Research on Multi-source Cooperative optimal dispatching of Active Distribution Network

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Abstract. Combined with the operation characteristics of active distribution network, the overall architecture of multi-source cooperative optimal dispatching is proposed. The key technologies, such as multi-aspect data association, fast simulation of active distribution network, multi-source cooperative optimal scheduling strategy, and evaluation of multi-source cooperative optimal scheduling policy, are studied. The dynamic optimal scheduling target of each unit running state is proposed, and a time dimension optimization scheduling strategy for pre-day and intra-day is proposed. The evaluation method of optimal scheduling strategy is studied. Finally, the proposed multi-source cooperative scheduling scheme of active distribution network is verified by MATLAB simulation in a typical node network.

1. Introduction
With the large-scale access of distributed energy sources, such as distributed generation, DG, flexible load, FL, Electric vehicle, EV, energy storage system, ESS, etc., in the distribution network, distributed power generation (distributed generation, DG), flexible load (flexible load, FL), electric vehicle (Electric vehicle, EV), energy storage system (energy storage system, ESS), etc. The traditional distribution network has evolved into an active distribution network (active distribution network, AND) with controllable and adjustable resources. As the development trend of distribution network in the future, active distribution network is an important technical means to realize wide access and high penetration of distributed generation in distribution network[1]. An important characteristic of active distribution network is that the distributed generation unit, electric vehicle unit, energy storage unit and micro-grid unit are controllable for the operators of distribution network. This will give a richer content to the active distribution network dispatching operation, which can self-adaptively and actively manage all kinds of distributed energy access, thus improving the absorption capacity of wind power and photovoltaic, and reducing the spare capacity of power generation units. Optimize the operation mode of the power grid, strengthen the ability of interaction with the demand side and so on, to ensure the security, economy and efficient operation of the distribution network.

In the active distribution network for distributed power generation energy management and optimal scheduling: Aiming at the problem of active distribution network dispatching and considering the influence of distribution network loss, a pre-day optimal dispatching model is put forward by Professor Dou Zhenhai, a domestic scholar, taking the maximum benefit of power company as the optimization goal[3]. Borghetti A, a foreign scholar, takes into account the benefit and cost of distributed power generation, and constructs a short-term two-objective optimization model of active distribution network to reduce the voltage deviation brought by the distribution network connected by distributed generation[4]. Because of the single time scale optimization calculation can not fully reflect...
the active distribution network, flexible operation characteristics: Pilo F, a foreign scholar, has proposed a short-term scheduling method, which consists of two stages. The first stage is used to optimize the pre-day scheduling of the second day of distributed power generation. The second stage is the midday scheduling per 15min adjusted to meet operational requirements and distribution network constraints\(^6\). In the aspect of optimal dispatching strategy of active distribution network for intermittent renewable energy consumption problem: Scholars at home and abroad mainly study from the point of view of source-load interaction, source-net-load interaction and energy storage equipment combined with the wind force, through the control of flexible load. Control of charging and discharging power of energy storage devices or coordinated control of "charge-storage" to accommodate large-scale access to renewable energy using the complementary characteristics of flexible loads and energy storage\(^7\)\(^-\)\(^10\).

2. Active Distribution Network Architecture

The main components of the scheduling architecture are as follows:

1. Supply-side resources: the two kinds of resources, including ESS and CDG.
2. Demand-side resources: mainly include EV cluster and flexible load. The EV cluster contains the EV power battery and its supporting charging piles which participate in the demand response. Flexible load consists of two types: shedding load and transferable load.
3. Renewable energy source: distributed wind generation, photovoltaic power generation.
4. ADN dispatch center: ADN scheduling center performs reasonable configuration of the schedulable resources and ensures the optimal operation of the ADN through coordinated control.

![Figure 1 Multi-source cooperative optimal dispatching architecture for active distribution network](image)

\[ C_{ESS,j} = \sum_{i=1}^{n} \left( C_{eo,i} P_{ESS,i} + \frac{C_{eo,i}}{365 \times 24 L_i} \right) \Delta t \]  \( (1) \)

In the formula, \( C_{ESS,j} \) The scheduling cost of the energy storage device in one cycle \( j \); \( C_{eo,i} \) The unit power operation and maintenance cost of the energy storage unit; \( P_{ESS,i} \) The energy charge/discharge power of
2.1.2. Controllable distributed power dispatching cost
Similar to ESS, it is expressed as follows:

\[ C_{CDG,m} = C_{fuel,m} + C_{om,m} + C_{dp,m} + C_{em,m} \]  

In the formula, \( C_{CDG,m} \) Scheduling cost of controllable distributed power supply m; \( C_{fuel,m} \) Fuel cost; \( C_{om,m} \) Operation and maintenance costs; \( C_{dp,m} \) Depreciation expense; \( C_{em,m} \) Environmental costs.

2.1.3. Flexible load scheduling cost
The calculation of flexible load scheduling cost uses a step compensation mechanism to encourage flexible load users to participate in the demand side response\(^{(1)}\), as shown in Figure 2. The compensation mechanism repeatedly superimposes the compensation cost of the previous step when calculating the compensation cost. As the load reduction of the flexible load user increases, the gains obtained by the user gradually increase, which stimulates the enthusiasm of the user to participate in the power grid dispatching.

\[ C_{ID,sub}^i = \begin{cases} 
C_i P_{D,x} & P_{D,x} \leq P_D^1 \\
C_i P_D^1 + (P_{D,x} - P_D^1)C_2 & P_D^1 < P_{D,x} \leq P_D^2 \\
\sum_{k=1}^{i-1} C_k P_D^k + (P_{D,x} - P_D^i)C_{i+1} & P_D^i < P_{D,x} \leq P_D^{k+1} 
\end{cases} \]

In the formula, \( C_{ID,sub}^i \) User x compensation for reducing the load; \( P_{D,x} \) The amount of load reduction reported by the user x; \( P_D^i \) User-received level-level load reduction; \( C_i \) The corresponding compensation fee for the k-th stage load reduction amount.

2.1.4. Electric vehicle scheduling cost
Electric vehicle will cause losses to users, such as battery loss, when participating in distribution network dispatching. Therefore, in the EV scheduling cost, this paper only considers the cost of compensation to the user. Specifically expressed as:

\[ C_{EV,sub}^i = \sum_{i=1}^{H} P_{EV,i}^i I_{EV,sub} \]

In the formula, \( C_{EV,sub}^i \) Compensation fee for electric vehicle i participating in dispatching service; \( H \) The number of scheduling periods within a scheduling period; \( P_{EV,i}^i \) Discharge power of the i-th EV at t period; \( I_{EV,sub} \) The compensation price involved in the dispatch.
3. Multiple time scale scheduling model

This paper establishes a multi-time scale scheduling strategy. On the time scale, the optimal dispatching of the active distribution network is divided into two stages: pre-day and intra-day, and the corresponding energy management strategy is worked out. The corresponding optimal scheduling model is established. The results of pre-day optimal scheduling are transferred to the intra-day optimal scheduling model. The pre-day scheduling plan corresponding to the time point is taken as the state value and the curve of intra-day optimization is given by means of rolling optimization.

3.1. Pre-day scheduling model

This section aims at the minimum running cost of the scheduling day. This paper only considers the cost of purchasing electricity from the active distribution network, and does not consider the sales revenue of the upper distribution network. Specifically expressed as:

$$\min f_1 = C_{ES} + C_{ES} + C_{R, com} - C_{EV, cd}$$

In the formula,

$$C_{ES} = \sum_{i=1}^{M} P_{ES}^i C_{grid}^{i} \Delta t$$

$$C_{R, com} = \sum_{i=1}^{M} (P_{WT}^{i} + P_{PV}^{i} + C_{WT} + C_{PV}) \Delta t$$

$$C_{EV, cd} = \sum_{i=1}^{M} \sum_{j=1}^{k} P_{CDG}^{i,j} C_{grid}^{i} \Delta t$$

In the formula, $P_{cd, i}$ Charging and discharging power for the i-th EV at time t; $P_{WT}^{i}$, $P_{PV}^{i}$ The wind power and photovoltaic power that ADN consumes at time t; $C_{grid}^{i}$ The switching power between ADN and the main network at t time, and the exchange price; $P_{WT}^{i}$, $P_{PV}^{i}$ Wind turbine unit, PV unit power operation and maintenance cost coefficient.

3.2. Intraday rolling scheduling model

Further precise optimization of pre-day scheduling by in-day rolling plan(Schedulable Unit and minimum Adjustment amount of Pre-Day Plan):

$$\min f_2 = \sum_{i=1}^{M} \sum_{j=1}^{k} \alpha_{i,j} [P_{CDG, in}^{i}(t) + P_{WT}^{i}(t) + P_{PV}^{i}(t) - (P_{CDG, out}^{i}(t) + P_{WT}^{i}(t) + P_{PV}^{i}(t))] + \sum_{i=1}^{M} [P_{ES, in}^{i}(t) - P_{ES, out}^{i}(t)]$$

At the same time, by reasonably controlling the schedulable resources, the coordination and tightness between the load curve and the output of the renewable power generation unit can be enhanced, which is conducive to the maximum consumption of renewable energy. Then the consumption rate function is expressed as:
They are the upper and upper limits of the SOC of the EV

The total energy for the i-th EV is

The total load reduction of the flexible load is

The output power of the controllable distributed power source is

In the formula, $P_{\text{RES}}(t)$ is the total generation power of RES at t time.

3.3. Constraint condition

3.3.1. Power balance constraints

In the formula, $\sum_{t=1}^{k} P_{\text{WT}}(t) + P_{\text{PV}}(t) + \sum_{t=1}^{k} P_{\text{RES}}(t) - \sum_{t=1}^{k} P_{\text{LOSS}}(t) - \sum_{t=1}^{k} P_{\text{ESS}}(t) + \sum_{t=1}^{k} P'_{\text{EV},i} = P'_{\text{L}}$

The upper and lower limits of the output power of the controllable distributed power source $P_{\text{CDG,m}}$ and $P_{\text{CDG,m}}$ are

The total load reduction of the flexible load at time t, EV cluster charge/discharge amount at time t, $P_{\text{LOSS}}$ Power loss at t time.

3.3.2. EV constraints

It mainly includes upper and lower SOC constraints, charge and discharge power constraints and grid-connected SOC constraints:

In the formula, $S_{E,V,min,i}$, $S_{E,V,max,i}$ are the upper and lower limits of the SOC of the EV cluster; $P_{j,i}, P_{d,i}$ are the rated charging and discharging power values of the i-th EV; $\eta_c, \eta_d$ are the charge and discharge efficiency; $S_{B,i}, S_{E,i}$ are the initial value and expected value of the SOC of the i-th EV; $E_{i,j}$ is the total energy for the i-th EV battery.

3.3.3. Energy storage device constraints

The upper and lower limits of the SOC of the energy storage device, the charge and discharge power constraints are similar to the EV constraints. The energy storage device SOC at the start of the scheduling is defined to be equal to the energy storage device SOC at the end of the scheduling.

3.3.4. Controllable distributed power constraints

In the formula, $P_{\text{CDG,m}}^{\text{max}}, P_{\text{CDG,m}}^{\text{min}}$ are the upper and lower limits of the output power of the controllable distributed power source $m$; $P_{\text{CDG,m}}^{\text{max}}, P_{\text{CDG,m}}^{\text{min}}$ are the output power of the controllable distributed power source is time t and t-1 respectively; $R_{\text{Lim,m}}$ is the up and down the power limit.

3.3.5. Flexible load constraints

In the formula, $P_{D,i}^{\text{max}}, P_{D,i}^{\text{min}}$ are the upper and lower limits of the load x can be reduced.
3.3.6. Node voltage constraint

\[ U_{i_{\text{min}}} \leq U_i \leq U_{i_{\text{max}}} \]  

In the formula, \( U_{i_{\text{max}}}, U_{i_{\text{min}}} \) They are the upper and lower limits of the simulation node voltage.

4. Improved Imperial Competition Algorithm

The Imperial Competition algorithm (ICA) is an evolutionary algorithm based on imperialist colonial competition mechanism proposed by Atashpaz-Gargari and Lucas in 2007. It is a socially-inspired stochastic optimization search method. The algorithm makes use of the colony moving to the imperialist countries to carry out local search, that is to say, the local search ability of the algorithm can be guaranteed by mining in a better region. In traditional ICA, imperial competition reflects the interaction of information between empires. However, in each iteration, imperial competition only assigns the weakest colonies to the strongest empires, a process that has little effect on the size of each empire. Multiple iterations are needed to reflect the lack of more effective information exchange between empires, which can lead to precocity.

In this paper, we introduce a differential evolution operator to improve the differential of ICA and construct the DE-ICA model. The optimization process is shown in figure 4 below:

5. Example simulation

5.1. Basic data

In this paper, the network example system shown in figure 6 is selected. Renewable energy generation systems in the system include photovoltaic (PV) and wind turbine (WT). Controllable micro-power supplies include diesel engines (DE), micro-turbine (MT) and fuel cell (FC), energy storage unit has battery pack (battery, Bat). The capacity of the photovoltaic power generation system is 150kW, the capacity of the wind power generation system is 150kW, and the maximum charge and discharge power of the battery pack is 160kW. In the example, the unit length impedance of the lines between nodes is 0.64+j0.1Ω/km. The energy consumption cost curve of each controllable micro-power supply is shown in figure 7. Other relevant information of each controllable microsource is shown in Table 1.
This example implements the policy of time-sharing electricity price. The valley is 00:00-08:00, the usual sections are 08:00-11:00, 16:00-19:00 and 22:00-24:00, the peak periods are 11:00-16:00 and 19:00-22:00. The timesharing price applied in the calculation example is shown in Table 2.

Figure 6 Example system structure diagram

Figure 7 Energy consumption cost curve of controllable micro power supply
Table 1 Information on controllable micropower sources

| Controllable microsource type | DE | MT | FC |
|-----------------------------|----|----|----|
| Capacity (kW)               | Lower limit | 3  | 5  | 4  |
|                            | Superior limit | 60 | 80 | 70 |
| Operational maintenance coefficient (RMB / kW) | 0.0859 | 0.0401 | 0.0286 |
| Startup cost (RMB)          | 1.5 | 3  | 2  |
| Minimum continuous running time (h) | 2  | 2  | 2  |
| Minimum continuous outage time (h) | 1.5 | 2  | 2  |
| Active output rate change limit (kW/h) | Rate of increase | 120 | 140 | 120 |
|                             | Rate of decline | 140 | 160 | 160 |

Table 2 Purchase and Sale Price

| Project                  | Peak period | Flat time | Valley time |
|--------------------------|-------------|-----------|-------------|
| Purchase electricity     | 1.56        | 0.7       | 0.43        |
| Sale of electricity      | 1.28        | 0.54      | 0.32        |

A total of 14 node loads are presented in the example system, and the load information is shown in Table 3, where the power factor of each node load is assumed to be constant.

Table 3 Examples of node load related information

| Load node number | Household load (kW) | Industrial load (kW) | Load power factor |
|------------------|---------------------|----------------------|-------------------|
| 1                | 0                   | 15                   | 0.9545            |
| 2                | 6                   | 16                   | 0.9487            |
| 3                | 12                  | 0                    | 0.9751            |
| 4                | 0                   | 20                   | 0.9751            |
| 5                | 10                  | 0                    | 0.9979            |
| 6                | 15                  | 0                    | 0.9615            |
| 7                | 12                  | 24                   | 0.974             |
| 8                | 0                   | 12                   | 0.9781            |
| 9                | 7                   | 0                    | 0.9417            |
| 10               | 9                   | 0                    | 0.9654            |
| 11               | 8.8                 | 0                    | 0.9772            |
| 12               | 12                  | 0                    | 0.9487            |
| 13               | 10                  | 0                    | 0.9728            |
| 14               | 4                   | 0                    | 0.979             |

Set the number of EV clusters participating in ADN scheduling to 25. For micro gas turbine, energy storage device participates in dispatching in every dispatching period, flexible load takes part in dispatching during peak and low period of load (transferable load), and the time of entering and leaving network of EV cluster conforms to normal distribution. It participates in scheduling at 17:00pm~9:00am.

5.2. Result analysis

By using the improved Imperial Competition algorithm to simulate the above node graph, as shown in figure 8 below, it can be obtained that, in the multi-time scale dispatching of active distribution network, the flexible load, energy storage, controllable distributed power generation can be obtained. The effective dispatching of EV cluster can effectively cut the peak and fill the valley of the distribution network load, and the peak and valley difference of the net load curve can be further reduced. At the same time, a series of operations such as centralized dispatching of energy storage and EV cluster, concentrated discharge at peak time, centralized charging at valley time, charging and storing energy when photovoltaic and wind power are surplus have effectively improved the
absorption rate of wind power and photovoltaic as shown in figure 9. At the same time running cost reasonable reduction as shown in Table 4.

| Project                  | Before optimization/RMB | After optimization/RMB |
|--------------------------|-------------------------|------------------------|
| Objective function       | 46124.86                | 43154.75               |

Table 4 optimal cost results of active distribution network

At the same time, the convergence of the differential evolution of the Empire competition algorithm, the improved particle swarm algorithm and the improved genetic algorithm are compared. The results are shown in figure 10, which proves that the algorithm has certain feasibility. Compared with the other two types of algorithms, the Imperial competition algorithm can obtain the optimal result in a short time, with fewer iterations and higher precision.

6. Conclusion
The aim of this paper is to reduce the operation cost of active distribution network and to improve the renewable energy consumption rate in order to solve the problem of multi-source cooperative optimal dispatching in active distribution network. An active distribution network optimal dispatching method based on multiple time scales and a real time modified optimal dispatching strategy are proposed. In the further simulation, it is verified that the model can effectively cut the peak and fill the valley of the active distribution network, reduce the operation cost and increase the absorption rate of renewable energy. The validity and correctness of the model are verified. At the same time, a differential evolution ICA is proposed and verified by simulation. The results show that the proposed method can be well adapted to the model proposed in this paper. At the same time, compared with AGA and
APSO, it is found that the ICA used in this paper has the advantages of less iterations and higher precision. Simulation also proves the feasibility of the algorithm.

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