scheduling strategies according to different energy types and load requirements, and improve the energy utilization efficiency and service quality.

Synergy is another important trend of load optimization dispatching of energy hubs. The future energy system will be diversified and distributed, and energy hubs need to be optimized together with multiple energy networks and distributed energy equipment. By building a multi-energy collaborative optimization platform, the information sharing and collaborative scheduling among different energy systems are realized. At the same time, the coordinated scheduling strategy will consider the complementarity and substitution of various energy sources, so as to realize the efficient utilization of energy and reduce energy waste.

Sustainability will be an important goal of optimizing the load scheduling of energy hubs. In the context of global response to climate change and promoting green and low-carbon development, energy hubs need to pay more attention to environmental protection and sustainable development. By optimizing the energy structure, improving the utilization rate of renewable energy, and reducing energy consumption and emissions, the green transformation and sustainable development of energy hubs are realized. At the same time, the sustainable scheduling strategy also needs to consider the social and economic impact of the energy system, and promote the comprehensive and sustainable development of the energy system.

In the future, the load optimization scheduling of energy hubs will pay more attention to the development of intelligence, refinement, coordination and sustainability. This will provide strong support for the efficient operation of the energy system and green and low-carbon development, and promote the green transformation and sustainable development of the energy structure.

## 7. Conclusion and Outlook

With the continuous growth of global energy demand and the increase of energy supply complexity, as a key node in the multi-energy system, the load optimization scheduling problem of the energy hub is particularly important. This paper summarizes the research status, method challenges and prospects of the optimal load scheduling of energy hub in the energy Internet environment, aiming to provide valuable reference for promoting the sustainable development and green transformation of energy system. Energy hub as the coupling system between energy supply and load demand of input-output two-port model, the coupling matrix and describes the energy distribution between electricity, heat, gas and other forms, and coupling relationship, provides an important tool for the optimal configuration and operation optimization of multi-energy system. Through the study of the optimal scheduling of energy hub load, the flexibility of multi-energy coordination and complementarity can be fully utilized to realize the optimal allocation and efficient utilization of energy resources. With the rapid development of the Internet of Things, big data, artificial intelligence and other technologies, new ideas and methods are provided for the load optimization scheduling of energy hubs. By introducing advanced information technology, the operation status of the energy hub can be monitored in real time, with data collection and intelligent analysis, providing powerful data support for optimal scheduling. At the same time, combined with mathematical planning, artificial intelligence and other optimization algorithms, a more accurate and efficient energy hub load optimization scheduling model can be built to realize the intelligent management and control of the energy system.

The optimal load dispatching of energy hub is one of the important areas of energy system research, which is of great significance for promoting the sustainable development and green transformation of energy system. In the future, with the continuous progress of technology and the deepening of research, the optimal load scheduling of energy hub load will play a more important role in improving energy utilization efficiency, promoting the development of renewable energy and promoting the reform of energy market.

In the future, the optimized load scheduling of energy hubs will show the following development trends:

**Intelligent and adaptive promotion:** through big data, cloud computing, emerging technologies such as artificial intelligence constantly development and innovation, the energy hub load optimization scheduling has achieved a new, high level of intelligent and adaptability, through the new means to real-time monitoring of energy supply and demand changes, through any time monitoring and analysis data automatically adjust optimization strategy, and break through the existing mode of new ways to deal with various complex, huge challenges, so as to better promote the development of the industry and progress.

**More energy collaborative optimization in-depth study:** further research will focus on collaborative optimization between a variety of energy, including solar energy, wind energy, hydropower, geothermal energy and other forms of energy interaction and mutual coordination, through the advantages and disadvantages of complementary, in order to maximize energy efficiency and reduce the purpose of the energy waste. In future studies, more attention will be paid to the collaborative optimization between multiple energy

sources to achieve efficient energy utilization and reduce energy waste. Through the construction of multi-energy collaborative optimization platform, the information sharing and collaborative scheduling between different energy systems are realized, so as to realize the efficient utilization of energy and reduce energy waste.

**Technological innovation of renewable energy consumption and utilization:** Through continuous development and improvement of technology, future research will pay more attention to the consumption and utilization of renewable energy. How to improve the utilization rate and stability of renewable energy has become a key topic in the academic circle. The introduction of advanced energy storage technology, demand side response and other means provides new ideas and methods for this topic, which helps to improve the absorption capacity and stability of renewable energy, so as to better promote the development and application of renewable energy.

**The synergistic research of the energy market and policy:** With the rapid development of the global energy market and the need of the sustainable energy system, the synergistic research of the future energy market and policy will also become the trend in the future. How to guide the development of the energy market, promote the coordination of market mechanisms, establish a more reasonable and suitable for the sustainable development of the energy system, so as to help guide the direction of energy consumption and investment, and promote the green transformation of the energy structure. Therefore, in the future, we not only need to pay attention to the continuous innovation and breakthrough of technology, but also the mutual collaborative research between policy and market is one of our future research directions. We must conduct more comprehensive research and analysis in order to contribute to the sustainable development of the energy system.

**Deep integration of energy hub and smart grid:** The deep integration of energy hub and smart grid is one of the important ways to realize the intelligence, automation and efficiency of energy system. With the continuous development of smart grid technology, its influence on the optimal load dispatching of energy hubs will gradually expand. Future research should further explore the deep integration of energy hubs and smart grids, so as to achieve more efficient, flexible and reliable energy supply and demand matching, and promote the sustainable development of the energy system.

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