Dispatching Operation Strategy for Microgrids Considering Market Factors

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Abstract. Microgrids, as one of the most essential parts of robust and smart grid, they could integrate distributed energy resources effectively and enhance the penetration of renewable energy. However, the pace of market-oriented reform introduces new problems to the operation of microgrid integrated to distribution networks. Thus, there’s urgent need to bring up with a more flexible and reliable dispatching operation strategy for microgrids. This paper proposes a new dispatching operation strategy with the aim of minimizing the operating cost under market reform. We take the load demand, the power generation cost, feed-in tariff and operation characteristics of distributed generations into full consideration. Finally, there are totally 14 operating modes for typical microgrids which are applicable to different situations. The case study proves its validity. Clearly, results in this paper could provide significant guidelines for microgrid planning and operating.

1. Introduction
The microgrid, as the integration of clean energy, has developed greatly. However, the distributed generations inside microgrids, such as PV (photovoltaics) and WT (wind turbines), own strong volatility. This leads to the volatility of microgrids. Therefore, the microgrid may be possible to be manifested as load characteristics. It is also very likely to show the characteristics of the power source. Needless to say, that introduces great challenges to planning and operation of integrated microgrids[1].

Microgrids contain different types of distributed generations and loads[2]. Paper [3] claimed that the model of integrated microgrid was closely related to its internal power source characteristics, network topology, load characteristics, and control strategy. And the load in the microgrid was divided into dynamic load and static load. In [4], the power source was roughly divided into inverter-type micro-sources and rotary motor-type micro-sources. Papers [5-8] established dynamic models of micro-sources, such as GT, WT and PV, and analysed their characteristics. The small-signal model of the microgrid was studied in [9-11].
However, above listed research results are mostly based on several mature market environments. Practically, during the pace of market-oriented power system reform in China, market environment varies from those mature ones. Thus, various market factors could inevitably complicate the operation. Thus, this paper proposes a new dispatching operation strategy aiming to minimize the operating cost under market reform. We take the load demand, power generation cost, feed-in tariff and operation characteristics of distributed generations into full consideration. Finally, there are totally 14 operating modes for microgrids applicable to different situations.

2. Microgrid type, energy configuration and characteristic index

2.1. Microgrid type
Microgrids could be categorized into 3 types according to characteristics inside the microgrid.
- Residential microgrid: The load in residential microgrid is lower in days while higher at night.
- Commercial microgrid: The load in commercial microgrid is higher in days while lower at night. And the load is gathering mainly in working peak hours of mornings and afternoons.
- Industrial microgrid: Similar to commercial microgrids, the load inside industrial microgrid is gathering mainly in working peak hours of mornings and afternoons. Differently, the load is generally divided into light industry and heavy industry. And load characteristics of different light industry vary greatly, while heavy industry owns higher load rate and is basically stable throughout the whole year.

2.2. Microgrid energy configuration

We take the typical commercial microgrid as the example in this paper. The microgrid structure is illustrated in Figure 1.

![Figure 1. Microgrid structure](image)

2.3. Output characteristic index of microgrids

The integration of microgrids brings some new features to load characteristics. They are load upper and lower limit, average load, difference between peak on/off power and typical daily load curves. Based on the statistical period, there are generally annual, monthly and daily average load.

3. Dispatching operation strategy for microgrids considering market factors

3.1. Objective function

The dispatching operation strategy for microgrids should be based on the goal of minimizing the operation cost of the microgrid itself:

\[
\min C = C_{co} - C_{pr}
\]

\[
C_{co} = \frac{1}{4} (\lambda_{ES} p_{ES}^i + \lambda_{PV} p_{PV}^i + \lambda_{GT} p_{GT}^i)
\]

\[
C_{pr} = \frac{1}{4} \lambda_{p} (p_{ES}^i + p_{PV}^i + p_{GT}^i - L_p)
\]

(1)
Here: $C$ is the daily operating cost; $C_{pr}$ is the selling revenue to the external grid; $C_{co}$ is the total cost of the power generation; $p_{t \text{ES}}, p_{t \text{PV}}, p_{t \text{GT}}$ are relatively the output of energy storage, PV and CCHP at time $t$, $V_{t \text{GT}}$ is natural gas consumption for CCHP, $\lambda_{t \text{ES}}, \lambda_{t \text{PV}}$ are the unit output cost of energy storage and photovoltaic, $\lambda_{t \text{GT}}$ is the unit gas cost, $\lambda_{t \text{g}}$ is the power price at time $t$, and $L_{g}$ is the cost of the power purchased from external power grid by the microgrid.

### 3.2. Constraints

PV works in the MPPT (maximum power point tracking) mode. And constraints of the ES are the same as those of residential microgrids. The thermal/cold output of CCHP should satisfy:

$$Q_{GTh} + Q_{gridh} \geq Q_{adem} \quad Q_{GTc} + Q_{gridc} \geq Q_{adem}$$  
(2)

Among them, $Q_{adem}$ and $Q_{adem}$ are the thermal and cold load demands; $Q_{GTh}$ and $Q_{GTc}$ are the thermal and cold capacity of CCHP; $Q_{gridh}$ denotes the thermal capacity of electric boiler, and $Q_{gridc}$ denotes the cold capacity of the electric chiller.

$$Q_{gridh} = P_{gh} \times C_{gh} \quad Q_{gridc} = P_{gc} \times C_{gc}$$  
(3)

In the above formulation, $P_{gh}$ and $P_{gc}$ are power consumptions of the electric boiler and chiller; $C_{gh}$ and $C_{gc}$ are the heating and cold coefficient of the electric boiler and chiller, respectively.

### 3.3. Dispatching operation strategy for microgrids

Based on the proposed model, there are totally 14 modes for microgrids operation as Figure 2 shows.

**Figure 2. Commercial microgrid dispatching operation strategy**

When operating in mode C1, the microgrid output and the cost of power generation are as follows:

$$P_{eq}^t = P_{PV}^t - P_{ch}^t - P_{l}^t \quad C_{eq}^t = \frac{1}{4} \cdot \lambda_{l}^t \cdot P_{eq}^t$$  
(4)

Meanwhile, the cost of ES output is as equation (5) shows.

$$\lambda_{ES}^t = \frac{1}{E^t} (\lambda_{ES}^{t-1} \cdot E^{t-1} + \frac{1}{4} \cdot P_{ch}^t \cdot \lambda_{l}^t)$$  
(5)

When operating in mode C2, the microgrid output and the cost of power generation are as follows:

$$P_{eq}^t = P_{PV}^t - P_{l}^t - P_{h-c}^t - \min \{P_{ch}^t, P_{PV}^t - P_{L}^t\} \quad C_{eq}^t = -\frac{1}{4} \cdot \lambda_{l}^t \cdot P_{eq}^t$$  
(6)

When operating in mode C3, the microgrid output and the cost of power generation are as follows:

$$P_{eq}^t = P_{PV}^t - P_{l}^t - P_{h-c}^t \quad C_{eq}^t = -\frac{1}{4} \cdot \lambda_{l}^t \cdot P_{eq}^t$$  
(7)

When operating in mode C4, the microgrid output and the cost of power generation are as follows:
When operating in mode C5, the microgrid output and the cost of power generation are as follows:

\[
P'_e = P'_{PV} - P'_{h,c} - P'_L \quad C'_e = -\frac{1}{4} \lambda'_g \cdot P'_e
\]  

(8)

When operating in mode C6, the microgrid output and the cost of power generation are as follows:

\[
P'_e = P'_{PV} - P'_{h,c} - P'_L \quad C'_e = -\frac{1}{4} \lambda'_g \cdot P'_e
\]  

(9)

When operating in mode C7, the microgrid output and the cost of power generation are as follows:

\[
P'_e = P'_{PV} - P'_{h,c} + P'_{dism} \quad C'_e = -\frac{1}{4} \lambda'_g \cdot P'_e + \frac{1}{4} \cdot \lambda'_es \cdot P'_e
\]  

(10)

When operating in mode C8, the microgrid output and the cost of power generation are as follows:

\[
P'_e = P'_{PV} - P'_{L} + P'_{GT} - P'_chm \quad C'_e = -\frac{1}{4} \lambda'_g \cdot P'_e + \frac{1}{4} \cdot \lambda_{GT} \cdot V'_{GT}
\]  

(11)

When operating in mode C9, the microgrid output and the cost of power generation are as follows:

\[
P'_e = P'_{PV} - P'_{L} + P'_{GT} - P'_chm \quad C'_e = -\frac{1}{4} \lambda'_g \cdot P'_e + \frac{1}{4} \cdot \lambda_{GT} \cdot V'_{GT}
\]  

(12)

When operating in mode C10, the microgrid output and the cost of power generation are as follows:

\[
P'_e = P'_{PV} + P''_{GT} - P'_L \quad C'_e = -\frac{1}{4} \lambda'_g \cdot P'_e + \frac{1}{4} \cdot \lambda_{GT} \cdot V'_{GT}
\]  

(13)

When operating in mode C11, the microgrid output and the cost of power generation are as follows:

\[
P'_e = P'_{PV} + P''_{GT} - P'_L \quad C'_e = -\frac{1}{4} \lambda'_g \cdot P'_e + \frac{1}{4} \cdot \lambda_{GT} \cdot V'_{GT}
\]  

(14)

When operating in mode C12, the microgrid output and the cost of power generation are as follows:

\[
P'_e = P'_{PV} - P'_L + P'_{GT} - P'_chm \quad C'_e = -\frac{1}{4} \lambda'_g \cdot P'_e + \frac{1}{4} \cdot \lambda_{GT} \cdot V'_{GT}
\]  

(15)

When operating in mode C13, the microgrid output and the cost of power generation are as follows:

\[
P'_e = P'_{PV} - P'_L + P'_{GT} - P'_chm \quad C'_e = -\frac{1}{4} \lambda'_g \cdot P'_e + \frac{1}{4} \cdot \lambda_{GT} \cdot V'_{GT}
\]  

(16)

When operating in mode C14, the microgrid output and the cost of power generation are as follows:

\[
P'_e = P'_{PV} - P'_L + P'_{GT} - P'_chm \quad C'_e = -\frac{1}{4} \lambda'_g \cdot P'_e + \frac{1}{4} \cdot \lambda_{GT} \cdot V'_{GT}
\]  

(17)
4. Case study

4.1. Parameters of typical microgrids
This paper chooses the microgrid case in Shanxi, China, and analyses examples based on the typical daily load data in different seasons. The operation state of ES is only determined by the cost of charging or discharging and the feed-in tariff. Thus, it can be assumed that the operation state of ES is the same in different seasons.

The load and power capacity parameters of the typical microgrid are shown in Table 1.

| Microgrid type     | Commercial microgrid |
|--------------------|----------------------|
| Power load (MW)    | 3                    |
| Cold load (MW)     | 1.5                  |
| PV capacity (MW)   | 3                    |
| ES capacity (MWh/MW) | 4.8/1           |
| CCHP capacity (MW) | 1.5                  |

Table 1. Load and power capacity of typical microgrid

The parameters of the power supply are shown in Table 2, and the typical daily curves of PV and microgrids loads are shown in Figure 2,3,4.

| Power source type | PV       | ES     | CCHP   | Diesel |
|-------------------|----------|--------|--------|--------|
| Capacity (MW)     | 3        | 4.8/1  | 1.5    | 1      |
| Power generating cost (RMB/kWh) | 0 | 0.25 | 2.5 | 1.36 |
| Construction cost (million RMB) | 24 | 9.6 | 4.5 | 0.8 |
| Failure rate (times/year) | 5 | 3 | 0.1 | 1 |
| MTTR(h)           | 24       | 24     | 8      | 24     |

Table 2. Microgrid power source parameters

Figure 3. Typical output curve of per unit PV

Figure 4. Microgrid typical daily load curve

Figure 5. Microgrid typical daily thermal and cold load curves
4.2. Output characteristics of typical microgrids

4.2.1. Output characteristics curve of typical microgrids. We can obtain the output characteristic curve of a typical microgrid via the microgrid dispatching operation model. And the characteristic curve of microgrid output is disassembled into three ones, as shown in Figure 5 below.

![Figure 5. Output characteristic curve of typical microgrids](image)

4.2.2. Characteristics index of typical microgrid output. The output characteristics index of typical microgrid can be obtained as Table 3 shows.

It can be seen that the peak output value of the industrial microgrid is the largest, and that of the commercial type is the lowest. This is usually caused by the similarity of load and power supply in commercial microgrids. The average output value of the industrial microgrid is the lowest. This is because the load in industrial microgrids always maintains in a high level throughout the day. Therefore, the average output value is the lowest; the commercial microgrid has the highest profits. It is due to the fact that there are various distributed generations in the commercial microgrid, which can be dispatched flexibly. Thus, it is easier to make profits while carrying out the economic dispatching operation strategy.

|                                | residential | commercial | industrial |
|--------------------------------|-------------|------------|------------|
| peak output (MW)               | 1.2366      | 1.1705     | 1.6874     |
| average output (MW)            | -1.7873     | -1.7973    | -1.7778    |
| peak-valley output (MW)        | 5.5706      | 5.7558     | 5.5001     |
| operating cost (thousand RMB)  | -34.394     | -35.616    | -32.943    |

4.3. Impact of feed-in tariff on the output characteristic of microgrids

When the power supplies output as Figure 6 shows, it is the most economical strategy. Based on the time-sharing electricity price policy and the output curve of ES, we can see that, when the feed-in tariff is lower than the cost of ES output, the ES can be charged. When the feed-in tariff is higher, the ES could discharge, delivering its stored electricity to the distribution network. Although the cost of CCHP is relatively high, the CCHP needs to output stably in order to satisfy the cold and thermal load of microgrids. And its output is consistent with the trend of changes in the superposition of cold and thermal loads. Besides, we can significantly increase the energy output of the microgrid by increasing the feed-in tariff.
Figure 7. Microgrid output curve of each energy and load

5. Conclusion

This paper establishes a dispatching operation model for microgrids with the objective of minimizing the operation cost. We consider comprehensive factor, including feed-in tariff, PV generation cost, and the operating characteristics of distributed energy sources. The case study takes commercial microgrid as an example to simulate the output characteristic curves of microgrid. Then we obtain the output characteristic indexes of microgrids and analyze the impact of feed-in tariff on microgrid’s output. Clearly, research in this paper could provide significant guidelines for microgrid planning and operating.

References

[1] Journalist, Jiansheng Ma. The national energy administration issued a guideline on the construction of a demonstration project for new energy micro-grids, 2015-07-23.
[2] Sao C K, Lehn P W. Control and power management of converter fed microgrids. IEEE Transactions on Power Systems, 2008, 23(3): 1088-1098.
[3] Price W W, Chiang H D, Clark H K, et al. Load Representation for Dynamic Performance Analysis (of Power Systems). IEEE Transactions on Power Systems, 1993, 8(2):472-482.
[4] Zhengyi Liu, Shuntao Tan, Xiangjun Zeng. Distributed generation and its impact on power system analysis. North China power technology, 2004 (10): 18-20.
[5] Liu Zhengyi, Tan Shuntao, Zeng Xiangjun, et al. Distributed generation and its impact on power system analysis. North China Electric Power, 2004(10): 18-20.
[6] Lasseter R. Dynamic models for micro-turbines and fuel cells//Power Engineering Society Summer Meeting, 2001. IEEE, 2001, 2: 761-766.
[7] Naka S, Genji T, Fukuyama Y. Practical equipment models for fast distribution power flow considering interconnection of distributed generators//Power Engineering Society Summer Meeting, 2001. IEEE, 2001, 2: 1007-1012.
[8] Zhengyi L, Xiangjun Z, Shuntao T, et al. A novel scheme of stability control for distributed generation systems//Power System Technology, 2004. PowerCon 2004. 2004 International Conference on. IEEE, 2004, 2: 1528-1531.
[9] Ackermann T, Garner K, Gardiner A. Embedded wind generation in weak grids—economic optimisation and power quality simulation. Renewable Energy, 1999, 18(2): 205-221.
[10] Fan Yuanliang, Jiang Quanyuan, Cao Yijia. Simplified small signal analysis of microgrid with the droop and PQ generators. Journal of Hunan University(Natural Science), 2012, 39(5): 53-58.
[11] Fan Yuanliang, Miao Yiqun. Small signal stability analysis of microgrid droop controlled power allocation loop. Power System Protection and Control, 2012, 44(4): 1-7.