Genetic Algorithm Based Economic Optimization of Microgrid Including Multi-Energy Supply System

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Abstract. It is necessary to reduce CO₂ emission and improve energy efficiency saving in microgrid power generation scheduling. In this context, both cost and benefit are analyzed. Considering the CO₂ emission, the energy efficiency saving and some constraint conditions, an economic model including the power supply and fuel gas supply is provided. The model is solved by genetic algorithm. The optimization results of calculation example show that the model provided is feasible and reliable. And it can also be applied to a large-scale power grid.

1. Introduction

With the increasing awareness of energy saving and environmental protection, distributed generation (DG) is paid more and more attention. Microgrid combines all kinds of distributed power, load, energy storage unit and control device to form a single controllable unit, providing electricity and heat energy to users at the same time, realizing cogeneration. Microgrid has become an effective technique for managing DG in smart grid, and it has been widely studied for the operation and control of microgrid. Therefore, it is necessary to study the microgrid [1], which is an effective supplement and strong support for the large power grid. Microgrid is clean and efficient. It can improve energy utilization and reduce environmental pollution [2].

To improve the energy efficiency and reduce CO₂ emission, the two aspects of cost and benefit are in consideration in this paper. Considering the emissions, an economic model including multi-energy supply is provided. The model is solved by genetic algorithm [3-4]. The analysis results show that the incorporation of microgrid into power grid can improve energy efficiency, reduce costs, and reduce CO₂ emission. It can also reflect the effectiveness and feasibility of economic operation of microgrid [5].

2. Economic Analysis of Microgrid

The economic analysis mainly includes benefit analysis and cost analysis. The difference value between benefit and cost can be used as an instruction of economic analysis.

The benefit of the microgrid mainly includes the benefit of the distribution network, the benefit of the user, the benefit of the social and so on. The benefit of distribution network refers that microgrid can improve power supply reliability, support voltage sags in distribution network, and delay or avoid equipment investment in distribution network. The benefit of the user refers that microgrid can reduce...
the energy cost of the thermal and thermal natural gas, improve the reliability of the power supply and provide the auxiliary service. The benefit of the social refers that microgrid can improve the utilization of energy and reduce the CO$_2$ emission.

The cost of microgrid mainly includes initial investment cost, the cost of operation and maintenance, the cost of fuel, the cost of emission penalty and so on. The initial investment cost is the microgrid construction cost. The cost of operation and maintenance includes network loss, cost of start and stop, cost of electricity purchase and so on. The cost of fuel mainly includes the cost of natural gas and fuel. The cost of emission penalty mainly includes the penalty cost of CO$_2$ emission released by power generation.

3. Economic Optimization Model of Microgrid

3.1. Microgrid Structure

In microgrid, five types of power supply are put into use, including Photovoltaic (PV), Wind Turbine (WT), Hydropower (HP), Microturbine (MT) and Fuel Cell (FC), as shown in Figure 1. The relationship of supply and demand can be seen clearly.

![Figure 1. The structure of microgrid.](image)

3.2. Objective Function and Constraint Condition

Then a microgrid model is established with the integration of power supply, thermal supply and gas supply. In order to maximize the benefit of microgrid and minimize the total cost of microgrid, the objective of establishing a microgrid economic model for grid operation is to be built. Considering the complexity of the model and the uncertainty of thermal energy demand, only the cost and benefit of electricity and natural gas supply are considered, and cost and benefit of thermal supply is not considered in this paper.

The objective function of the economic model established in this paper is

$$
\text{min} \left\{ \sum_{n=1}^{N} C_n \frac{R(1+R)^{l_{en}}}{(1+R)^{l_{en}}-1} + C_{\text{BATTERY}} \frac{R(1+R)^{l_{\text{BATTERY}}}}{(1+R)^{l_{\text{BATTERY}}}-1} + \sum_{n=1}^{N} C_{\text{BATTRY}} P_n + \sum_{n=1}^{N} E_n \lambda + \alpha P_p - \beta P_s + \gamma T + \delta G_{\text{MT}} + \delta G_{\text{FC}} + \delta G_p - \varepsilon G_s \right\}
$$

(1)

where, $n=1$~$N$, where $N$ is the total number of power supply in the microgrid; $C_n$ is the initial cost for the $n$ power supply; $l_{en}$ is the lifecycle of the $n$ unit. $R$ is the rate of interest; $C_{\text{BATTERY}}$ is the initial cost of energy storage device; $l_{\text{BATTERY}}$ is the lifecycle of energy storage device; $C_{\text{BATTRY}}$ is the maintenance cost of the $n$ unit. $P_n$ is the power produced per hour of the $n$ unit. $E_n$ is CO$_2$ emission from the $n$ unit. $\lambda$ is emission penalty price. $\alpha$ is power price purchasing from the grid; $P_p$ is power purchasing from the grid; $\beta$ is power price selling to the grid; $P_s$ is power selling to the grid; $\gamma$ is the cost of each start-stop. $T$ is the start-stop frequency of the power supply; $\delta$ is gas price purchasing from the microgrid; $G_{\text{MT}}$ and $G_{\text{FC}}$ are the natural gas required for the produced by MT and FC; $G_p$ is the natural gas purchasing from the grid; $\varepsilon$ is gas price selling to the microgrid; $G_s$ is the gas selling to the microgrid.
The equality constraint of the model is the power balance constraint, that is
\[ P_d = P_{PV} + P_{WT} + P_{HP} + P_{MT} + P_{FC} + P_{P} + P_{P} - P_{loss} \quad (2) \]
where, \( P_d \) is the total power demand per hour, \( P_{PV}, P_{WT}, P_{HP}, P_{MT} \) and \( P_{FC} \) are the power produced by PV, WT, HP, MT and FC, respectively. \( P_{loss} \) is the power loss of the microgrid.

The inequality constraints of the model include power upper and lower limit constraint, \( \text{CO}_2 \) emission constraint and start-stop times constraint. The upper and lower limit constraint is
\[ P_{nmin} \leq P_n \leq P_{nmax} \quad (3) \]
where, \( P_{nmin} \) and \( P_{nmax} \) are the upper and lower limit of the output of the \( n \) unit, respectively. The emission constraint of \( \text{CO}_2 \) is as follows:
\[ \sum_{n=1}^{N} E_n \leq E_{max} \quad (4) \]
where, \( E_{max} \) is the maximum emission limit of \( \text{CO}_2 \). The start-stop frequency constraint is as follow:
\[ T < T_{max} \quad (5) \]
where, \( T_{max} \) is the maximum frequency limit of the microgrid.

4. Solving Method
Genetic algorithm is one of the evolutional computing techniques developed in recent years. Genetic algorithm is a computational model of biological evolution process of natural selection and genetic mechanism simulating Darwin's theory of biological evolution. It's a way to search for optimal solution by simulating natural evolution process. Genetic algorithm starts from a population representing potential problems, and a population is composed of a number of individuals (individual) encoded by genes. Each individual is actually an entity with the characteristics of a chromosome. Chromosome is the main carrier of genetic material, that is, the collection of multiple genes. Its internal expression is a combination of genes, which determines the external expression of individual shape [6].

The research is based on daily load distribution. According to the power supply of microgrid shown in Figure 1 and the microgrid economic model built above, the formula (1) can be simplified that the objective function contain only cost of power generation and \( \text{CO}_2 \) emission. The power balance constraint, power upper and lower limit constraint, emission constraint of \( \text{CO}_2 \) and start-stop frequency constraint are in considered. Genetic algorithm can be achieved by Matlab, and the simulation calculation is carried out. The flowchart of genetic algorithm is given in Figure 2. The load in microgrid is predicted and analyzed. The daily load curve is shown in Figure 3. The daily load curves of summer, winter, spring and autumn are expressed by curves 1, 2, 3 respectively.

![Figure 2. The flowchart of genetic algorithm.](image)
5. Case Study

5.1. Parameter Settings
The output power of PV will be greatly influenced by sunshine intensity in different seasons. Therefore, the output power of PV should also be analysed in summer, winter, spring and autumn. As shown in Figure 4, the curves 1, 2, 3 represent the output power of PV in summer, winter, spring and autumn.

![Figure 4. Daily output power of PV.](image)

The output power of WT is influenced by wind. The output power of HP is influenced by water. Therefore, the output power of WT and HP are assumed as a constant to simplify calculation. The generation power cost of PV, WT and HP are low, and during the generation power, there is nearly no CO₂ emission. Then it is assumed that there is no cost or CO₂ emission during the generation power of PV, WT and HP. The cost and CO₂ emission are only from MT and FC. The parameter settings are shown in Table 1.

![Figure 3. Predicted load curve in different seasons.](image)

| Parameter                  | Value     | Parameter                  | Value     |
|----------------------------|-----------|----------------------------|-----------|
| Output power of WT         | 3.5 kW/h  | Output power of HP         | 2 kW/h    |
| CO₂ emission penalty price | 0.30 yuan/kg | CO₂ emission limit        | 200 kg    |
| CO₂ emission parameter of MT | 0.72     | CO₂ emission parameter of FC | 0.43     |
| Fuel consumption coefficient of MT | 0.40 m³/kWh | Fuel consumption coefficient of FC | 0.25 m³/kWh |
| Maintain cost of MT        | 0.04 yuan/kWh | Maintain cost of FC       | 0.03 yuan/kWh |
| Power upper limit of MT    | 330       | Power upper limit of FC    | 25        |
| Power lower limit of MT    | 30        | Power lower limit of FC    | 5         |

5.2. Simulation Result
In order to minimize the objective function (total cost), the output power curves of MT and FC after optimization are shown in Figure 4. Curves 1, 2, 3, 4 represent the output power of FC in summer, the output power of MT in summer, the output power of MT in winter, and the output power of MT in
spring and autumn, respectively. As shown in Figure 5, curves 1, 2, 3 represent the total cost of microgrid in summer, winter, spring and autumn, respectively.

Figure 5. The output power of MT and FC after optimizing.

Figure 6. The total cost after optimizing.

6. Conclusion
1) In summer, CO2 emission is reduced by 17.8% after optimizing, and then total cost is the lowest. It is because that PV can generate more power than in winter, and generation power of MT is reduced
2) Without considering selling electricity to the grid, the clean energy is firstly to generate electricity, such as PV, WT and HP. And then the lower emission and higher efficiency units are on the turn to generate electricity, such as MT. Finally, the higher emission units are used to generate electricity, such as FC.
3) The model provided in this paper can be used to each multi-energy supply system, including thermal supply. Actually, thermal supply is more popular in winter and further work is currently in progress to forecast the uncertainty of thermal energy demand.

7. References
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