Research on Optimal Dispatch of Active Distribution Network with Distributed Energy Storage

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Abstract. In order to alleviate the energy crisis and improve environmental quality, the efficient use of renewable energy has become a development trend. In order to integrate various types of distributed generation (Distributed Generation, DG), to achieve large-scale renewable energy consumption, improve the utilization efficiency of distribution network resources, and improve the reliability and power quality of users, active distribution network technology has come into being, and it has attracted more and more attention from researchers. As an important part of the active distribution network, distributed energy storage has the advantages of centralized energy storage that can achieve independent control and "plug and play", wide geographical distribution, flexibility and convenience. At the same time, because energy storage has power and the dual characteristics of load, using it to participate in the optimal dispatching of the distribution network, can effectively reduce the operating cost of the distribution network and to a certain extent realize the peak cut and valley filling of the power grid, and improve the power quality of the distribution network.

1. Introduction
At present, most of energy storage used in the research of economic optimal dispatch of active distribution networks is configured and dispatched according to the centralized energy storage mode. There are few researches on optimal dispatch of distributed energy storage. On the basis of fully considering the characteristics of distributed energy storage, formulating reasonable scheduling and coordinated optimization strategies for multi-energy storage are the two key points in the research process of distributed energy storage optimization scheduling, and also two major difficulties. Therefore, in this paper, the active distribution network with various controllable and uncontrollable DGs and distributed energy storage is taken as the research object. By formulating a reasonable distributed energy storage coordination scheduling strategy, the optimal scheduling research of distributed energy storage is carried out[1]. Distributed energy storage is an important part of the active distribution network. The dual characteristics of load and power supply can be controlled by coordination and optimization, which can effectively improve the operation economy of the active distribution network while reducing network losses and improving power quality[2-3].
2. Research status of distributed energy storage and its applications

2.1. Research status of energy storage technology development
At present, there are many types of energy storage used in active distribution networks. According to the characteristics of energy storage, energy storage can be divided into energy-type energy storage such as pumped storage, battery storage, etc. with large energy density and large storage capacity and power-type energy storage such as flywheel energy storage, super capacitor energy storage with large power density, fast response speed, and frequent charge and discharge [4]. From the perspective of energy conversion, energy storage can be divided into four types: physical energy storage, electrochemical energy storage, electromagnetic energy storage, and phase change energy storage [5]. The following is a comparative analysis of the working principles and characteristics of several common energy storage. The comparison results are shown in Table 1:

| Characteristic | Pumped Hydro | Flywheel Energy | BatteryEnergy | Super Capacitor |
|----------------|--------------|-----------------|---------------|----------------|
| Energy Density(Wh/kg) | >100         | 5~50            | 20~100        | 1~10           |
| Power density (W/kg)   | >200         | 180~1800        | 50~200        | 7000~18000     |
| Cycle life (times)     | >10⁶         | 10³             | 7000~18000    | >10⁶           |
| effectiveness(%)       | 80           | 90~95           | 80~85         | >95            |
| Response time          | Minute level | <1s             | <1s           | <1s            |
| Application scenario   | System standby | UPS            | Power Quality | High power    |

2.2. Research status of distributed energy storage applications
According to the different application scenarios and access methods of energy storage devices in the distribution network, energy storage technologies can be divided into centralized energy storage and distributed energy storage. Centralized energy storage refers to connecting the entire energy storage system with power from several megawatts to hundreds of megawatts and a continuous discharge time of more than a few hours, which is easy to centrally control and install. [6]. Distributed energy storage refers to the distributed installation of energy storage units with power ranging from several kilowatts to several megawatts and a capacity of less than 10MWh on the DC bus or load side of wind power, photovoltaic and other renewable energy generation with intermittent and fluctuating power[7]. The schematic diagrams of centralized energy storage and distributed energy storage technology accessing the distribution network are shown in Figure 1 and Figure 2, respectively.

Centralized energy storage is mainly used in high-power and long-term power demand scenarios. When used in conjunction with large-scale new energy power stations, it can effectively reduce the instability caused by the connection of new energy power generation to the grid, realize the transfer of new energy and Power system peak-shaving and valley-filling, frequency modulation and accident standby. However, large-scale centralized energy storage has difficulties in implementation and large transmission losses. Insufficient use of DC buses in wind power, photovoltaic and other AC and DC power generation systems, which limits its development to a certain extent.

Compared with centralized energy storage, distributed energy storage is relatively high in cost and is in the stage of preliminary engineering practical application, which requires further in-depth research. However, distributed energy storage technology has the advantages that centralized control energy storage, such as independent control and "plug and play", wide geographical distribution and flexibility, are not available. It is mostly used to provide short-term voltage and power support for the system.
In addition, as can be seen from FIG. 2 and FIG. 3, distributed energy storage can also be divided into two system structures according to their access locations. In Figure 2, the energy storage units 1 and 2 are directly connected in parallel to the DC bus side of the new energy distributed generation to support the DC bus voltage; in Figure 3, after the DC/AC converters are separately configured on the output terminals of the energy storage units 1 and 2, the energy storage is connected in parallel to the distributed generation AC side to achieve fast and accurate tracking of the grid-side reference power. At the same time, it realizes decentralized control and adjustment of the output power of each distributed energy storage unit to meet their respective power requirements, thereby improving the flexibility of power scheduling of the entire distributed energy storage system[8].

### 3. Scheduling strategy of distributed power and distributed energy storage

#### 3.1. Distributed power system scheduling strategy

Combined with the core goal of the active distribution network to absorb large-scale renewable energy, we will not reduce the output of wind power/photovoltaic and other renewable energy, and give priority to ensuring its output; for controllable distributed power generation such as micro gas turbines, when the electricity price of the distribution network and the higher-level power grid is higher than the controllable distributed power generation price, the controllable distributed power generation system will be put into operation, otherwise, the controllable distributed power generation system will not be put into operation[9].

In order to reduce the impact of active distribution network power fluctuations on the main grid side, the main network implements a certain range of constraints on the purchase of electricity in the active distribution network based on its own operation and the load forecast value of the distribution network, that is, the power purchased from the main grid in each period of the active distribution network must not be lower than the minimum value or exceed the maximum value. When the load of the active distribution network exceeds the range limited by the main grid side, the active distribution network shall perform the operation of abandoning the power or cutting the load by itself. Therefore, a certain cost of power loss and load shedding are generated[10].

#### 3.2. Scheduling strategy of distributed energy storage system

During periods of high electricity prices, distributed energy storage is in a state of discharge, releasing energy to the distribution network; during periods of low electricity prices, distributed energy storage is in a state of charging, absorbing electrical energy from the distribution network; in the flat electricity price period, if the period before and after the period is a period of high electricity price, in order to maximize the economic benefits of energy storage participation in dispatch, distributed energy
storage will be in a state of charge, if the period before and after the period of low electricity price, the
same. In order to maximize the economic benefits of energy storage participating in dispatching, distributed energy storage will be in a discharged state. In other cases, distributed energy storage will be in a floating charge state, neither charging nor discharging[11].

4. Active distribution network economic optimal dispatch model
The economic optimal dispatch of the active distribution network with distributed energy storage will, on
the basis of ensuring the safe, stable and efficient operation of the system, through various active
control methods, at the same time, the operation and scheduling strategies of various types of controllable DG and distributed energy storage at different time periods are formulated to achieve the efficient distribution of large-scale renewable energy generation by the active distribution network, and at the same time to achieve the economic operation of the entire power grid. In this paper, on the basis of ensuring the consumption of renewable energy generation and the safe operation of the power grid, a day-ahead economic optimization dispatching model is established by taking the operation cost of active distribution network in the whole dispatching cycle as the objective function and taking into account the constraints such as the safe operation of the network.

4.1. Objective function
\[
\min F = \sum_{i=1}^{T} [F_M(t) + F_Y(t) + F_C(t)]
\]  

In the formula, F is the total cost within the system dispatch period T; \(F_M(t)\) is the purchase cost of the active distribution network; \(F_Y(t)\) is the operating cost of energy storage; \(F_C(t)\) is the network loss cost of the active distribution network system.

4.2. Constraints
The optimal dispatch of active distribution network needs to consider the constraints of all time periods in the entire dispatch cycle. Since the optimal dispatch model of the active distribution network in this topic takes energy storage into consideration, in addition to the traditional node voltage constraints and power flow equation constraints, the energy storage capacity constraints and charge and discharge power constraints should also be considered. The constraints are as follows:

4.2.1. Trend constraint of active distribution network.
\[
P_i(t) - \sum_{j=i} \sum_{k=i} P_{DGj}(t) = U_i(t) \sum_{k=i} U_k(t) [G_{ik}(t) \cos \theta_{ik}(t) + B_{ik}(t) \sin \theta_{ik}(t)]
\]
\[
Q_i(t) - \sum_{j=i} \sum_{k=i} Q_{DGj}(t) = U_i(t) \sum_{k=i} U_k(t) [G_{ik}(t) \sin \theta_{ik}(t) - B_{ik}(t) \cos \theta_{ik}(t)]
\]  

That is the power flow balance equation at time t. \(P_i(t)\) and \(Q_i(t)\) is the injected active power and reactive power at node i, \(P_{DGj}(t)\) and \(Q_{DGj}(t)\) is the active and reactive power of wind power, photovoltaic power generation and energy storage at node i; \(U_i(t)\) and \(U_k(t)\) is the voltage of node i and node k, node k is the node connected by i; \(G_{ik}(t)\) and \(B_{ik}(t)\) is the real and imaginary parts of the admittance of the distribution network branch ik; \(\theta_{ik}(t)\) is the phase angle difference of the nodes at both ends of the branch ik.

4.2.2. Node voltage constraint.
\[ U_{\text{min}} \leq U_i(t) \leq U_{\text{max}} \]  
(3)

In the formula, \( U_{\text{min}} \) and \( U_{\text{max}} \) are the lower limit and upper limit of each node voltage.

4.2.3. Constraints on the power purchase of the active distribution network from the main grid.

\[ P_{\text{min}} \leq P(t) \leq P_{\text{max}} \]  
(4)

In the formula, \( P_{\text{min}} \) and \( P_{\text{max}} \) are the maximum and minimum power purchase power from the active distribution network to the main grid, that is, the upper and lower limits of the power purchased by the main grid for each time period.

4.2.4. Energy storage power constraints.

\[ P_{\text{r,ESS,min}} \leq P_{\text{r,ESS}}(t) \leq P_{\text{r,ESS,max}} \]  
(5)

In the formula, \( P_{\text{r,ESS,min}} \) and \( P_{\text{r,ESS,max}} \) are the minimum generating power and the maximum generating power of the \( r \)-th energy storage system, and the charging power of the energy storage system is regarded as the load.

4.2.5. Constraints of remaining energy storage capacity.

\[ E_{r,\text{min}} \leq E_r(t) \leq E_{r,\text{max}} \]  
(6)

\[ E_r(0) = E_r(24) \]  
(7)

In the formula, \( E_{r,\text{min}} \) and \( E_{r,\text{max}} \) are the upper and lower limits of the remaining capacity of the \( r \)-th energy storage.

5. Conclusion

With the deepening of smart grid technology, in addition to generator sets in the active distribution network, originally unschedulable resources such as loads become schedulable, and equipment with high flexibility such as energy storage participates more actively in scheduling to improve system safety, stability, economy. How to efficiently and reasonably coordinate all the available resources in the distribution network and improve the economic, technical and environmental benefits will be a difficult problem for the active distribution network optimization dispatch technology and method in the development of the power grid.

Acknowledgments

This paper was supported by Xi’an Shiyou University Graduate Innovation and Practice Ability Training Project and Undergraduate Training Programs for Innovation and Entrepreneurship of Shaanxi Province (S201910705070).

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