

Research and Application of Integrated Energy Coordination Optimization Control in Distribution Network

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Abstract. In recent years, China's new energy industry has developed rapidly, and photovoltaic and wind power installed capacity has ranked first in the world. However, at the same time of rapid development of new energy sources, the problem of consumption has become increasingly prominent, and the phenomenon of abandoning wind and abandoning light is serious. This paper will start from the power generation principle of distributed power supply and the charge and discharge mechanism of energy storage. Through the analysis of the characteristics of distributed power supply, the new energy consumption is the most, the thermal power input is the minimum, and the distributed power supply is established. The cooperative optimization model of distribution network is constructed, and the coordinated optimization control model based on distribution network automation technology is constructed, and the experimental simulation is carried out to obtain the optimal coordinated energy optimization control model for distribution network to realize the safety, high efficiency and high degree of regional distribution network.

1. Introduction

At present, China's distributed power grid-connected technology has gradually matured. However, complex, diverse, multi-flow distribution networks have problems such as difficulty in multi-object coordination, difficulty in real-time accurate control of multiple targets, and low power quality. Due to the uneven distribution of resources and the intermittent nature of the resources themselves, along with the large-scale access of distributed power sources such as wind turbines and photovoltaics, it poses certain hidden dangers to the stability of large power grids. The emergence of distributed power grid-connected technology effectively solves the problem of energy form conversion of renewable energy. However, the intermittent and volatility characteristics of distributed power supply have affected the stability of the power grid. When it is connected to the grid, it will lead to system power imbalance, voltage over-limit, frequency instability and other problems and may eventually lead to system load-loss failure. With the increasing diversification of stakeholders in the active distribution network and the increasing penetration rate of distributed power, the control center has higher and higher requirements for communication bandwidth and computer storage devices, with "information concentration, decision-making concentration". Traditional centralized optimization scheduling technology has encountered unprecedented challenges. Up to now, relevant units at home and abroad have carried out a lot of research in the fields of collaborative optimization control algorithm and distribution network planning strategy, but for the current "source-network-load-storage" deep coupling integrated energy distribution network, related control methods and the control platform still needs to be improved.



Compared with the traditional distribution network, the integrated energy distribution network has more energy forms and has the characteristics of active consumption, active absorption and active control, which has a profound impact on the planning and operation of the distribution network. Compared with the traditional distribution network, the integrated energy city distribution network is more complicated in terms of initial energy source, energy balance mode and terminal load demand, and its planning method is especially facing severe challenges; the integration of power facilities planning methods and transportation service facilities site selection Theory, established a coordination planning model for distribution network and electric vehicle charging network considering traffic network flow, but failed to introduce the concept of supply-side reform. The system energy supply form and energy conversion device are relatively simple, only considering the power network and transportation network. Combined and still not deviated from the traditional distribution network planning; consider the comprehensive balance of various consumption energy including electricity, cold and heat load, but only involves pure energy supply planning, without considering the physical of actual power network and natural gas network Constraint; under the premise of taking into account the physical constraints of the network, the energy center composition and capacity planning is carried out for a small municipal area, but there is only one energy one-way conversion mode between electric energy and natural gas. At the same time, only the integration of the power network and the natural gas network is considered, and the power network, the natural gas network and the transportation network are closely related and highly integrated in the integrated energy system. If the planning process of the three is independent or only partially related, it will cause unnecessary decision-making. Conflict and cost waste.

This paper will start from the power generation principle of distributed power supply and the charge and discharge mechanism of energy storage. Through the analysis of the characteristics of distributed power supply, the new energy consumption is the most, the thermal power input is the minimum, and the distributed power supply is established. The cooperative optimization model of distribution network is constructed, and the coordinated optimization control model based on distribution network automation technology is constructed, and the experimental simulation is carried out to obtain the optimal coordinated energy optimization control model for distribution network to realize the safety, high efficiency and high degree of regional distribution network.

2. Integrated Energy Distribution Network Planning Strategy

The integrated energy system is an important frontier for exploring the internal operating mechanism of different energy sources and promoting advanced energy technologies. It has important research significance. At present, the development of integrated energy systems has been highly valued at the national level, and research related to integrated energy optimization operations has also been actively carried out. Li Yang et al. respectively constructed an economic evaluation model and a two-layer optimization model for the distributed energy system on the Internet, and established the relationship between the internal energy efficiency characteristics of the unit and the external energy distribution to achieve efficient operation of internal units and external energy economic distribution. At present, from the whole source of "source-network-load" at present, the optimal hybrid power flow algorithm of integrated energy system with integrated distribution network reconfiguration is proposed to optimize the integrated energy system, and the most common AC-DC hybrid transmission network is proposed. The second-level planning mathematical model of excellent power flow; in order to more accurately reflect the value of different energy sources in the integrated energy system, better motivate users to use energy reasonably, establish the optimal power flow model of the cogeneration system, and propose a new multi-model The energy price of the energy coupling pricing mechanism is studied, and the energy price of the node is studied in the cogeneration system. The problems of the comprehensive energy system reliability assessment are summarized from the three aspects of model, algorithm and index system. The energy consumption balance system of regional energy and heat load is studied, but the constraints of the actual transmission channel are not considered. The direct unidirectional conversion mode of electric energy and natural gas is considered, but the multi-energy

complementary deep coupling relationship of electric and thermal renewable energy is not considered. Analyze.

3. Distribution Network Integrated Energy Coordination Optimization Control Modeling

3.1. User load response characteristics modeling

In the context of future integrated energy systems, based on the user's multi-type energy demand characteristics and energy habits, the user-side load types can be basically divided into basic power load, transferable load, interruptible load, and thermo-electric transferable load. The responsive characteristic models of different types of loads are as follows:

3.1.1. Basic electricity load. The basic power load mainly refers to the load that satisfies the user's basic energy demand. The user's demand is approximately rigid, and such load is often not responsive. At the same time, the pure subjective random characteristics exhibited by the user during the power consumption process make the load have a certain timing characteristic, but also exhibit a certain random uncertainty.

3.1.2. Transferable load. The transferable load mainly refers to the user load whose duty cycle can be transferred or whose operating power has adjustable characteristics during the working cycle. Since the transferable load has a flexible working time window or adjustable working load power, the integrated energy service provider can sign a contract with the user according to the market conditions and regulate the transferable load of the user. At the same time, the relatively flexible power consumption characteristics make the scheduling of such loads less affected by the user's electrical experience. For the power load that can be transferred during the work cycle, the working power is not adjustable during the working cycle, but the time window of the work cycle can be translated according to the needs of the integrated energy service provider or the system. The load characteristic model is:

$$x_i^t - y_i^t = K_i^t - K_i^{t-1} \quad \forall t \in [\tau_i^{\text{low}}, \tau_i^{\text{up}}] \quad (1)$$

$$x_i^t + y_i^t \leq 1 \quad \forall t \in [\tau_i^{\text{low}}, \tau_i^{\text{up}}] \quad (2)$$

$$\sum_{t \notin [\tau_i^{\text{low}}, \tau_i^{\text{up}}]} K_i^t = 0 \quad (3)$$

$$\sum_{t \in [\tau_i^{\text{low}}, \tau_i^{\text{up}}]} K_i^t = T_i^{\text{ot}} \quad (4)$$

$$\sum_{k=t-T_i^{\text{tr}}+1}^t x_i^k \leq K_i^t \quad \forall t \in [\tau_i^{\text{low}}, \tau_i^{\text{up}}] \quad (5)$$

$$K_i^t p_i^{\text{sr}1} = p_{i,t}^{\text{sl}}, \quad x_i^t, y_i^t, K_i^t \in \{0, 1\} \quad (6)$$

where $i \in R$ represents the i th user in the user set R ; τ_i^{low} and τ_i^{up} are the earliest start time and the latest shutdown time of the type of power load for the i -th users; K_i^t is the working state variable of the load in the t th period, and $K_i^t = 1$ indicates that the type of load is on, $K_i^t = 0$ means that it is in the shutdown state; x_i^t, y_i^t are state variables for starting and shutting down the load of the type in the t -th period; $T_i^{\text{ot}}, T_i^{\text{tr}}$ are the minimum working time and the shortest continuous working time of the i -th user for the type of load, respectively; $p_i^{\text{sr}}, p_{i,t}^{\text{sl}}$ are the rated power of the type i load and the actual load value during the t th time, respectively, for the i -th user.

For a transferable load whose working power can be adjusted during the working period, it is often only required for a total amount of power supplied by the system within a certain time range, such as electric vehicles or distributed energy storage. Therefore, the actual power level of each type of load can be adjusted according to the needs of the integrated energy service provider. The load response characteristic model is as follows:

$$\text{SOC}_i^{t+1} = \text{SOC}_i^t + \eta_a^+ p_{i,t}^{\text{ch}} - p_{i,t}^{\text{dch}} / \eta_a^- \quad \forall t \in [\alpha_i^{\text{low}}, \alpha_i^{\text{up}}] \quad (7)$$

$$p_{i,t}^{\text{ch}} \leq p_{\text{ch}}^{\text{max}} d_{i,t}^{\text{ch}}, \quad p_{i,t}^{\text{dch}} \leq p_{\text{dch}}^{\text{max}} d_{i,t}^{\text{dch}} \quad \forall t \in [\alpha_i^{\text{low}}, \alpha_i^{\text{up}}] \quad (8)$$

$$\text{SOC}_i^{\text{min}} \leq \text{SOC}_i^t \leq \text{SOC}_i^{\text{max}}, \text{SOC}_i^{\alpha_i^{\text{up}}} \geq E_i^{\text{des}} \quad \forall t \in [\alpha_i^{\text{low}}, \alpha_i^{\text{up}}] \quad (9)$$

$$\eta_a^+ p_{i,t}^{\text{ch}} \leq \text{SOC}_i^{\text{max}} - \text{SOC}_i^t, \quad p_{i,t}^{\text{dch}} / \eta_a^- \leq \text{SOC}_i^t \quad (10)$$

$$d_{i,t}^{\text{ch}} + d_{i,t}^{\text{dch}} \leq 1 \quad \forall d_{i,t}^{\text{ch}}, d_{i,t}^{\text{dch}} \in \{0,1\} \quad (11)$$

where $\alpha_i^{\text{up}}, \alpha_i^{\text{low}}$ are the upper and lower bounds of the i-th user's load working time interval, respectively; SOC_i^t is the stored electricity of the type of load; $p_{i,t}^{\text{ch}}, p_{i,t}^{\text{dch}}$ are respectively the charging of the i-th user of the type of load during the t-th period Discharge power; $d_{i,t}^{\text{ch}}, d_{i,t}^{\text{dch}}$ are the charge and discharge 0-1 state variables of the type of load in the t-th period; $p_{\text{ch}}^{\text{max}}, p_{\text{dch}}^{\text{max}}$ are the maximum charging and discharging rates of the type of load, respectively; η_a^+, η_a^- are the charging of the type of load, respectively. , discharge efficiency; $\text{SOC}_i^{\text{max}}, \text{SOC}_i^{\text{min}}$ are the maximum and minimum storable power of the ith user of the type of load, respectively; E_i^{des} is the minimum available power required for the type of load at the end of the working time interval.

4. Constraints on comprehensive energy collaborative distribution network planning model

The goal of integrated energy collaborative planning is to ensure the safe and stable operating conditions of the system, consider the optimal use of resources, minimize system investment and operating costs, and minimize clean energy, improve energy efficiency, and reduce pollution and emissions. Considering the construction cost of power grid construction cost, CHP construction cost and wind-solar complementary system, as well as the cost of power generation and the cost of punishment for abandoning wind and abandoning light, the minimum planned system cost is the goal, and the mathematical model of optimization planning is established. The objective function of the model The expression is:

$$F = \min(f_1 + f_2 + f_3) \quad (12)$$

where: F is the total cost of the regional integrated energy system; f_1 is the investment cost of the integrated energy system; f_2 is the unit's power generation cost; f_3 is the penalty cost of the light and loss load.

$$f_1 = k u_{\text{GRID}} \sum_{i \in \varphi} u_i^{\text{GRID}} + k u_{\text{CHP}} \sum_{i \in \varphi} u_i^{\text{CHP}} + k u_{\text{GF}} \sum_{i \in \varphi} u_i^{\text{GF}} + k u_{\text{EV}} \sum_{i \in \varphi} u_i^{\text{EV}} \quad (13)$$

where: k is the annualized investment coefficient; φ is the regional energy station collection; $u_i^{\text{GRID}}, u_i^{\text{CHP}}, u_i^{\text{GF}}, u_i^{\text{EV}}$ are the capacity of the public grid, cogeneration, wind and light system and charging facility of domain unit i; $u_{\text{GRID}}, u_{\text{CHP}}, u_{\text{GF}}$ and u_{EV} are their unit capacity construction costs respectively.

$$f_2 = \sum_{i \in S_G} (\alpha_i + \beta_i P_{Gi} + \delta_i P_{Gi}^2) \quad (14)$$

where: S_G is the generator collection; P_{Gi} is the active power of the generator; α_i , β_i , δ_i are the fuel cost coefficients of the power generation.

$$f_3 = p_{\text{penal},1} \sum_{i=1}^T L_{\text{des},t} + p_{\text{penal},2} \sum_{i=1}^T L_{\text{loss},t} \quad (15)$$

where: $p_{\text{penal},1}$ is the penalty price for the unit to discard the wind and abandon the light; $L_{\text{des},t}$ is the amount of discarded wind for the system t period; $p_{\text{penal},2}$ is the unit penalty price for the regional loss load; $L_{\text{loss},t}$ is the loss load caused by the system due to insufficient rotation reserve; Schedule the total running time.

At the same time, each energy source must meet the following constraints according to its characteristics.

Considering that the regional user is constrained by the upper and lower limits of the node voltage, the voltage amplitude must meet the following requirements:

$$U_{\min} \leq U_i \leq U_{\max} \quad (16)$$

where: U_i is the large user voltage amplitude of the region; U_{\min} and U_{\max} are the minimum and maximum amplitude limits of the user node voltage, respectively.

Constrained by the feeder current of the planning area, the current amplitude must meet the following requirements:

$$|I_i| \leq I_{\max} \quad (17)$$

where: I_i is the current value in a distribution system of any feeder group in the planning area; I_{\max} is the upper limit of the current value of the distribution system in the planning area.

5. Case analysis

In order to test the effectiveness of the above-mentioned integrated energy city distribution network planning method, this paper uses a regional integrated energy system coupled by a node distribution network, an 18-node natural gas network and a 23-node transportation network for simulation analysis.

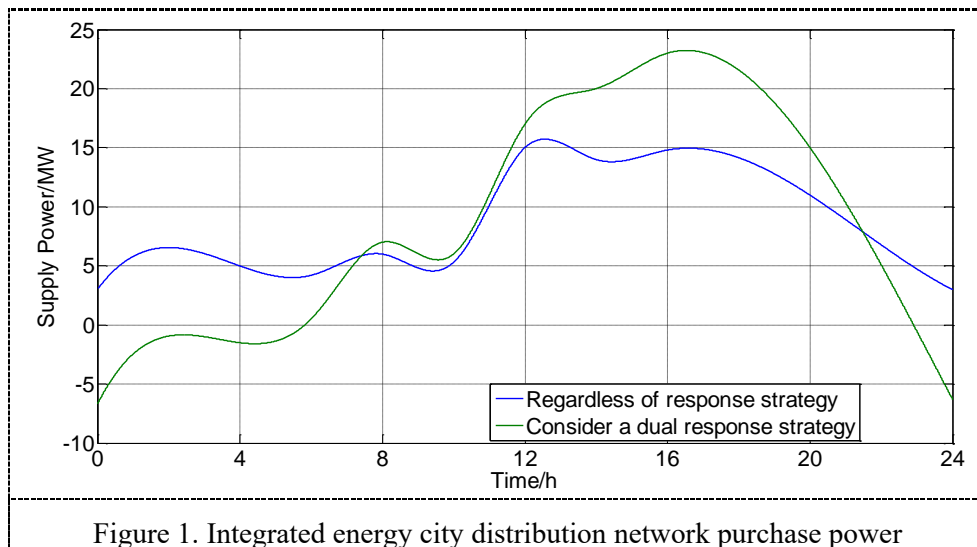


Figure 1 is a comparison of the situation in which the integrated energy city distribution network purchases electric power from the main network while considering the integrated energy supply conversion response strategy and the slow charging station price-type demand response strategy, and the response strategy is not considered. When the response strategy is not considered, the power purchased from the upper power grid is negative at some moments. If the capacity of the upper power grid is absorbed, the wind power planning capacity may need to be reduced. Therefore, the above dual response strategy can not only play the role of peak clipping, but also improve the system's ability to accept wind power.

It can be seen that since the ratio of the electrical load to the thermal load of the integrated energy unit of each terminal is the same in the example, the ratio of the planned capacity of the device is also consistent, and the capacity is positively correlated with the load. In addition to the change in load size, the fan planning capacity is also related to the capacity of the charging station. The capacity of the slow charging station is large and the fan capacity of the terminal integrated energy unit with the fast charging station will increase.

The comprehensive energy supply transformation response strategy proposed in this paper for supply-side reform can comprehensively consider the multi-load demand, make full use of energy conversion characteristics, and adjust the energy supply structure and conversion mode in real time, so as to reduce energy without changing the end-user load demand. The average price is to reduce the comprehensive energy cost, achieve power peaking and valley filling to optimize system operation characteristics.

6. Conclusion

In this paper, based on the power generation principle of distributed power supply and the charge and discharge mechanism of energy storage, through the analysis of the characteristics of distributed power supply, the new energy consumption is the most, the thermal power input is the minimum, and the distributed power supply is established. The cooperative optimization model of distribution network is used to construct a coordinated optimization control model based on distribution network automation technology, and the experimental simulation is carried out to obtain the optimal coordinated energy optimization control model for distribution network. The method utilizes the terminal integrated energy unit model to couple the original independent power network, natural gas network and transportation network to the integrated energy city distribution network for unified coordination planning, which can avoid decision conflicts, reduce resource waste, and improve system comprehensive construction and operation economy, and this method The planning pattern has certain versatility and universality. Realize the safe, efficient and high-quality operation of the regional distribution network, and promote the construction of the power Internet of Things. Based on the above-mentioned comprehensive energy planning pattern, how to enrich the energy conversion devices, energy network types in the planning model to further improve the energy integration level; how to describe more accurate; how to portray more accurate and detailed analysis models for energy conversion devices can be the focus of the next phase.

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