Optimization Strategy for Day-ahead Scheduling of Micro-grid Based on the Cost-effective of User Side

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Abstract. Micro-grid, with its important role in coordinating and controlling between distributed generations and the grid, has received widespread attention. Due to the randomness and fluctuation of the new energy output, the access to new energy has adversely affected the economic operation of micro-grid-containing power systems. However, if a reasonable ratio of the new energy is determined when developing the day-ahead scheduling strategy of the micro-grid, it can effectively ensure the economic benefits during the operation. This paper proposes a day-ahead scheduling optimization for micro-grid based on the cost-effective of user side. Various constraints related are taken into consideration, such as charging and discharging margins of storage devices, battery state of charge and generation capacity of the new energy, and the capacity of the electric transmission line. The model is constructed with the goal of minimizing the power supply costs. The prices of time-of-use electricity and the issues of energy exchange between the micro-grid and the external power grid are included as well. As for the method, Cplex is used for its good performance in solving mathematical programming models combined with the operation data of the micro-grid, hence, an optimized day-ahead scheduling of the micro-grid would be generated.

1. Introduction

At present, China’s new energy grid-based approach to consumption can be broadly divided into two categories. One is the concentrated delivery, the other one is the local consumption. According to the data from the National Energy Administration, by the end of 2017, the cumulative installed capacity of wind power and solar power in China reached 164 million and 130 million KW. The high proportion of renewable energy access poses new challenges to the safe and stable operation of the power grid. If the new energy is consumed locally, it will be unified with the load and energy storage devices to form a micro-distribution system, which is called "micro-grid". To a certain extent, the micro-grid can reduce the adverse effects of distributed energy access on the grid. Although the micro-grid is less than the large-scale grid, it has several advantages. One of those is its internal application of wind, light, storage for joint power generation. The others include the excellent economy and the resulting environmental benefits. Due to these advantages, micro-grid has been further promoted in the power system. Therefore, the study of scheduling of micro-grid becomes significant.

In [1], it included the wind power in the industrial micro-grid, which suppressed the load fluctuation as well as reducing the power generation cost of the micro-grid. However, it did not consider the complementary cooperation of other new energy sources. In [2], Alternating Direction Method of Multipliers (ADMM) was used to completely decouple the various regions in the micro-grid, hence to economically dispatch the interior of the micro-grid. But it did not take the energy exchange between
the micro-grid and the external power grid into account. According to [3], the load model in the micro-grid was carefully classified, in order to minimize the daily operating cost of the system. Based on which, [3] formulated the corresponding scheduling strategy. However, the effect of the transmission capacity of the line on the power exchange was not considered, though the bi-directional power flow between the micro-grid and the external power grid was. Literature [4] fully considered both the power exchange and the role of power market and then proposed a profit-optimal scheduling strategy based on game theory. But the process of energy storage participation was simplified.

In order to give full play to the regulatory capacity of new energy, this paper considers the constraints of energy storage battery’s own performance and the transmission capacity of the grid and grid lines. And then, this paper establishes a mathematical model of micro-grid optimal scheduling of micro-grid with the goal of minimizing the average load power supply cost. Using peak-valley electricity prices, micro-grids can charge batteries at the low prices and discharge at the peak ones, hence reduces the costs. Additionally, the optimal ratio of the new energy at different times can be determined, which helps to study the optimal operation strategy of micro-grid under time-sharing electricity price mechanism.

2. Generation of the optimized day-ahead scheduling of the micro-grid

Based on the operation situation of the main network, the whole day is divided into three periods: peak, flat and valley. And the electricity prices are lower in the valley and flat periods and higher in the peak periods[5]. Thus, the micro-grid can use the market to obtain more profit margin, improve the operational efficiency of the micro-grid, and reach a win-win situation between the micro-grid and the main network.

Different scheduling strategies are adopted according to different time periods where the current scheduling moment is located, and different ranges where the battery state of charge is located.

In the cases of full use of renewable energy and abandonment of wind and light, the composition of the load power supply for each period, the total cost of electricity for the whole day, and the load average purchase price are calculated. After a comparative analysis, the cost of optimal conditions for the amount of new energy into the network is determined.

3. Establishment of the optimized day-ahead scheduling of the micro-grid

3.1. The objective function

The objective function is constructed with the goal of minimizing the average load power supply cost, as in (1).

\[ \min \ C = C_{\text{new}} + C_{\text{buy}} + C_{\text{battery}} - W_{\text{sell}} \]  

(1)

The expressions in the above formula:

\[ C_{\text{new}} = \sum_{t=1}^{T} \frac{24}{T} \left( C_{w} P_{\text{plant},t} + C_{v} P_{\text{plant},t} \right) \]  

(2)

\[ P_{\text{plant},t} = P_{\text{well},t} + P_{\text{off},t} + P_{\text{wind},t} \]  

(3)

\[ P_{\text{plant},t} = P_{\text{well},t} + P_{\text{off},t} + P_{\text{wind},t} \]  

(4)

Where: \( C_{\text{new}} \) is the new energy power generation costs; \( C_{w} \) is the cost of wind power generation; \( C_{v} \) is the cost of PV power generation; \( P_{\text{plant},t} \) is the output of wind power at time \( t \); \( P_{\text{plant},t} \) is the output of PV power at time \( t \).

\[ C_{\text{buy}} = \sum_{t=1}^{T} \frac{24}{T} C_{\text{buy},t} P_{\text{buy},t} \]  

(5)

\[ P_{\text{buy},t} = P_{\text{buy},t} + P_{\text{bary},t} \]  

(6)

Where: \( C_{\text{buy},t} \) is the time-of-sale electricity price of the grid; \( P_{\text{buy},t} \) is the power purchased by the micro-grid from the grid, \( P_{\text{buy},t} \) is the power obtained from the grid by the load; \( P_{\text{bary},t} \) is the
power of the storage battery from the grid.

\[ C_{\text{battery}} = \sum_{t=1}^{T} \frac{24}{T} C_{\text{dis}} P_{\text{dis},t} \] (7)

\[ P_{\text{dis},t} = P_{\text{dis},t} + P_{\text{dis},t} \] (8)

Where: \( C_{\text{battery}} \) is the cost of electricity purchase; \( C_{\text{dis}} \) is the battery charge to discharge cost; \( P_{\text{dis},t} \) is the battery discharge power; \( P_{\text{dis},t} \) is the battery power supply to the load; \( P_{\text{dis},t} \) is the battery power supply to the grid.

\[ C_{\text{sell}} = \sum_{t=1}^{T} \frac{24}{T} C_{\text{sell},t} P_{\text{sell},t} \] (9)

\[ P_{\text{sell},t} = P_{\text{sell},t} + P_{\text{sell},t} + P_{\text{sell},t} \] (10)

Where: \( C_{\text{sell}} \) is the electricity sales of micro-grids; \( C_{\text{sell},t} \) is the selling power of the micro-grid; \( P_{\text{sell},t} \), \( P_{\text{sell},t} \), \( P_{\text{sell},t} \) are the sales power of the wind power, PV and battery to the grid respectively.

\[ Q_{\text{LOAD}} = \sum_{t=1}^{T} \frac{24}{T} P_{\text{LOAD},t} \] (11)

Where: \( Q_{\text{LOAD}} \) is the total daily load; \( P_{\text{LOAD},t} \) is the real-time load of micro-grid.

### 3.2. Model constraints

Sections should be numbered with a dot following the number and then separated by a single space:

1) Consider the energy storage battery’s own performance

Charge state upper and lower bound:

To prevent the overcharge and the over discharge of the battery, the state of charge of the battery (SOC, State-of-Charge, which is the ratio of remaining battery capacity to battery capacity) should meet the following constraints[6].

\[ S_{\text{min}} \leq S_{t} \leq S_{\text{max}} \] (12)

Where: \( S_{\text{max}} \) is the upper limit of charge state; \( S_{\text{min}} \) is the lower limit of charge state; \( S_{t} \) is the state of charge at time \( t \).

Charge and discharge state constraints:

Considering the truth of that in the same time interval, the battery cannot be in charge and discharge at the same time, the battery charge and discharge conditions need to meet the following constraints.

\[ X_{t} \cdot Y_{t} = 0 \] (13)

Where: \( X_{t} \), \( Y_{t} \) is a 0,1 variable which representing the charge and discharge status.

Energy state periodic constraints:

Its energy status needs to be equal throughout the scheduling period.

\[ S_{0} = S_{T} \] (14)

Where: \( S_{0} \), \( S_{T} \) is the battery initial and the end of the scheduling cycle SOC state.

Charge and discharge maximum power per unit time constraints:

\[ \begin{cases} 0 \leq P_{\text{cha},t} \leq 0.2E_{b}X_{t} \\ 0 \leq P_{\text{dis},t} \leq 0.2E_{b}X_{t} \end{cases} \] (15)

Where: \( P_{\text{cha},t} \) is the battery charge power; \( P_{\text{dis},t} \) is the battery discharge power; \( E_{b} \) is the battery capacity.

Charge and discharge times constraints:

\[ \begin{cases} \sum_{t=1}^{T} |X_{t+1} - X_{t}| \leq N_{1} \\ \sum_{t=1}^{T} |Y_{t+1} - Y_{t}| \leq N_{2} \end{cases} \] (16)
Where: \( N_1, N_2 \) are the number of battery charge and discharge within a day limit respectively. Consider storage battery charge balance and discharge balance:

\[
\begin{cases}
P_{\text{cha},t} = P_{\text{buy},t} + P_{\text{wb},t} + P_{\text{vb},t} \\
P_{\text{dis},t} = P_{\text{disl},t} + P_{\text{disg},t}
\end{cases}
\]

(17)

Where: \( P_{\text{cha},t} \) is the battery charging power.

2) Consider the tie line transmission capacity

\[
\begin{cases}
P_{\text{buy},t} \leq P_{\text{max}} \\
P_{\text{sell},t} \leq P_{\text{max}}
\end{cases}
\]

(18)

Where: \( P_{\text{max}} \) is the contact line transmission capacity.

3) Consider the balance between loads

\[
P_{\text{w},t} + P_{\text{v},t} + P_{\text{dis},t} + P_{\text{buy},t} = P_{\text{LOAD},t}
\]

(19)

4) New energy consumption constraints

When new energy is completely consumed:

\[
\begin{cases}
P_{\text{w},t} = P_{\text{well},t} + P_{\text{w},t} + P_{\text{wb},t} \\
P_{\text{v},t} = P_{\text{sell},t} + P_{\text{v},t} + P_{\text{vb},t}
\end{cases}
\]

(20)

When new energy can be not completely consumed:

\[
\begin{cases}
P_{\text{w},t} \geq P_{\text{well},t} = P_{\text{well},t} + P_{\text{w},t} + P_{\text{wb},t} \\
P_{\text{v},t} \geq P_{\text{well},t} = P_{\text{sell},t} + P_{\text{v},t} + P_{\text{vb},t}
\end{cases}
\]

(21)

4. Case study

4.1. Parameter settings

To schedule, 24 hours a day will be divided into 96 time periods at 15-minute intervals in this paper. It is known that wind power installed capacity is 250kW, power generation cost is 0.52 yuan / kWh, PV installed capacity is 150kW, and power generation cost is 0.75 yuan / kWh. Disregarding the battery loss, the rated capacity of the battery is 300 kWh, the operating range of the battery SOC is \([0.3, 0.95]\), the initial SOC value is 0.4, the cost from charging to discharging is 0.2 yuan / kWh, the daily number of charge and discharge restrictions is 8 times, and the tie line transmission capacity is 150kW. Amongst them, the prices of each period on the grid side are shown in Table 1.

| Time(h)          | 0:00-7:00 | 7:00-10:00 | 10:00-15:00 | 15:00-18:00 | 18:00-21:00 | 21:00-24:00 |
|------------------|-----------|------------|-------------|-------------|-------------|-------------|
| Sales price      | 0.22      | 0.42       | 0.65        | 0.42        | 0.65        | 0.42        |
| (yuan)           |           |            |             |             |             |             |
| Purchase price   | 0.25      | 0.53       | 0.82        | 0.53        | 0.82        | 0.53        |
| (yuan)           |           |            |             |             |             |             |

4.2. Model solving

The economic operation of micro-grid is a multi-dimensional, dynamic optimization problem with complex equations and inequality constraints. This paper uses Cplex software to solve the model. From the optimization results shown in Fig. 1, due to the full utilization of renewable energy, the PV power supply is not started at the initial stage, and all the load power supply is provided by the wind power. The battery output curve shows that when the battery starts to supply power to the load, the total amount of new energy output generated is less than the load. At this time, wind power, PV, and battery start to supply power to the load. When involving the battery, power supply is still unable to meet the needs, the micro-grid began to purchase electricity from the grid side. At the 60th scheduling
moment, after 15:00, the output of wind power and PV power decreases, and the load start to increase. Only purchasing electricity from the grid can maintain the load balance.

As can be seen from Fig. 2, the battery is already fully charged before the 28th scheduling time, which is before 7:00. At the 56th scheduling time, around 14:00, the storage capacity begins to drop, indicating that the discharge process has started. Combined with Figure 1, the battery begins to supply power to the load in this period. At the 64th scheduling time, at 16:00, it starts to continue charging. From the time-of-use price, it is clear that during this period, the electricity purchase price is at flat and valley moment. And according to the load and the predicted power of renewable energy, in the next period, there is not enough renewable energy to supply the load. What's more, the electricity purchase price is at the peak. Therefore, the battery chooses to charge in the flat and valley period, at 16:00, and to discharge in the peak period. This reflects the battery's role of "energy real-time shift", thereby reducing the cost of purchasing electricity from the external power grid and improving the economic benefits of the micro-grid itself.

Figure 1. Load power supply composition when the renewable energy completely absorbed.

Figure 2. Battery storage capacity when the renewable energy completely absorbed.

Figure 3 is the composition of each period of the power supply when allowing the abandonment of wind and light. PV output is smaller but relatively concentrated in the period when electricity price is higher. The dispatching scheme purchases a large amount of electricity from the grid, and the battery supply to the load only appears when the exchange power of the micro-grid and the grid exceeds 150 kW or the purchase price of electricity is high.

When the wind and light conditions are allowed to abandon, the battery storage capacity is shown in Fig.4. The battery can store PV, wind power and electricity purchased from the grid. It can also choose the storage object after comparing these three prices. When the electricity purchase price is high or when the exchange power of the micro-grid and the grid exceeds 150kW, it meets the precondition of power switching constraint and achieves the goal of minimizing the load power supply cost.

Figure 3. Load power supply composition when new energy not completely consumed.

Figure 4. Battery storage capacity when new energy can be not completely consumed.
Calculated in full use of new energy sources, the total cost of electricity for the whole day is 2212.46 yuan. The average purchase price of electricity is 0.625 yuan/kWh. Under the condition of abandoning the wind and the light, the average purchase price of the load is 0.4837 yuan / kWh, and the total price of electricity supply for the day is 1735.49 yuan. The new energy utilization under the two schemes is shown in Figure 5 and Figure 6. The amount of abandoned wind power is 1498.2 kWh, and the total wind power generation is 2783.1 kWh, with a wind abandonment rate of 53.8%. The amount of abandoned PV power is 408.54 kWh, and the total amount of PV power generation is 629.145 kWh, with a light abandonment rate of 64.94%.

5. Conclusion
In this paper, by considering the performance of the energy storage battery and the related constraints of the transmission capacity between the micro-grid and the grid, a mathematic model of optimized operation of micro-grid is established with the goal of minimizing the average load power supply cost. Meanwhile, the optimal ratio of new energy at different times is determined, and a micro-grid optimization network scheduling program is developed, with the purpose of optimizing the cost of power supply. Moreover, the following conclusions are drawn:
Through the example analysis, it can be seen that compared with the total energy consumption of new energy sources, the micro-grid wind abandonment rate is 53.8%, and the light abandonment rate is 64.94% under the condition of the wind and the light abandonments. However, the power supply cost of the whole day is reduced by 476.97 yuan. The average unit price of load decreases from 0.625 yuan / kWh to 0.4837 yuan / kWh, which is a decrease of 22.6%. Although new energy is not fully utilized, the economy of the system is improved.
Above all, improving the economy during the operation of micro-grid does not mean utilizing as much new energy as possible. The new energy generation capacity, the time-of-use electricity prices, the energy storage battery performance should be involved. In addition, store when the main grid electricity price is underestimated and sell when the price is at the peak. After considering all these conditions, an appropriate scheduling strategy will be developed.

6. References
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