Economic Dispatch of Micro-grid Based on SQP—Validation and Results

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Abstract. An economic dispatch strategy of micro grid based on sequential quadratic programming is introduced and formulated in the authors’ former paper in the context of mathematical model and formulations. In this paper, a small micro grid system in Yantai City, established by Shandong Electric Power Company, is used to investigate the performance of the proposed model in more detail. The results show that: in the independent micro grid operating mode, when the load is small, the operating costs of micro grid have a large difference before and after the control. In the grid-connected operation mode, the micro grid generates as recommended is more economical than full-power generation. Therefore, this paper can achieve the optimal output of each micro source and the economic operation with satisfying the load requirements.

1. Introduction

In recent years, with the global energy crisis and environmental pollution, microgrid has become one of the focuses of people’s attention. As an effective way to exert the efficiency of distributed generation, microgrid technology has become a hot topic in the research of smart grid theory and technology [1-4]. In order to realize the grid connected or island operation of microgrid, minimize the adverse impact of intermittent energy on the grid, it is of great significance for effective energy management of microgrid [5-7]. Micro grid economic dispatch is an important part of micro grid energy management. Its purpose is to reasonably distribute the treatment of each unit on the premise of meeting the normal demand of all loads, so as to minimize the total operation cost of micro grid and obtain the best economic benefits [8-10].

This paper analyzes the micro grid economic dispatch models introduced and formulated in the authors’ former paper through several case studies. In Section 2, case studies are conducted on a small micro grid system in Yantai City. According to the calculation results, the economic scheduling can be realized with a high practical value. In Section 3, conclusions are given.
2. Mathematical model solution

2.1. Economic Dispatch in Independent Micro Grid Operating Mode

The solution of this model takes into account the problem that the transmitted electric power in the independent micro grid operating mode is greater than the load power. As shown in Figure 1, the curve of a typical load is:

![Figure 1. Typical daily electrical load curve.](image1)

According to the typical load curve shown in Figure 1, the method of sequential quadratic programming is used to solve the problem by MATLAB. In the process of solving, photovoltaic power generation and wind power generation are at full capacity to control the fuel cell and micro gas turbine to operate in the most economical way.

Under the same load, it is assumed that photovoltaic power generation and wind power generation are all put into use, and then the power generated by the fuel cell is dispatched, and the electricity generated by the micro gas turbine is finally dispatched. After calculation of operating costs, the comparison curve of operating costs before and after control is obtained, as shown in Figure 3.

It can be seen from Figure 3 that, under the same electrical load, the operating cost after control is indeed more less than the cost before control, and the smaller the electrical load is, the larger the operating cost gap before and after control is.

![Figure 3. Operating costs before and after control.](image3)

2.2. Economic Dispatch of Micro-grid System in Grid-connected Operation Mode

The small cogeneration system of heat and power in the system provides winter heating and can provide part of the electric load. The insufficient electric power is provided by other micro power sources, and the part that cannot be satisfied can be purchased from the main distribution network; On the contrary, any surplus electricity can be sold to the main distribution network system. Of course, the above process must be built on the basis of economic operation, that is, when the cost of power generation is greater than the purchase price of electricity, only consider the purchase of electricity, when the cost of electricity generation is less than the sale price of electricity, only consider the sale of electricity.

According to the thermoelectric load curve of a fixed day in winter as shown in Figure 4, the output power of each micro power source and the power purchase and sale of the system are simulated below.

Table 1 illustrates the purchase and sale of peak load in a micro grid.
Table 1. Energy prices and electricity sales table.

| Energy types       | Natural gas | 2.05 yuan/m³ |
|-------------------|-------------|--------------|
| Purchase electricity | Peak periods 9:00-12:00 18:00-23:00 | 1.21 yuan    |
|                   | Flat periods 07:00-09:00 12:00-18:00 | 1.00 yuan    |
|                   | Valley periods 23:00-7:00         | 0.62 yuan    |
| Sell electricity  | Peak periods 9:00-12:00 18:00-23:00 | 0.85 yuan    |
|                   | Flat periods 07:00-09:00 12:00-18:00 | 0.78 yuan    |
|                   | Valley periods 23:00-7:00         | 0.35 yuan    |

(a). From 23:00 to 7:00, since the electricity price is less than the power generation cost of the fuel cell, FC will not generate electricity during this period. The insufficient power load will be purchased from the superior power grid, and if there is any surplus power load, it will be sold to the superior power grid.

(b). Between 7:00 and 23:00, the electricity purchase price is higher than the power generation cost of the fuel cell, and the electricity sale price is higher than the power generation cost of fuel cell, so the FC is full.

(c). From 7:00 to 9:00 and 23:00 to 7:00, due to the power purchase price is greater than the micro gas turbine power generation costs, and selling electricity price is less than the cost of the micro gas turbine, so the micro gas turbine doesn’t meet the demand of heat load, if the electric load has not been met, the micro gas turbine continues efforts, until no more meeting the demand of electricity load power.

(d). At 9:00 to 12:00 and 18:00 to 23:00, the power purchase price is larger than the power generation cost of the micro-turbine, so the micro-turbine is at full capacity.

(e). Between 23:00 and 7:00, the electricity purchase price is less than the power generation cost of the micro gas turbine, so the micro gas turbine does not generate much power when the power load is full.

The power generation cost of the fuel cell in the micro grid is 0.65 yuan, and the power generation cost of the micro gas turbine is 0.8 yuan.

Table 2. Generation schedule of each micro-source

| Micro-source   | 23:00-7:00 | 7:00-9:00 | 9:00-12:00 |
|----------------|------------|-----------|------------|
| Fuel cell      | Generator not producing | Full capacity | Full capacity |
| Micro gas turbine | Heating load | Based on meeting the heating load, if the electrical load has not been met, the generator continues to output. | Full capacity |
| Photovoltaic generation | Full capacity | Full capacity | Full capacity |
| Wind generation | Full capacity | Full capacity | Full capacity |
| Micro-source   | 9:00-12:00 | 12:00-18:00 | 18:00-23:00 |
| Fuel cell      | Full capacity | Full capacity | Based on meeting the heating load, if the electrical load has not been met, the generator continues to output. |
| Micro gas turbine | Full capacity | Full capacity | Full capacity |
| Photovoltaic generation | Full capacity | Full capacity | Full capacity |
| Wind generation | Full capacity | Full capacity | Full capacity |

According to the load curve of a typical day of cogeneration of heat and power, energy price, purchase and sale electricity table and micro-power generation schedule shown in Table 2 and Figure 4, the output simulation of each micro-source is obtained by using sequential quadratic method, as shown in Figure 5.
The premise of purchasing and selling electricity is that wind power generation and photovoltaic power generation at full capacity do not participate in dispatching. Micro gas turbine first meet the heat load, on this basis, according to the micro gas turbine power generation cost and time-of-use block electricity rate comparison, it is concluded that when the wave crest, micro gas turbine units generate electricity at full capacity. In flat periods, the micro gas turbine first meet the heat load, if there is residual load continue to contribute for the use of micro power grid load, but nothing more than to send. In valley periods, micro gas turbine only provides heat load. According to the power generation cost of the fuel cell, when it does not generate power at the trough, the peak and fragment are at full capacity. According to this principle and the load situation, the table of electricity purchase and sale on a typical day as shown in Figure 5 is calculated and obtained.

In the grid-connected state, with the same load, comparing the operating costs of micro-grid system before and after control, the cost calculation principle before control is that wind power generation, photovoltaic power generation, micro gas turbine power generation and fuel cell power generation are all at full capacity, and the operating cost is calculated. After control, the calculation is conducted according to the results shown in Figure 6, and the results are drawn into a column diagram as shown in Figure 7.

It can be seen from Figure 6 and Figure 7, in the grid-connected operation mode, under the same load, the required output of the micro grid is more economical than that of the full-power grid. When the load is small, the operating costs before and after control have a large difference, and the economically controlled micro grid is obviously more economical than that of the full-power micro grid.

3. Conclusions
The results show that the sequential quadratic programming method proposed in this paper is applied to the economic dispatch of micro grid system, which achieves the optimal output of each micro-power source and achieves the economic operation under the same load. According to the grid-connected operation mode, under the same load, the output of micro-grid is more economical than that of full-power grid. When the load is small, the operating cost varies greatly before and after control. For off-grid operation mode, the operating cost varies greatly when the load is small.
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