The Researches on Optimal Operation of Microgrid Based on Benders Decomposition

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ABSTRACT

One of the important parts of the research on micro-grid energy management is the study of economic operation. The purpose of the research is to meet the load demand and to realize the optimal cost and the maximum benefit. This paper purposes an economic scheduling strategy of microgrid based on the Benders Decomposition method, takes the operation constraints under two microgrid operation modes into consideration, decomposes the problem into the main problem with the minimum operation cost and the sub-problem with the minimum islanding unbalanced power, attaches the Benders cut resulting from the island's unbalanced power generation to the constraints of the main problem, minimizes the amount of unbalanced power in the island's microgrid by continuous iteration.

Keywords: Microgrid, economic dispatch, Benders Decomposition, unbalanced power.

INTRODUCTION

In order to obtain the optimal economic operation plan of the micro grid, it is necessary to set up the economic operation model of each micro grid and to develop a reasonable optimization algorithm according to the characteristics of the micro grid. The objective function and constraints are two components of the economic operation mode of micro grid. To realize the minimum investment cost of micro-grid and maximum of comprehensive benefits are often the goals of micro-grid operation. Active power balance constraints, reactive power balance constraints, schedulable distributed generation output constraints, energy storage capacity constraints are often the constraints of the optimal operation of the micro grid. The nonlinear programming method is a conventional algorithm for the optimization algorithm of micro grid. For solving more complex optimization problems,
intelligent algorithm has become a hot research object. Some of the commonly used intelligent algorithms include: neural network algorithm, genetic algorithm and so on. At present, there are two categories of studies on the economic operation of micro grid at home and abroad. The details are as follows. The first category: The research on economic operation of micro components based on certain components. The main contents are as follows:

(1) Establishing a model of energy storage device to study its impact on the economic operation of micro grid. Ding Ming et al. has established the economic operation optimization model of micro grid system that contains sodium-sulfur battery energy storage.[1]

(2) The impact of CHP’s access on the operation mode of micro grids is that it requires both active balance and thermal (cold) balance in operation [2,3];

(3) From the load side, studying the impact of schedulable loads such as electric vehicles on the economic operation of micro grid. In recent years, the interaction between electric vehicles and power grids has received much attention. It is because of its flexibility and access to electric vehicles that can reduce the operation cost of the micro-grid and save the investment of static energy storage devices in the micro grid[4].

The second category: The research on economic operation of micro grid based on operation target. The main research contents are as follows:

(1) In the perspective of investors, taking the economic and environmental protection optimization fully into account to achieve a good planning of the micro grid.

(2) In the perspective of users, taking the economic and reliability optimization of the micro grid fully into account [5]; taking the reliability and economy power supply of users as the main optimization indicators.

(3) Taking the possible risk of spin-off and load loss in micro grids fully into account [6] to avoid its fluctuations that may happen in the isolated islands or during the output of micro sources.

Most of the existing researches on economic operation imitate the solution models and algorithms of large power grids or distribution network with distributed power, and often do not consider the characteristics of the micro grid itself. For example, the output intermittent, energy storage device characteristics, schedulable load characteristics of some distributed power; some research only consider the grid-connected or micro grid optimization operation in the islanding operation mode; or the algorithm used is too complicated, the robustness is poor, especially the undesirable convergence has little prospect in practical application.

OPTIMAL OPERATION STRATEGY OF ISLANDING OPERATION
CONSTRAINT OF MICRO-GRID

Since the main problem and the sub-problem are linked together by using the method of Benders Decomposition and the final optimization result is closely related to the micro grid operation strategy and islanding allowable operating time, this section first introduces the method of the Benders Decomposition, then proposes micro grid operation strategy based on the Benders decomposition. microgrid architecture is shown in Figure 1.
Figure 1. Micro Grid architecture.

Benders Decomposition Method

The core of the Benders decomposition method is to separate the subproblem from the main problem in parallel and solve them mainly by returning a series of subproblem solutions to the main problem through the Bendez cut. This method has already been implemented in the power system \[7\].

The basic principle of Benders decomposition is as follows, for a mixed programming problem \( P \) as follows:

\[
\begin{align*}
\min & \quad c^T x + f(y) \\
\text{s.t.} & \quad Ax + F(y) \leq b \\
& \quad x \geq 0, y \in S
\end{align*}
\]

(1.1)

Where \( y \) is a complex variable and the entire constraint matrix contains \( y \), when \( y \) is fixed, the subset of variables \( x \) is completely independent; \( A \) is a coefficient matrix; \( c \) and \( b \) are coefficient vectors; \( f(y) \) is a function of variable \( y \); \( S \) is a feasible set of \( y \).

Benders Decomposition first selects a feasible variable \( y \) fixed as \( \tilde{y} \) then solve the sub-problem \( P1 \):

\[
\begin{align*}
\min & \quad c^T x \\
\text{s.t.} & \quad Ax \leq b - F(\tilde{y}) \\
& \quad x \geq 0
\end{align*}
\]

(1.2)

Applying duality principle of linear programming to solve the dual problem \( P2 \) of \( P1 \) Problem:

\[
\begin{align*}
\max & \quad [b - F(\tilde{y})]^T u \\
\text{s.t.} & \quad A^T u \leq c \\
& \quad u \geq 0
\end{align*}
\]

(1.3)

Where \( u \) is the dual variable of problem \( P1 \).

Given the upper bound: \( U_u = [b - F(\tilde{y})]^T u \) + \( f(\tilde{y}) \).
After solving the sub-problem P2, the original problem P can be written as follows:

\[
\min \{\max \{[(b-F(y)]^T u | u \leq c, u \geq 0\} + f(y), y \in S\} (1.4)
\]

Then P31 is written as the following pole form problem P32 through transformation:

\[
\min \{f(y) + \max \{[(b-F(y)]^T u, i = 1, 2, \cdots, m\} y \in S\} (1.5)
\]

Introducing any new variable z, the above main problem can be written as follows P3:

\[
\begin{align*}
\min & \quad z \\
\text{s.t.} & \quad z \geq [(b-F(y)]^T u_i + f(y) \quad i = 1, 2, \cdots, m \\
& \quad y \in S
\end{align*}
\]

(1.6)

Given the lower bound: LB = \min z.

To sum up, Benders Decomposition method is used to decompose the original optimization problem P into sub-problem P2 and main problem P3, and modify the upper and lower bound UB and LB of the system through repeated iterative processes. When UB = LB, the optimal solution can be obtained.

**The Optimal Operation and Decomposition Strategy of Microgrid**

Figure 2 depicts the flow chart of the microgrid optimization strategy. The optimization problem is decomposed into the main problem under grid operation and the sub-problem under island operation.

![Figure 2. The optimization strategy flow chart of microgrid.](image)

The optimal variables of main problem are: start - stop state of the unit, the schedulable output, the charging and discharging state and capacity of energy storage battery, schedulable load operation plan, interaction states of the main network and micro-grid energy. The subproblem is mainly used to test the adequacy of microgrid in islanding operation and to ensure that the load cannot be powered off during the islanding operation. If islanding is not
feasible after the primary grid fails, that is to say the microgrid does not have sufficient backup capacity for local loads, a constraint cut 1 based on the start-stop of unit, charging-discharging strategy of battery, serve as a new constraint on the main problem that will be used to correct the current optimization scenario. Cut1 indicates that the energy deficit problem of subproblems can be solved by adjusting the start-stop strategy of the generator set and the charging-discharging strategy of energy storage. This is corrected from the power supply end. The revised optimization solution will be tested again in the next islanding problem until it can successfully operate in all scenarios.

However, in some scenarios, the modification of the start-stop strategy or the charging-discharging strategy of the storage battery does not provide the energy to satisfy the island adequacy requirement. In this case, the cut2, which is based on the constraints of the scheduled load runtime, serves as a new constraint on the main problem to correct the current optimization scenario. Cut 2 shows that in addition to the start-stop strategy of the generator or the charging-discharging strategy of the energy storage battery, adjusting the operation period of the schedulable load operation period can also solve the insufficient energy problem of subproblems, such as reducing the power consumption pressure when the schedulable load in the power peak is transferred to the valley. Obviously, this would affect the user satisfaction by adding cut 2 to the constraint of the main problem and adding a penalty of user satisfaction to the objective function of the main problem.

Cut2 is modified from both the power and load sides, when islanding operation is feasible in all scenarios, then it will get the final operational scheme [8].

The main problem determines the start-stop strategy of schedulable units and the charging-discharging strategy of storage battery. In the subproblems, the above two strategies are unchanged. The present microgrid load requirements, price information of the PCC point can be determined on the basis of ensuring a certain degree of accuracy.(In the case that microgrid is connected to the grid, the power is sold to the main network side when the internal power supply is in surplus; In the case of insufficient internal power supply, power is purchased from the main network side).

Optimization scheme is aimed at the present schedule. Assuming that the scenario within 1h is unchanged, each optimization scheme has to go through 24 optimization calculations. In fact, as long as in the accurate prediction period, each optimization cycle can be greater than 1 day. The reason why choose 1 day as the optimization cycle is that the market price information can be accurately delivered to the main control unit of microgrid, and it is also easy to track the energy storage system charging-discharging states.

**CALCULATION EXAMPLE ANALYSIS**

This paper uses a modified European low-voltage microgrid [9], the network structure as shown below:
The calculation example system includes a wind turbine WT, a photo voltaic generator PV, a CHP gas turbine, diesel generator DG, a storage battery BAT. A variety of specific parameters of the unit are shown in Table 1:

Energy storage battery capacity is 10MW · h, charging-discharging power range is 0.4MW-2MW and the minimum charging - discharging time is 5h.

<table>
<thead>
<tr>
<th>Unit abbreviation</th>
<th>Unit type</th>
<th>Cost Coefficient (yuan/MWh)</th>
<th>nominal power range (MW)</th>
<th>Minimum running/shut-off time (h)</th>
<th>Power increment/decrement in unit time (MW/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT</td>
<td>NQ</td>
<td>0</td>
<td>0-1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PV</td>
<td>NQ</td>
<td>0</td>
<td>0-1.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CHP</td>
<td>Q</td>
<td>162.7</td>
<td>0.8-6</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>DG</td>
<td>Q</td>
<td>366.5</td>
<td>1-10</td>
<td>3</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table I. Generator set parameter (Q: scheduable unit combination, NQ: unscheduable unit combination).

**Microgrid Operation Optimization Considering Grid-Connected Constraints**

According to the optimization model of grid-connected microgrid mentioned in this paper, the optimization results of microgrid in one day are shown in Figure 4, and the optimization results of schedulable load optimization are shown in Figure 5:
It can be seen from Figure 4, the comparatively economical diesel generators work 24 hours a day; The CHP gas turbine is turned on when the market price is greater than the cost coefficient of the CHP gas turbine; In the 00:00-06:00 period, the market price is lower, the battery will charge, while in the 16:00-20:00 period, the market price is higher, the battery will discharge. Therefore, it can be seen that the start-stop state of the schedulable unit and the charge-discharge status of the storage battery only depend on whether the market price is lower or higher than the cost coefficient of each unit.

It can be seen from Figure 5 that the working period of the schedulable load is the initial working period because only the power supply strategy of the schedulable unit and the storage battery needs to be adjusted during the optimization of the microgrid which only considers the grid-connected operation constraints, then it can satisfy the basic requirement of constraint without changing the scheduling strategy of load side.
After considering the constraint of islanding operation, in the hourly optimization calculation, we must consider the constraints that the microgrid will follow after it enters the standalone operation. If the islanding operation cannot be sustained, then the generated Bender cut shall be added to the main problem of grid-connected operation to correct variables. Optimized schedulable unit output and energy storage charging and discharging capacity are shown in Figure 6:

![Figure 6](image)

Figure 6. Microgrid optimization results considering the islanding operation constraint.

It can be seen from Figure 6, in order to balance the unbalanced power in the island, CHP gas turbines need to be operated under uneconomical conditions. Energy storage discharging time also extends from 5h in scenario 1 to 7h in scenario 2. However, during the optimization of Case 2, no cut2 was generated and there was no significant change in the power plan of the schedulable load. This shows that when applying the 24-1 islanding operation criterion, it only needs to adjust the unit combination strategy and the charging and discharging of the storage battery strategy to meet the objective function of sub-problems. In addition, under the scenario 2, the electricity purchase of microgrid from the main network was reduced by 11.13MWh due to the increased use of local power. Considering the islanding operation constraints, the total cost of microgrid operation is 69,800 yuan per year, which is 4.4% more than the scenario 1, mainly for maintaining the sustainable operation of the island.

CONCLUSION

By adjusting the unit combination, the output of schedulable generation, the charging and discharging state of the energy storage battery, the power consumption period of schedulable load, microgrid purchase and sale electricity and period from the main network side, the economy of microgrid has been significantly improved. At the same time, after taking into account the island optimization problem, the reliability of the microgrid is landing operation is further guaranteed. Case study shows that:
1) After considering the problem of islanding optimization, the adequacy of the microgrid islanding operation has been guaranteed. Although the operating cost of microgrids has increased, the proportion of increase to that of operation costs is very small.

2) After considering the $T-\tau$ islanding operation criterion, as the duration of islanding operation increases, it is necessary to reduce the imbalanced power during islanding operation through load side response. The larger the $\tau$, the higher the operating cost of the microgrid.

3) The Benders Decomposition method compared with the traditional integrated calculation method, its significant feature is that it decomposes the complex calculation into many simple calculations, which improves the calculation speed.

REFERENCES


