Overview of Regional Integrated Energy System Operation Optimization Based on Comprehensive Demand Side Respons

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Abstract. Regional Integrated Energy System (RIES) provides a new way to solve the energy dilemma. In order to improve the economic benefits of a regional integrated energy system, a regional integrated energy system with energy storage considering Integrated Demand Respones (IDR) is proposed. Under the premise of not affecting user comfort, fully mobilizing user-side resources can improve the comprehensive utilization efficiency of energy, reduce energy costs, and consume more renewable energy. This paper introduces the concept of IDR, layered interactive architecture and interaction mechanism, analyzes the multi-energy, and focuses on the analysis of integrated energy system scheduling considering IDR uncertainty. Finally, the key scientific issues in IDR research are summarized, and future research directions are prospected.

1. Introduction
The integrated energy system effectively integrates a variety of energy sources such as cold, heat, electricity, and natural gas, and can fully tap the potential of each energy system, becoming an important party in today's energy revolution and a new strategic competition focus for countries. The rapid development of IES has proposed a new solution for the consumption of renewable energy. Regional Integrated Energy System (RIES), as a form of IES, has large load demand and various forms of energy consumption. Demand-side response in RIES can effectively improve energy efficiency and increase the level of renewable energy consumption [1], is getting more and more attention.

At present, the research on IES can be roughly divided into the following aspects:

1) IES modeling and energy flow analysis. Literature [2-3] proposed a hybrid power flow algorithm suitable for multiple scenarios for the coupling relationship of various energy systems in an integrated energy system. Literature [4] extended the concept of probabilistic power flow to the energy flow analysis of IES, which improved the accuracy of energy flow analysis.

2) Coordinated planning of IES. Generally, the objective of minimizing investment and operating costs is to study equipment selection, capacity allocation, pipeline planning and other issues. Reference [5] gives a typical multi-energy system source system EH modeling example, and proposes an EH optimization planning model. Reference [6] also considers the power grid, natural gas network, and transportation network, and proposes an IES urban distribution network planning method that considers economical, charge and discharge energy efficiency.

3) Operation control of IES. The operation control of IES mainly takes economic indicators such as operating cost as the optimization target, and outputs the optimal operation strategy of various
equipment in IES. Reference [7] considered the tunability of the thermoelectric ratio of CHP units, and constructed an IES double-layer optimization model. The IES optimized scheduling model proposed in [8] fully considers the energy cascade utilization within the user, and improves the energy utilization efficiency as a whole.

(4) Comprehensive evaluation of IES. At present, the evaluation of IES mainly focuses on the aspects of risk assessment [9-10], reliability assessment [11], energy efficiency assessment [12-13], and benefit assessment [14-16]. For the new generation energy system, it is necessary to carry out quantitative risk characterization and weak link identification, so as to enhance the risk resistance and help the energy transition [17].

The above-mentioned literature has mainly carried out related research on the system economics of demand-side response participation system operation in RIES, and achieved some results. The potential of IDR to transfer energy is still at the stage of qualitative analysis, and quantitative analysis is lacking. Based on the core concepts of IDR, this paper analyzes the IDR layered interactive architecture and interaction mechanism, and analyzes the comprehensive energy system scheduling considering IDR uncertainty. Finally, the key scientific issues in IDR research are summarized, and future research directions are prospected.

2. IDR basic concepts

Power DR is the transfer of demand-side load in the horizontal time. It has certain shortcomings. For example, it will affect the user's comfort and lead to low user participation. It cannot fully stimulate the load response potential of the user. After large-scale distributed new energy power generation is connected to the power grid, there may be insufficient response capabilities. Therefore, based on a comprehensive energy network based on multi-energy collaborative management [18], Aras Sheikhi and Shahab Bahrami first proposed the concept of IDR in 2015 [19].

2.1 IDR layered interactive architecture

IDR emphasizes intelligence and two-way interaction. The IDR interactive architecture is divided into three layers: the central management layer, the middle coordination layer, and the bottom execution layer on a spatial scale. Strictly controlled steps such as issuing instructions and execution feedback to achieve coordinated and optimized multi-level energy interaction throughout the network.

(1) Central management, the central management is mainly the distribution network dispatch center, which is responsible for the flow monitoring and dispatching, transaction settlement, and planned maintenance of the entire distribution network.

(2) Intermediate coordination layer, the middle coordination layer is the master station energy management center, which is responsible for coordinating the information exchange between the central management layer and the bottom autonomous layer to ensure the interconnection and interoperability of the information of the participants and the safety of energy consumption on the demand side.

(3) Bottom execution layer, the bottom-level user owns the substation energy management system, so that the distributed autonomous system substation energy management system can collect data on its own energy usage, distributed power output and energy storage status based on the general quasi-steady-state model of various equipment in the system to assist The user formulates an optimal energy consumption plan, so that the user's overall energy consumption has the highest economic benefits.

2.2 IDR interaction mechanism

This section proposes an IDR mechanism based on a bidding model, in which power grid companies sign demand response energy management contracts with industrial users. At the same time, considering the different response times of different equipment resources, the mechanism includes multiple time scales such as day-to-day planning and day-to-day corrections, so that different rate resources need to be coordinated to eliminate prediction errors and disturbances step by step.
2.2.1 Day-Ahead Interaction Mechanism and Inter-day interaction mechanism

The day-ahead stage refers to making an optimal decision on whether to activate the interaction mechanism and specific peak-cutting plan the next day through situation awareness, energy analysis, and other means. It can be divided into the following three stages:

Phase 1: Based on the forecast results of cold, heat, electric load, and intermittent distributed energy and market energy prices, the user formulates the energy consumption plan for the user, and uploads the energy consumption plan to the energy management center of the main station in the form of the energy consumption gate power curve. The master station energy management center judges whether there is a risk of power exceeding the limit according to the energy consumption curve reported by all users. If there is a risk of power out-of-limits, the energy management center of the master station sends peak demand (peak-cut period and peak-cut demand) the next day to each user, triggering IDR.

Phase 2: The energy management system of the substation performs IDR calculation based on the received peak shaving instruction to meet the peak shaving demand of the superior. The user's maximum controllable capacity and demand response plan are calculated; the user is based on the peak shaving amount and peak shaving cost. Calculate the demand response quote, and finally report the peak shaving amount and response quote to the master station energy management center.

Phase 3: If the master station energy management system finds that all user demand response plans cannot meet the peak shaving demand, it formulates a load interruption plan for the out-of-limits part, thereby reducing the power consumption of the park.

The intra-day interaction stage refers to: if the previous day's interaction plan is accurate, the substation energy management system controls the user's equipment according to the determined previous day's planning curve, and for users who have deviations from the previous day's response plan, according to the degree of deviation, the corresponding Economic punishment; if there is a deviation or emergency in the previous interactive plan, the correction and rescheduling will be performed. Therefore, the main task at this stage is to modify the previous peak cutting plan.

2.3 General steps of IDR's multi-energy system scheduling

After investigating the existing research results, this paper summarizes the general method of IDR's multi-energy system scheduling, which can be divided into the following steps:

(1) Multi-energy system modeling: According to the equipment in the system and the coupling relationship between the equipment, a unit model, an energy storage system model, and a demand response model need to be established. It mainly includes the unit model, the energy storage device model, and the demand response model, and the modeling is performed according to the characteristics of the actual model.

(2) Definition of objective function: From the perspective of scheduling optimization of the entire system, different objective functions can be set up at different time scales based on the researcher's different research goals and needs. Usually there are factors such as minimizing the economic operating costs of all participants (government, energy users, system operators, etc.), maximizing the environmental friendliness of the entire system operation, maximizing the renewable energy penetration rate, maximizing user satisfaction, etc.

(3) Constraint settings: Each and every component unit in a multi-energy system has its own corresponding operating restrictions and operating environment. When the subsystems are coupled with each other, additional system-level restrictions (such as power transmission capacity restrictions) are generated. The main constraints usually considered in system scheduling that takes into account IDR include, but are not limited to, the constraints on energy supply and demand balance such as electrical energy, thermal energy, cold energy, natural gas, overloading the power grid, meeting user comfort, energy price changes, and dispatchable IDR to meet conditions.

3. Integrated Energy System Scheduling Considering IDR Uncertainty

3.1 IDR uncertainty analysis
Integrated demand response (IDR) is a derivative and expansion of DR on the demand side. It is the embodiment of multiple energy interconnection ideas on the energy side in the context of the Energy Internet (EI). Users can choose a suitable energy usage scheme through some energy conversion devices according to different energy prices, policy incentives and their own needs. Because there are more choices, it is more subjective and random, and it is more difficult to accurately predict the form of energy consumption. The IDR project not only inherits the uncertain factors contained in the traditional DR project, but also exacerbates the uncertainty in the scheduling of multi-energy systems due to its particularity.

3.2 Basic method for scheduling with IDR uncertainty
In the energy system, there are inevitably many uncertain factors, especially the load forecast in the comprehensive demand side response in the context of the energy Internet. In order to establish ideal and accurate models and make better decisions, their uncertainty must be taken into account. At present, the mainstream methods for solving the uncertainty of energy systems can be divided into probability method, possibility method, hybrid method and fuzzy theory method, as shown in Figure 1 [20].

![Figure 1. Common methods for considering uncertainty in energy systems](image)

Probabilistic methods are based on stochastic theory and probability theory to process random input data, and use probability density function (PDF) to model uncertain parameters. Uncertainty modeling methods based on probability theory mainly include Monte Carlo simulation (MCS) [20], scene analysis (SA) [21-22], and point estimation method (PEM) [23].

The probabilistic method is another main method for solving uncertainties. This method was proposed by Lotfi A. Zadeh in 1965. The input uncertain parameter set is represented by an appropriate fuzzy membership function. The fuzzy membership function represents the expected level of the objective function, the degree of satisfaction of constraints, and the uncertainty range of the model coefficients. Therefore, it is important to establish a suitable fuzzy membership function.

The robust method is a new method to solve the optimization problem under the influence of uncertainty [24], especially in the absence of a sufficient understanding of uncertainty.

Probabilistic method, possibility method and robust optimization method are the most commonly used methods to solve the problem of uncertainty. They are also widely used in multi-energy system scheduling considering the uncertainty of demand-side response.

4. IDR key technologies and prospects
IDR is still in the early stages of research, and there is still a long way to go before landing and participating in commercial applications. The road will not be very long. The future research framework is shown in Figure 2.
4.1 IDR and renewable energy joint dispatch
There has always been a good complementary effect between electric power DR and renewable energy generation. Many studies have shown that DR can effectively improve the power system's ability to absorb renewable energy. IDR, as an extension of DR in the integrated energy network, is more flexible than DR. How to construct a joint operation scheduling strategy for IDR, taking into account the related constraints of multi-energy networks under different energy coupling forms and supply modes. Compared with DR, it is better to complement renewable energy power generation, which deserves further research.

4.2 Multiple Randomness Analysis
Random analysis is an important part of IDR research. In addition to the current research on new energy output, the uncertainty of users' own energy consumption and demand prediction, there are still changes in the willingness of users to participate in IDRs, random failures of production equipment / energy conversion equipment / energy transmission equipment, and short-term energy market price changes. And even the impact of weather on heat generation / storage efficiency. These uncertainties are coupled to each other to some extent, which greatly increases the complexity of modeling.

5. Conclusion
This paper introduces the IDR proposal and its connotation and value in the context of the Energy Internet. It also introduces the interactive mechanism of IDR and the general steps of multi-energy mobilization. On this basis, the typical IDR projects at home and abroad are summarized and sorted out, and the research situation of IDR in multi-energy system dispatching is also analyzed. Compared with traditional demand-side response projects, IDR emphasizes the coupling of different energy flows and comprehensive utilization of energy. The uncertainty factor is stronger in scheduling optimization. For system operators, it must be considered when making decisions. Finally, the key technologies and research directions of IDR's future development are analyzed and summarized.

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