Hierarchical dispatching model of power grid under electrochemical energy storage constraints

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Abstract—Aiming at the hierarchical and zoning operation control of active distribution network, focusing on electrochemical energy storage, theoretical analysis and simulation research are carried out. Firstly, the basic principle of electrochemical energy storage is analyzed, and the working characteristics such as state of charge, power loss and charge discharge power are studied. Secondly, from the perspective of economic indicators, the power consumption cost of electrochemical energy storage is studied, and the objective function of global optimal dispatching of active distribution network is constructed. Then, the energy constraints and power constraints of electrochemical energy storage are studied as an important supplement to the active distribution network optimal scheduling model. Thirdly, the application of electrochemical energy storage in regional autonomous control is analyzed, and the regulation strategy of power fluctuation is studied from the perspective of standby capacity and power deviation. Finally, combined with a specific application example, the simulation analysis is given. The simulation results show that electrochemical energy storage can effectively optimize the hierarchical scheduling of active distribution network.

1. Introduction
With the access of a large number of distributed energy sources, the distribution network is gradually transformed from a simple passive network to a complex active network. The traditional control mode and operation mode are difficult to meet the new development needs[1]. Different from the traditional distribution network, the active distribution network improves the consumption and power supply quality of new energy and ensures the safe and reliable operation of the system through the coordinated control and effective management of resources such as source, network, load and storage. Electrochemical energy storage has the advantages of stable performance and flexible control. It has been widely used in active distribution network and has become an important way of power regulation and energy control[2]. At present, the active distribution network usually adopts the hierarchical and zoning operation scheduling scheme combining global centralized optimization and regional decentralized autonomy. Therefore, it is necessary to study the influence and role of electrochemical energy storage in the above links. Focusing on electrochemical energy storage, based on the analysis of its working principle, the power consumption function and the approximate conditions of power and energy are deduced, and the optimal scheduling model is constructed[3]. At the same time, based on the analysis of power deviation and reserve capacity, the regional power regulation scheme is studied, which provides a reference for the operation scheduling of active distribution network.
2. Hierarchical dispatching model of power grid under energy constraints

2.1. Electrochemical energy storage energy constraint algorithm

Electrochemical energy storage generally takes energy storage battery as the carrier and uses specific electrochemical reaction to realize energy storage and release\[4\]. Taking the commonly used lithium iron phosphate battery as an example, the working principle and characteristics are analyzed. The electrochemical reaction process of lithium iron phosphate battery is as follows.

\[
\text{LiFePO}_4 \xrightarrow{\text{discharge}} \text{Li}^+ + e^- + \text{FePO}_4
\] (1)

Where \( \text{Li}^+ \) is lithium ion, \( e^- \) is electron, and \( \text{FePO}_4 \) is iron phosphate. The charge and discharge of lithium iron phosphate battery essentially corresponds to the process of lithium ion de-intercalation and intercalation\[5\]. In a sense, the amount of lithium ions generated by electrochemical reaction determines the capacity of the battery. SOC is usually used to characterize the current capacity of the battery, which is defined as follows

\[
SOC = \frac{Q_i}{Q_r}
\] (2)

Where \( Q_i \) is the battery power at \( i \) time and \( Q_r \) is the rated power. The value range of SOC is \( 0 \sim 1 \), 0 means that the battery is completely empty, and the power is cleared at this time. When the value is 1, it means that the battery is fully charged, and the power is the rated power at this time. The charging (discharging) efficiency is defined \( \eta \) as follows:

\[
\eta = \frac{P - P_n}{SOC}
\] (3)

Where, \( P \) is the charging (discharging) power, and the charging direction is taken as the reference direction, that is, \( P \) is positive during charging and negative during discharging. \( P_n \) is the power loss, and the reference direction is consistent with \( P \)[6]. There are \( n \) electrochemical energy storage equipment in the active distribution network, and the dispatching plan is divided into \( m \) time areas, so the loss cost is as follows

\[
f_{\text{ESS}} = \sum_{m=1}^{M} \sum_{n=1}^{N} a_m \cdot (1 - \eta_n) \cdot |P_{\text{ESS},m,n}| (4)
\]

Where \( a_m \) is the cost conversion coefficient in \( m \) period, \( \eta_n \) is the charging (discharging) efficiency of the \( n \)th electrochemical energy storage equipment, and \( P_{\text{ESS}} \) is the charging (discharging) power of the equipment in \( M \) time period. The calculation formula of the above cost is further given. Since this paper focuses on electrochemical energy storage, it will not be repeated here. Undirected graph is used to represent hierarchical heterogeneous network virtual machine and network node set \( S = \{s_1, s_2, \ldots, s_n\} \) can represent a collection of virtual machines, not an edge set \( T = \{t_{ab}\} \) represents a virtual machine \( s_n \) and \( s_m \) set of communication data between, node weight \( c(s_n) \) can describe the multi-functional computing performance of virtual machine, and analyze the heterogeneous factors of virtual machine computing performance according to the formula:

\[
\phi = f_c \sqrt{\sum_{s} \left( c(s_n) - \overline{c(s)} \right)^2 / \left( i \times \max \left( c(s_n) \right) \right)} (5)
\]

In the formula: \( \overline{c(s)} \) represents the average node weight, the larger the \( \phi \) is, the greater the error in the computing performance of layered heterogeneous network virtual machines, and vice versa. After electrochemical energy storage is configured, the above constraints need to be considered in the optimal dispatching of active distribution network. For the SOC constraints described, it is difficult to call them directly, which needs to be processed and transformed into a relationship with power as
variables. Here, SOC constraints are analyzed from the perspective of energy, and the following relationship can be obtained:

\[
\begin{align*}
E_{\text{EES}, m,n} & = E_{\text{EES}, m-1,n} + \eta_s P_{\text{EES}, m,n} \cdot \Delta T \\
E_{\text{EES}, \text{min}, n} & = E_{\text{EES}, n} | (\text{soc}_n = \text{soc}_{\text{min}, n}) \\
E_{\text{EES}, \text{max}, n} & = E_{\text{EES}, n} | (\text{soc}_n = \text{soc}_{\text{max}, n})
\end{align*}
\]  

(6)

Where \( E_{\text{EES}, \text{min}, n} \) and \( E_{\text{EES}, m,n} \) are respectively represents the energy reserve of the nth electrochemical energy storage equipment in time periods m and N, \( \Delta t \) is the time interval divided by the dispatching plan, \( E_{\text{EES}, \text{max}, n} \) and \( E_{\text{ESS}, n} \) are energy reserves corresponding to the lower and upper SOC limits of the equipment.

2.2. Optimization of hierarchical dispatching structure of power grid

By establishing the processing method of local dispatching layer, taking r-dg and matched es device as a relatively independent optimization subject r-dg owner or power generation, make decisions outside the upper regional dispatching layer. The reason is that the optimal dispatching of power grid usually takes economic quality as the goal, but in the current environment, r-dg usually hopes to maximize the utilization of renewable resources to achieve clean and environmental protection power supply. The cross regional interconnected power grid with wind power and thermal power is considered, and its structure is shown in the figure.

\[\text{Area A} \quad \text{Area B}\]

\[\text{Wind power} \quad \text{Photovoltaic} \quad \text{Thermal power}\]

\[\text{Conventional load} \quad \text{Flexible load}\]

Fig.1 Hierarchical processing structure of cross regional interconnected power grid

It is assumed that area B with concentrated load is the receiving end power grid, and the power supply of the receiving end power grid does not include large-scale new energy power generation, but there is a large-scale flexible load. Through this goal, r-dg can improve its output level as much as possible and maximize the utilization of renewable resources. Through this goal, ES can be used to stabilize the output fluctuation of r-dg and provide better output characteristics for power grid. The optimal scheduling model is.

\[
\begin{align*}
\text{Max} & \alpha \sum_{j=1}^{N} \rho_{j,t} (t) P_{j,t} (t) \quad \beta \sum_{i=1}^{N} P_{i,t} (t) \quad \frac{1}{N} \sum_{i=1}^{N} P_{j,t} (t) \quad \forall t \in N_T
\end{align*}
\]

(7)

\[
\begin{align*}
E_{\text{ES}, (t+1)} & = E_{\text{ES}, t} + P_{\text{ES},i,t} (t) \eta_{\text{ES},i,t} \Delta t - \frac{P_{\text{ES,dis},t} (t)}{\eta_{\text{ES,dis}} } \Delta t \\
E_{\text{ES}, \text{min}} & \leq E_{\text{ES}, t} \leq E_{\text{ES}, \text{max}} \\
|E_{\text{ES}, (T)} - E_{\text{ES}, (0)}| & \leq e_{\text{ES}}
\end{align*}
\]

(8)
Where: $P$ represents the length of the scheduling period set $[0,1,...,n]$. $T$ and $t$ represent the weight coefficients of the two optimization objectives respectively. In the objective function $\eta_{ES,dis}$ represents the joint power selling price of RDG and es. $P(1)$ represents the combined output of RDG and es. Constraint conditions and mean the dispatch generation power and predicted maximum generation power of RDG respectively, and PSD (1) and pesh ( ) mean the discharge and charging power of ES device respectively. ES (0) indicates the state of charge of ES device. $P_{joi}(t)$ and $P_{ji}(t)$ represents the maximum discharge and charging power of ES device respectively. $\rho$ Represents the discharge efficiency and charging efficiency of the ES device, $\epsilon_{ES}$ Indicates the allowable variation range of the charging state of ES device at the end of the dispatching cycle relative to the beginning.

2.3. Realization of hierarchical dispatching in power grid
In the day ahead time scale, the power grid dispatching center first determines the load peak period according to the load forecasting curve of the next day, and forms each load aggregation of this information together with the compensation method of load reduction. Specifically, it is to reduce the compensation price per unit of electricity, The compensation price set in this paper has a linear relationship with the load level, and its calculation formula is as follows:

$$I^h = a^h \left( P_{\text{Forecast}}^h - P_s^h \right) + b^h$$

Where, $P$ is the electricity price level of period $h$; $a$ and $b$ respectively represent the first-order coefficient and constant term of the time period $h$ electricity price calculation formula; $P_{\text{Forecast}}^h$ is the predicted load value of period $h$; $P_s^h$ Is the total load reduction for period $h$. Through the above two stages, optimize the load curve to achieve the goal of load peak shaving and valley filling, and then upload the optimized load curve to the dispatching center. The cross regional interconnected power grid system studied includes wind turbine generator set, photovoltaic generator set, thermal power generator set, load demand and DC tie line. The definitions of input nodes and output nodes in the network are shown in Table 1.

| Enter the number of nodes | Describe                                              |
|----------------------------|-------------------------------------------------------|
| 1                          | Intelligently forecast the load at t time of the previous day |
| 2                          | Intelligently forecast the load at T-1 time of the previous day |
| 3                          | Intelligently forecast the load at $t+1$ of the previous day |
| 4                          | Intelligently forecast the load at t time in the first two days |
| 5                          | Intelligent load forecasting for the first three days t |
| 6                          | Intelligent prediction of maximum temperature          |
| 7                          | Intelligent prediction of minimum temperature          |

Aiming at the scheduling optimization problem of cross regional interconnected power networks, a similarity measurement method based on net load power Euclidean distance and dynamic time bending distance is proposed. Finally, specific single source and multi-source knowledge transfer methods are designed. Simulation experiments show the rationality of the proposed similarity measurement method and the effectiveness and superiority of transfer reinforcement learning to solve the scheduling optimization problem of cross regional interconnected power grids.

3. Analysis of experimental results
In order to verify the operation effect of active distribution network with electrochemical energy storage, simulation analysis is carried out. The simulation conditions are as follows: the maximum charge (discharge) power of EFS in an autonomous region is 250 kW, and the discharge power in a
dispatching section is 100 kW. At 5s, the power deviation of -200kW is generated due to the sudden drop of DG power. At 10s, large power fluctuation occurs in the adjacent area, and the power deviation of 50KW is shared in this area. The power grid signal monitoring video processing chip of DSP model is adopted, and the MPEG-4 video compression standard is used. The specific experimental parameter settings are shown in Table 2.

| Grid voltage | Sinusoidal waveform distortion rate limit /% | Odd harmonic voltage content /% | Even harmonic voltage content /% |
|--------------|---------------------------------------------|---------------------------------|----------------------------------|
| 0.35kv       | 4.0                                         | 2.9                             | 1.0                              |
| 5kv          | 2.9                                         | 2.1                             | 0.9                              |
| 9kv          | 2.9                                         | 2.1                             | 0.9                              |
| 32kv         | 1.9                                         | 1.2                             | 0.5                              |
| 55kv         | 1.9                                         | 1.2                             | 0.5                              |

Table 2 experimental parameter settings based on the above table, the power dispatching error values in the power grid hierarchical dispatching process under the traditional neural network method and this method are compared and analyzed. The specific simulation results are shown in the figure 2, 3.

![Fig. 2 Power dispatching deviation of traditional AC / DC hybrid active distribution network](image1)

![Fig. 3 Power dispatching deviation of AC / DC hybrid active distribution network in this method](image2)

From the simulation results, it is not difficult to find that compared with the traditional methods, this method can be effectively used for the operation control of active distribution network and avoid scheduling error. Further, for example, AC / DC hybrid active distribution network, the effectiveness of the proposed scheduling strategy is verified. For each optimization model, the mature and efficient industry solver cplex12.6.0 developed by IBM is used to solve it. In the process of hierarchical dispatching, the harmonic component of power grid decreases gradually with the increase of harmonic times. Since different data acquisition frequencies have different effects on the 2nd, 4th and 6th harmonics of fundamental wave, the selection of connection weight and inertia coefficient is also different, as shown in Table 3.
Table 3: Connection weight and inertia coefficient under different harmonic times

| Harmonic number | Connection weight | Inertia coefficient |
|-----------------|-------------------|--------------------|
| Fundamental wave| 0.015             | 0.02               |
| 2               | 0.015             | 0.02               |
| 4               | 0.010             | 0.01               |
| 6               | 0.005             | 0.01               |

AC areas 2 and 3 have similar topological structures, but the locations of regulation points in each power grid area are different, as shown in the table. Based on this, further management of regulation nodes is carried out. The specific distribution is as follows.

Table 4: Regional control nodes of AC distribution network

| AC distribution network area | C-DG1 node | C-DG2 node | C-DG/ES node |
|------------------------------|------------|------------|--------------|
| A                            | 8          | 11         | 13           |
| B                            | 5          | 9          | 13           |
| C                            | 6          | 8          | 15           |

Based on the regional regulation nodes of each AC distribution network, the hierarchical regulation and optimization results of r-dg and es in DC area are further recorded, as shown in the figure 4:

Fig. 4: Optimization results of hierarchical dispatching in flow distribution grid area

It can be seen that with the power regulation capacity of the energy storage unit, Si'an can effectively control and manage the power grid dispatching data, and under the guidance of this method, the power grid hierarchical dispatching shows a smoother output characteristic as a whole.

4. Conclusion

The basic principle and working characteristics of electrochemical energy storage are studied, the objective function and constraints of active distribution network scheduling optimization with electrochemical energy storage are analyzed, the regional regulation strategy based on power deviation and standby power is discussed, and the simulation analysis is given, which has certain reference significance. Due to the limited time and energy, the characteristic analysis of electrochemical energy storage is not thorough enough. The simulation analysis is not comprehensive enough, the solution of the optimal value based on the objective function and constraints needs to be studied, and the regional power regulation strategy needs to be expanded. In addition, electrochemical energy storage is only a part of active distribution network. The working principle, basic characteristics of other links of active distribution network and their role in hierarchical and zoning operation scheduling need to be discussed and studied, and will be further deepened and improved in the future.
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