Research on Modeling of Wind-solar Hybrid Microgrid and Control Strategy of Maximum Power Load

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Abstract. As an important form of receiving renewable energy, microgrids can be a useful supplement to large grids, which can solve the power supply problem of residents in remote mountainous areas, pastoral areas, and islands. Modeling and simulation of energy management for microgrid operation characteristics with wind and solar storage have important practical significance. In this paper, mathematical models of photovoltaic cells and wind power systems are established, simulation models are constructed, and their respective characteristics are simulated and analyzed to verify the correctness of the mathematical models. A simulation model of maximum power point tracking for wind and solar power systems was established based on the respective shortcomings and limitations of independent operation of wind power systems and photovoltaic systems. According to the simulation results, it can be seen that the maximum power control technology used in this system can achieve maximum power tracking for wind power generation systems and photovoltaic power generation systems. The simulation results verify the correctness of the system and the feasibility of the control strategy.

Keywords: Wind-solar complementary system; Microgrid; Maximum power load control.

1. Introduction
In today's society, economic development is overly dependent on the consumption of fossil energy, and fossil energy is non-renewable. Consumption of fossil energy will cause environmental pollution and energy exhaustion, which will restrict social development [1]. New energy sources such as wind energy, solar energy, and tidal energy have the characteristics of clean and pollution-free, huge reserves, etc. How to research and develop new energy sources has become a hot topic in countries around the world today [2]. Microgrid, as the best way to accept new energy, has played an important role in optimizing the energy structure, which can save energy and reduce consumption and improve energy efficiency [3]. Microgrid is an independent system that can realize self-control, protection and management. It has the characteristics of small scale and strong flexibility. It can realize energy interaction with large external power grids and can operate independently on its own. At the same time, microgrid is also one of the important components of today's smart grid. Similar to the smart grid, the microgrid has a strong self-healing feature. When the user's power consumption changes, the microgrid can quickly achieve new supply-demand balance and energy optimization based on feedback information; it can also be carried...
out in time when a fault occurs in the microgrid self-adjustment; when the security of the smart grid is impacted by natural disasters, the microgrid can also guarantee emergency power supply.

With the in-depth study of microgrids, whether they can provide stable and reliable power quality is one of the requirements that microgrids must meet [4]. Relevant scholars have proposed a multi-functional grid-connected inverter topology to ensure the power quality of the micro-grid [5]. However, the topology is too complicated and is of little use for the actual micro-grid project engineering. Researchers have selected power nodes near inverters in microgrids as a goal to manage power quality, but have not considered the economic feasibility of node selection [6]. Although the wind-solar complementary power generation system has more advantages than a single power generation system, its output is highly uncertain and intermittent due to its environmental impacts such as temperature and climate, which results in large fluctuations in its output power. Meeting the grid connection requirements of the State Grid Corporation limits its large-scale development. Relevant scholars have proposed an energy management strategy based on optimizing the working state of the battery, based on the full lifecycle cost theory, an objective function for optimizing the capacity was established, and the capacity of the hybrid energy storage device was optimized using an improved chaos optimization algorithm [7]. Researchers use supercapacitors and batteries as hybrid energy storage devices [8]. The output of the hybrid energy storage device is divided into high-frequency and low-frequency components, and the respective characteristics of the hybrid energy storage are used to compensate the high- and low-frequency components. Relevant scholars have designed a reasonable DC / DC converter control strategy, using sliding mode variable structure control instead of traditional PID control, using droop control strategy, and using simulation to verify that hybrid energy storage devices can improve the power quality of wind-solar complementary systems [9]. Relevant scholars have proposed a current hysteresis loop to control the battery charge and discharge energy management scheme for the fluctuation of photovoltaic output power [10]. The introduction of feed-forward of input voltage and load current improves the control accuracy of the system and reduces the dynamic response time.

This article mainly builds two mathematical models based on Matlab / Simulink's simulation and system principles, sets up simulation models of the two systems, and analyzes the data. Specifically, the technical contributions of this article are summarized as follows:

First, this paper establishes the mathematical model of each micro power supply, analyzes the working principles of photovoltaic cells and wind power systems, and establishes mathematical models.

Second, the maximum power tracking control strategy of the combined wind and solar power generation system is analyzed, and the maximum power tracking principles of the two power generation systems are proposed to provide a theoretical basis for the maximum power of the wind-solar hybrid power generation system.

Third, based on the analysis of the simulation models of the two systems, a simulation model for maximum power tracking of the wind-solar hybrid power generation system is established and the data is analyzed.

2. Research on modeling simulation and control strategy

2.1. Wind-solar hybrid power generation system

The system studied in this article is a system that uses natural wind and sunlight as two natural energy sources to supplement each other to generate electricity. It is mainly composed of solar modules and wind turbines to provide electrical energy to the load, and the battery stores excess electrical energy. New energy generation system combined with multiple energy generation system power generation technology, maximum power point tracking technology, inverter, battery charge and discharge management technology and other technologies.

If you choose a method for power generation, solar power or wind power, you will be limited by problems such as sunlight intensity, sunlight time, weather issues, or wind speed. The existence of these problems will lead to instability of the power generation system and unbalanced load. There will be related problems such as insufficient power supply. However, in actual weather, light and wind speed
are relatively complementary in time. When the light is relatively weak, the wind speed is often strong, and when the light is relatively strong, the wind speed is relatively small. For another example, the intensity of solar radiation in winter is relatively weak and the wind speed is relatively large. In the summer, the wind speed is relatively small, the intensity of sunlight irradiation is relatively large, and the irradiation time is longer.

The wind-solar complementary power generation system used in this paper is mainly composed of wind turbine generators (wind turbine blades, transmission systems), system rectifiers, photovoltaic cell arrays (solar battery packs), system DC/DC converters (buck circuits), and system components. Battery pack, maximum power controller (MPPT control), DC motor (DC load) and other parts. Figure 1 shows the structure of a wind-solar hybrid power generation system.

![Figure 1. Schematic diagram of wind-solar hybrid power generation system](image)

According to the change of wind power and light intensity, the working modes of wind-solar hybrid power generation system are divided into 4 types.

(1) When the wind speed is large and the intensity of sunlight is relatively insufficient, the wind power generation system supplies power to the load alone, and the battery stores the excess electrical energy.

(2) When the solar radiation intensity is relatively large, sufficient, and continuous, the wind energy speed is relatively unsatisfactory. The solar power system alone supplies power to the load, and the battery stores excess electrical energy.

(3) When the wind speed intensity (satisfaction) and sunlight intensity radiation intensity (satisfaction) can both meet the power generation conditions, the two systems supply power to the load at the same time, and the excess energy is stored in the battery.

(4) When the conditions of light intensity and radiation intensity (not satisfied) and wind intensity and wind speed (not satisfied) cannot meet the system conditions, the battery will supply power to the load until the battery's power is exhausted.

2.2. Wind power system

The amount of power generated by a wind turbine is closely related to the wind speed, and the wind speed has a large uncertainty. Its size is easily affected by factors such as the environment and the climate. The probability density function is:

\[ \varphi(v) = \frac{k}{c} \left( \frac{v}{c} \right)^{k-1} e^{-(v/c)^k} \]  

(1)
In the formula, \( v \) is the actual wind speed (m / s), \( k \) is the shape parameter, and its value is generally \( k = 1.8 \sim 2.8 \), and \( c \) is used to reflect the average wind speed.

In this article, we mainly consider the impact of the change of wind speed on the system caused by the change in wind turbine output power, so this paper uses the relationship between wind speed and wind turbine output power as shown below:

\[
P_w(v) = \begin{cases} 
0 & v < v_{CI}, v > v_{CO} \\
\frac{v^k - v_{CI}^k}{v_{R}^k} & v_{CI} < v < v_{R} \\
\frac{v_{R}^k}{v_{CO}^k} & v_{R} < v < v_{CO} 
\end{cases} 
\tag{2}
\]

In the formula, \( P_R \) represents the rated power of the fan generator, \( v_{CI} \) represents the cut-in wind speed of the fan, \( v_{CO} \) represents the cut-out wind speed of the fan, and \( v_{R} \) represents the rated wind speed of the fan.

Figure 2 (a) shows the actual wind speed curve from the Los Angeles wind farm. The wind turbine output power obtained from this wind speed is shown in Figure 2 (b).

![Wind speed curve](image1)

![Fan output power curve](image2)

**Figure 2.** Wind speed curve and fan output power curve

### 2.3. Photovoltaic power generation system

The relationship between the photovoltaic cell output voltage \( U \) and the current \( I \) is:

\[
I = I_{ph} - \frac{U + IR_s}{R_{sh}} - I_s \left\{ \exp \left[ \frac{q(U + IqR_s)}{AKT} \right] - 1 \right\} 
\tag{3}
\]

Among them, \( I_{ph} \) is the photo-generated current, which is proportional to the light intensity; \( R_s \) is the series resistance, which is a low resistance value less than 1 \( \Omega \); \( R_{sh} \) is the parallel resistance, which is generally a high resistance value of the order of 103 \( \Omega \); \( I_s \) is the reverse saturation current of the diode, the order of magnitude is generally \( 10^{-1}A \); \( q \) is the amount of electronic charge, \( 1.6 \times 10^{-19}C \); \( A \) is the factor of the ideal diode \( P_N \) junction, the value range is 1 to 5; \( k \) is the Boltzmann constant, and \( T \) is the ambient temperature.
For different light intensity, the I-U and P-U characteristic curves of photovoltaic cells are shown in Figure 3.

![I-U and P-U characteristic curves of photovoltaic cells](image)

**Figure 3.** Characteristic curves of photovoltaic cells at different temperatures and the same light intensity

As can be seen from Figure 3, when the light and temperature are constant, the output current and voltage are not constant. Its P-U characteristic is a non-linear single peak, and the output power has a maximum value. When the ambient temperature is constant, as the light intensity increases, the short-circuit current $I_{sc}$ of the photovoltaic cell increases significantly, and the two are approximately proportional to each other. The open-circuit voltage $U_{oc}$ increases slowly, and the maximum output power $P_{m}$ of the photovoltaic cell increases significantly. Both $I_m$ and $U_m$ at the power point increase.

2.4. Simulation results and analysis of variable pitch wind turbine

When the external natural wind (wind energy) converts its energy into the mechanical energy of the system through the blades of the wind turbine, it is generated by the action of the wind generator. This link is an important part of the wind power system, and it is also the core part. The generator not only affects the output of the system, at the same time, the generator also affects the safe, stable and reliable operation of the entire generator set. Therefore, the research and establishment of the mathematical model of the wind turbine is the premise of building a simulation model, and it can provide sufficient theoretical basis for the simulation modeling and construction of the system.

In this paper, a variable pitch wind turbine is used in the wind power generation system. The simulation time is 10 seconds, and the rated wind speed of 7m / s in the first 5 seconds is changed to a random wind that changes randomly in the next 5 seconds, thereby adjusting the system.

Figure 4 is a simulation diagram of the output power of a variable pitch wind turbine. According to the power change in the figure, the maximum power tracking of the system can be quickly implemented, thereby realizing the functions of the system.
2.5. Solar power system simulation results and analysis

This paper mainly uses the variable step size perturbation observation method for maximum power tracking control. Unlike ordinary perturbation observation methods, this article will not ignore the influence of solar radiation intensity and ambient temperature on the system, because the direction of perturbation by ordinary perturbation observation methods may be disturbed due to changes in solar radiation intensity or ambient temperature, resulting in misjudgment. The optimized disturbance observation method is based on the working principle. Generally, the entire system is adjusted by adjusting the duty cycle of the Buck converter to achieve the adjustment of the maximum power of the system. Since the output power of a photovoltaic power generation system is closely related to the intensity of sunlight (radiation) and the temperature of the solar panel, the first work of the research is to observe and find the specific position of the maximum power point on the volt-ampere characteristic curve, only the specific location is determined to ensure that the battery can achieve the maximum power output at any sunlight intensity and temperature, so as to ensure that the photovoltaic cell can always work at the maximum power point. The maximum power output of a photovoltaic power generation system is shown in Figure 5.

According to the above simulation data, we can prove based on the results that when the light intensity changes and the wind speed changes, in the shortest time, the maximum power control module can quickly respond to the action, perform tracking control in real time, and make the system shorter. It is in the maximum working state and outputs the maximum power. It adopts a perturbation method that changes the step size. The duty cycle is mainly controlled based on the trigger pulse of the Buck circuit. The analysis results have achieved fast and accurate maximum power point tracking control, verifying the feasibility of the method. And the results prove that the disturbance observation method coordinated control method used in this paper has good control effect, so that it is feasible to adjust the maximum power of the system.
3. Conclusion
Based on the working principle of micro power supply, mathematical models of photovoltaic cells, wind power generation systems, and hybrid energy storage devices were established, and simulation models were set up. The simulation results of the output power of the photovoltaic cell when the external conditions are changed verify the correctness of the model in this paper. The wind turbine output power based on the wind speed data simulation of the Los Angeles wind farm validates the feasibility of the wind turbine model established in this paper. The simulation results of supercapacitors and batteries verify the correctness of the mathematical model. Based on the analysis of the simulation models of the two systems, a simulation model for maximum power tracking of the wind-solar hybrid power generation system is established. According to the conditions of different wind speeds and different light intensity and radiation intensity, the classification and simulation of the system are performed. However, the system studied in this paper does not adopt inverters to transmit electrical energy to the grid, but only studies independent wind-solar complementary power generation systems. In the future work, the overall performance of the system should be improved, the system should be made more optimized, so that the energy of the system can be exerted more.

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