Research on Revenue Maximizing Dispatch Strategy for New Energy Micro-grid

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Abstract. In this paper, a mathematical model for micro-grid energy management, including photovoltaic, wind power, micro gas turbine and energy storage devices, is established. On this basis, considering the impact of electricity price on user demand, this paper proposes a micro grid scheduling strategy based on revenue maximization.

1. Introduction
With the growth of my country’s electricity demand and the expansion of the coverage of the grid, successive accidents and difficulties reflect the weak side of the grid: Energy shortage and environmental pollution pose a serious threat to social security and stability [1]. As a result, distributed power generation technology with favourable characteristics such as lower pollution and higher energy efficiency has been produced, which can make the power supply of the grid more reliable. However, the large randomness of distributed power generation will have a very large negative impact on the stability of the grid system.

As a “grid-in-the-grid”, the micro-grid can not only be connected to the grid, but also can be disconnected from the main grid when the main grid fails to operate on an island. For large power grids, the micro-grid can be regarded as a controllable unit that can act within a few seconds to meet the needs of the external transmission and distribution network for users, micro-grids can meet specific needs, such as reducing feeder losses, increasing local reliability and maintaining local voltage stability. The micro-grid and the power distribution network can exchange energy through PCC and serve as a backup for each other, thereby improving the reliability of power supply. This article will establish the mathematical model of the micro power supply according to the different operating characteristics of the micro power supply, and establish the simulation model of the power supply in the micro grid. On this basis, this paper proposes a strategy for scheduling and operating micro-grids to maximize the revenue under certain constraints.

2. Micro-grid power supply model with new energy

2.1. Photovoltaic power generation system
Photovoltaic power generation is to generate electricity through solar energy, the photovoltaic cell is the most important part: Under the irradiation of sunlight, the valence electrons in the atoms break away...
from the covalent bond and generate many positive-negative charge pairs, which are collected at both ends of the battery after the internal electric field force, thereby generating a potential difference. The U-I relationship of the battery is:

\[ I_{pv} = I_{ph} - I_0 - I_{sh} = I_{ph} - I \left[ \exp \left( \frac{U_{pv} + IR_s}{U_T} \right) - 1 \right] - \frac{U_{pv} + IR_s}{R_{sh}} \]  

Where \( I_{ph} \), \( I_0 \), \( R_s \), \( R_{sh} \) and \( U_T \) respectively represent photocurrent, diode reverse saturation current, equivalent series resistance, equivalent parallel resistance and thermal voltage. Usually \( R_s \) is very small compared to \( R_{sh} \) [2], therefore, the formula (2.1) can be approximately simplified as:

\[ I_{pv} = I_{ph} - I_0 \left[ \exp \left( \frac{U_{pv} + IR_s}{U_T} \right) - 1 \right] \]  

In this paper, through the Simulink simulation platform, the simulation module of the photovoltaic cell as shown in Figure 1 is built, and the appropriate parameters are selected by referring to the relevant literature.

![Figure 1. Simulation modeling of photovoltaic cells.](image)

From the power generation principle of photovoltaic cells and the simulation results, it can be seen that the output power of photovoltaic cells is only affected by irradiance, photovoltaic cell operating temperature and the load carried by photovoltaic modules, and each influencing factor has a nonlinear effect on the operating characteristics of photovoltaic cells. Therefore, when the irradiance and the working temperature of the photovoltaic cell are constant, the photovoltaic cell will output different voltage values according to the load of the photovoltaic module, but there is one and only one voltage value that makes the photovoltaic cell work at the maximum power, the power point corresponding to this voltage value \( U_{max} \) is called the maximum power point \( P_{max} \).

2.2. Wind power generation system

Wind power is a process of converting wind energy into electrical energy. Wind power systems are mainly divided into two types: off-grid wind power systems and grid-connected wind power systems. According to aerodynamics, the output power of a wind turbine in an ideal state is as follows:

\[ P_w = \frac{1}{2} \rho \pi R_w^2 \nu^3 C_p \]  

Among them, \( R_w \) is the power output of the wind turbine, \( \rho \) is the air density flowing through the wind turbine, \( R_w \) is the radius of the currently used fly turbine blade, \( \nu \) is the wind speed flowing through the wind turbine, \( C_p \) is the wind energy utilization coefficient related to the tip speed ratio of the wind turbine and the blade pitch angle. The value of \( C_p \) is different for different wind turbines. Combined with the above, the wind turbine model is established, as shown in Figure 2.
2.3. Micro gas turbine
The micro gas turbine generator set is composed of a micro gas turbine, a built-in high-speed inverter generator directly driven by the gas turbine, and a digital power controller (Digital Power Controller, DPC). The core equipment—the micro gas turbine is composed of radial impeller machinery, combustion chamber. It is composed of a plate-tilted regenerator with a power range of hundreds of kilowatts or less. The ultra-small gas turbine fueled by natural gas, methane, gasoline, and diesel uses a regenerative cycle. Its power generation efficiency can reach 30%, if the implementation of cogeneration, the efficiency can be increased to 75%.

When the micro gas turbine is used as a distributed power generation, its mathematical models include: gas turbine model, brushless permanent magnet generator model and power electronic inverter equipment model, as well as speed/load control model, temperature control model and fuel control model, etc.

There are many types of gas turbines currently on the market. Different micro gas turbines have great differences in power and efficiency. The model used in this article is a CapstoneC65 micro gas turbine. According to the technical parameters provided by the product, its output power and efficiency can be described. The functional relationship between power generation efficiency is as follows:

\[ \eta_1 = 0.0753 \left( \frac{P_{MT}}{65} \right)^3 - 0.3095 \left( \frac{P_{MT}}{65} \right)^2 + 0.4174 \left( \frac{P_{MT}}{65} \right) + 0.1068 \] (4)

Where \( \eta_1 \) is the current power generation efficiency and \( P_{MT} \) is the current output power of the micro gas turbine. The figure below is the fitting curve of output power and power generation efficiency.

2.4. Energy storage unit
The storage battery needs an inverter to convert direct current into alternating current to connect to the grid. The active and reactive power output through the inverter are as follows:

\[
\begin{align*}
P &= \frac{u_a u_R}{X} \sin \delta \\
Q &= \frac{u_a}{X} (u_R - u_c \cos \delta)
\end{align*}
\] (5)

In the above formula, \( X \) is the impedance of the connecting line; \( u_a \) is the output voltage of the grid; \( u_R \) is the output voltage of the battery system. The output active and reactive power can be changed by adjusting \( \delta \) and \( u_R \).

Energy storage technology has now been extensively studied, and a large number of technical results have been achieved. Traditional single storage batteries have high energy density but slow response speed. Frequent power fluctuations of distributed power sources will cause frequent charging and discharging of batteries and affect battery life. Supercapacitors have high power density and fast
response speed. The hybrid energy storage system formed by the combination of the two can exert their own characteristics, while suppressing system power fluctuations, and extending the life of the energy storage unit.

In order to effectively suppress power fluctuations caused by photovoltaic and load mutations, and maintain the stability of the micro-grid system, a hybrid energy storage device is added to the photovoltaic power generation micro-grid system, and a second-order low-pass filtering link is constructed to distribute the system power fluctuations, so that batteries and super capacitors absorb or release the low-frequency and high-frequency components in power fluctuations, and at the same time, combines the state of charge of the energy storage element to control the working state of each energy storage unit converter.

3. Micro-grid dispatching operation strategy

3.1 Scheduling constraints

Dispatching constraints are one of the optimization goals that Micro-grid (MG) must get when performing energy optimal dispatch. With the goal, when the MG is running on or off the grid, it needs to control and adjust the state of charge (SOC) of the energy storage system (ESS) battery in real time, and take into account the life state of the ESS and the health status (Section Of Health, SOH) of the battery to extend its service life.

The magnitude of the SOC state value reflects the electric quantity, and the value equals to 0% and 100% respectively indicate that the electric quantity is zero and full. There are 5 limits for SOC in MG on-grid and off-grid operation states, namely: the maximum and minimum allowed SOC when MG is running, corresponding to $SOC_{MAX}$ and $SOC_{MIN}$ , the upper and lower alarm limits $SOC_{MIN}$ and $SOC_L$ , and the recommended maintenance $SOC_R$ . Regardless of whether the MG is on-grid or off-grid, it must meet $SOC_{MIN} < SOC_{ESS} < SOC_{MAX}$ . When the SOC exceeds its upper and lower limits, an alarm will be issued. The MG initiates an emergency response, and the ESS will promptly respond by charging or discharging to adjust the SOC state to be within the normal range.

During grid-connected operation, when the SOC state value of ESS exceeds the maximum value, it is zone C+, and it is zone C- when below the minimum value. Zone B+ is when the state value exceeds the maximum limit and is less than the maximum value. The value is zone B between lowest limit and the minimum value, and between the lowest limit and the highest limit is zone A. Zone C+ and C- are SOC dangerous areas. MG energy optimal scheduling must controls the SOC state value not to enter this zone, and tries to keep the SOC state in zone A. When SOC enters B+ or B- zone, MG energy optimal scheduling should adjust the SOC value to zone A as soon as possible.

3.2 Revenue maximization scheduling strategy

Maximization of revenue is one of the energy optimization control requirements that MG needs to fulfil when it’s connected to the grid. In reality, this goal can only be achieved by adjusting the SOC in the MG through real-time electricity prices.

According to the fluctuation range of real-time electricity prices, the revenue maximization scheduling strategy is divided into the following three scenarios, as shown in Figure 3.

Scenario 1: $SE_{NML} < SE(t) \leq SE_{MAX}$, that means, when the real-time electricity price is greater than the normal price and not greater than the maximum electricity price, if $SOC_L < SOC_{ESS} < SOC_H$ , then the ESS storage power should be sold. The discharge power of the ESS increases in proportion to $SE - SE_{NML}$ . The higher the $SE(t)$, the faster the SOC decreases. The MG energy optimization scheduling goal is to adjust the SOC to zone A1. When $SE(t) = SE_{MAX}$, the SOC can be reduced to $SOC_L$.

Scenario 2: When $OE < SE(t) \leq SE_{NML}$, that is, when the real-time electricity price is not greater than the normal electricity price and greater than the distributed power generation on-grid price, if $SOC_L \leq SOC_{ESS} < SOC_H$. That is, the SOC is not less than its optimal value, and part of the ESS stored energy can be sold. The MG control goal is to adjust the SOC to area A2, that is, $SOC_{NML} \leq SOC_{ESS} < SOC_B$, when $SE(t) = SE_{NML}$, keep the SOC at $SOC_{NML}$.
Scenario 3: When $S_{E_{\text{MIN}}} \leq S_{E}(t) \leq O_{E}$, that is, when the real-time electricity price is not greater than the on-grid electricity price of distributed generation and not less than the minimum electricity price, the power company increases the electricity consumption by lowering the SE. When $S_{OC_{\text{ESS}}} < S_{OC_{H}}$, the ESS will store electrical energy and gradually increase the input power of the ESS. The increase in the charging power of the ESS is proportional to $|S_{E}(t) - O_{E}|$, that is, the lower the $S_{E}(t)$, the faster the SOC growth rate. The goal of MG energy optimization scheduling is to adjust the SOC to area A3, that is, $S_{OC_{A}} \geq S_{OC_{B}} \geq S_{OC_{C}}$. When $S_{E}(t) = S_{E_{\text{MIN}}}$, the SOC can be increased to $S_{E}(t) = S_{E_{\text{MIN}}}$; When $S_{E}(t) = O_{E}$ keep the SOC at $S_{OC_{B}}$.

![Figure 3. Optimal scheduling strategy based on revenue maximization](image)

4. Conclusion

Combined with actual needs, theoretical analysis and experimental verification of the problems in different states of micro-grid are carried out. The full text is summarized as follows:

1. The distributed power generation units in the micro-grid system are mainly composed of wind power and photovoltaic power generation. These two kinds of energy have the characteristics of abundance, wide distribution, clean and environmental protection, and actually are two relatively common natural resources. In this paper, the idea of combining these two types of power generation is proposed, which not only improves the stability of the micro-grid power generation system, but also enables more energy to be actually used.

2. Based on the different operating characteristics of photovoltaic cells, wind generators, diesel generators, and storage batteries, the power supply simulation model in the micro-grid is established. According to the mathematical model of each micro power source, the output power of the micro power source is estimated. This lays the foundation for establishing the model of the micro-grid system in the following article.

3. Maximization of revenue is one of the energy optimization control requirements that micro-grid needs to fulfil when it is connected to the grid. In reality, this goal can only be achieved by adjusting the SOC in the micro-grid through real-time electricity prices. According to the realization method of the profit maximization goal, the micro-grid needs to pay attention to the real-time electricity price to adjust the SOC state of the ESS, which produces the corresponding relationship between the electricity price and the SOC state value. In the third section of our paper, with dispatch constraints as a prerequisite, it
proposes three specific scenarios of revenue maximization dispatching strategies based on real-time electricity price fluctuations.

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