Research on the Portable and Intelligent Photovoltaic Power Generation System Based on Microgrid

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Abstract. A new design scheme of photovoltaic power generation system was proposed in the paper. The photovoltaic power generation technology was applied into an independent microgrid system, combined with intelligent grid technology and energy storage technology, and thus a portable and intelligent photovoltaic power generation system based on microgrid was constructed. The system was composed of solar power generation system, energy storage system, distribution apparatus and other parts. The photoelectric and line tracking methods were combined to make the battery panel conduct three-dimensional sun-chasing movement when it moves. The perturbation and observation method with variable step based on power prediction was raised so as to achieve maximum power point tracking. The battery energy management system was responsible for controlling the battery charging and discharging, as well as state detection, which ensured continuous and stable power supply of the load. The system could be expanded to build portable emergency power source, of great significance to rescue and relief work, military operation, field scientific investigation, navigation and so on.

1. Introduction
The paper focused on portable and intelligent photovoltaic power generation system based on microgrid with higher efficiency and rapid networking, aiming to solving the power supply problem in regions with an undersupply of electricity or without power supply system (damaged power supply systems included). At present, most of the photovoltaic power generation systems are fixed, and the power generation systems of vehicles and ships are auxiliary power supply. The power generation system studied in the paper adopted three major technologies: maximum power point tracking (MPPT), solar-cell panel tracking control technology and energy storage system control technology. With modular design, it can be assembled on mobile equipment such as automobiles, ships, airplanes and so on, as emergency power supply to offer AC and DC power. The power supply requirements of electrical equipment in special occasions, such as rescue and relief work, military operations, field scientific investigation, navigation and aviation can also be satisfied.

2. Integral Structure of the System
The portable and intelligent photovoltaic power generation system based on microgrid mainly consists of photovoltaic power generation system, illumination tracking system, energy storage system, distribution apparatus and other parts. The structure diagram of the system is shown in Figure 1.
Figure 1. Structure diagram of the system

The hardware part of the system is displayed in Figure 2. In the main circuit part, solar panels are connected to DC bus through DC/DC; DC/AC inverters convert DC to 50 Hz AC to supply electricity for AC load; energy storage batteries are connected to DC bus through bidirectional DC/DC; DC load is connected to DC bus directly. The information collection module mainly collects photovoltaic system, energy storage system, load and other related information, and then sends it to the central processing unit for calculation and control.

Figure 2. Block diagram of hardware system

3. Control Technology of the System

Extensible photovoltaic panels and energy storage system are included in the portable and intelligent photovoltaic power generation system based on microgrid, and two power sources provide electricity to the load jointly. The control of the whole system covers sun illumination tracking control, maximum power tracking control, energy storage system control and system monitoring.

3.1. Principle and Realization Method of the Sun-chasing System

The power supply capacity of photovoltaic panels will be affected by the changes of the external environment. An integrated control system is required to provide stable, reliable and safe electricity for the load. The overall diagram of the solar illumination tracking system is shown in Figure 3.

Figure 3. Diagram of solar illumination tracking system
The overall scheme of the system is to run different tracking modes under varied weather conditions. The system firstly judges the current weather condition by rain or shine detection circuit, and then determines the tracking that the system will operate. The flow diagram of the main program is shown in Figure 4.

![Figure 4. Flow diagram of the main program](image)

When the system is in an automatic mode and the illumination intensity is relatively strong, it will apply the operation mode of sunny day, collecting illumination intensity deviation and identifying positions through the photoelectric sensor. Single-Chip Microcomputer drives the stepping motor to rotate and adjust, so as to realize photoelectric tracking; when the illumination intensity is weak, the system will apply the operation mode of cloudy day, calculating the local elevating angle, azimuth angle and angle difference at the moment by gathering clock information. Single-Chip Microcomputer drives the stepping motor to rotate and adjust, thus tracking the motion trail of the sun. It can also be switched to manual mode by keystrokes, and the stepping motor can be adjusted by pressing the keys.

### 3.2. Control Strategy of MPPT

The traditional perturbation and observation method has three major defects in the control process: oscillation, misjudgment and fixed step. In order to realize maximum power point tracking, the perturbation and observation method is improved on the basis of traditional algorithm, and a new one with variable step based on power prediction is put forward in the system.

For ensuring the tracking accuracy and the reaction speed of maximum power point, the control method with fixed step is replaced by one with variable step. The working principle of the variable-step method is as follows: when the working point is far from the maximum power point, a larger step is selected to increase the reaction speed of the system and quickly approach the maximum power point; when the working point is near to the maximum power point, a smaller step is chosen to improve the accuracy of the system and make it infinitely close to the maximum power point. Following is the calculation formula of variable step:

\[
\Delta U = \omega \left( \frac{dP}{dU} \right) = \omega \frac{P(n+1) - P(n)}{U(n+1) - U(n)} \tag{1}
\]

In the formula, \(dP\) represents the power difference between the N+1 time of and the N time of voltage disturbance. \(dU\) represents the voltage difference between the N+1 time of and the N time of
voltage disturbance. \( \omega \) is a proportional constant, which is determined by the characteristics of system (generally 0.2).

When the illumination intensity and temperature are stable or change slowly, the change of step can take into account the dynamic and steady-state performance of the system, but it can not solve the problem of judgement very well. As a consequence, the control method of power prediction is proposed. The basic working principle is as follows: on the premise that sampling frequency reaches a certain speed, the change rate of illumination intensity per unit time remains constant, and the change of output power of photovoltaic module is also approximately constant, similar to the signal of linear change, as shown in Figure 5.

In times of \( t = nT \), the output voltage of photovoltaic module is \( U_{(n+1)} \) and the output power is \( P_{(n)} \). If no disturbance signal is added to the voltage, the output power after half a cycle is \( P_{(n+1/2)} \). Due to high sampling frequency, the output power reaches the level of linear variation. In another word, the difference value \( \Delta P_2 \) between the predicted value \( P^*_{(n+1)} \) after one cycle and the output power \( P_{(n+1/2)} \) after half a cycle equals to \( \Delta P_1 \) which refers to the difference value between \( P_{(n+1/2)} \) and the initial output voltage \( P_{(n)} \).

![Figure 5. Schematic diagram of power prediction](image)

After one period \( t = (n+1)T \), the prediction power is as follows:

\[
P^*_{(n+1)} = 2P_{(n+1/2)} - P_n
\]

(2)

When the prediction power is obtained, the voltage interference is added at \( t = (n+1)T \), and the actual voltage and power value of \( t = nT \) are measured to be \( U_{(n+1)} \) and \( P_{(n+1)} \). \( P^*_{(n+1)} \) and \( P_{(n+1)} \) can be regarded as two points on the same output characteristic curve at approximately the same time. The difference is that the predicted value is not disturbed by voltage, but the actual value is obtained by voltage disturbance. By comparing the two data, the disturbance caused by sudden change of external conditions is avoided, the correct disturbance direction being obtained, and the problem of misjudgement is effectively avoided. According to the above improvement strategies, the flow chart of the improved perturbation and observation method is shown in Figure 6.
By comparing the traditional perturbation and observation control algorithm with the improved one, the accuracy and rapidity of the algorithm with variable step based on power prediction are verified. The simulation models of the traditional perturbation and observation method and the improved one with variable step based on power prediction are shown in Figure 7 and Figure 8 respectively.

The parameters of photovoltaic array are as follows: $P_m = 12$ kW, $U_m = 460.2$ V, $I_m = 26.4$ A, $I_{sc} = 27.87$ A, $U_{oc} = 575.85$ V. The input parameters of photovoltaic arrays are substituted into the general model of photovoltaic cells to simulate. Under different conditions, the output power of photovoltaic arrays is as follows:

1. Steady temperature: $T = 25^\circ C$

The output power of MPPT control based on traditional perturbation and observation algorithm is shown in Figure 9. The illumination intensity is 1 kW/m² at the starting point. The voltage rises gradually from the moment of 0. The maximum power point is tracked around $t_1 = 0.039$ s, and the output
power is $P_{\text{mp}} = 11.87$ kW. At 0.1 s, the illumination intensity decreases to 0.8 kW/m², and the output power begins to oscillate. The oscillation amplitude is $\Delta y = 0.302$ kW, and the oscillation time is about 0.03 s. The stable output power is measured to be 9.109 kW in the end.

![Fig. 9 Output power of traditional perturbation and observation method](image)

Figure 10. Output Power of perturbation and observation method with variable step based on Power Prediction

The output power of the improved perturbation and observation method is shown in Figure 10. The initial illumination intensity is 1 kW/m². The voltage rises gradually from the moment of 0, and the maximum power point is tracked around $t_1 = 0.024$ s. The output power is $P_{\text{mp}} = 11.97$ kW. At 0.1 s, the illumination intensity decreases to 0.8 kW/m², resulting in a short period of intense oscillation. The oscillation amplitude is $\Delta y = 0.109$ kW, and the oscillation time is about 0.019 s. The output power tracked at last is 9.175 kW.

(2) Steady illumination intensity

The change of temperature has little effect on the output power, and thus only output power at the moment of temperature changing suddenly is analysed. The key parameters are marked in the Figure 11. At 0.2 s, the temperature changes from 25°C to 15°C suddenly, and the output power has a transitory but violent fluctuation, which is traced back to the maximum power point quickly. Under the same changing conditions, the output power tracked by the controlling strategies of improved perturbation and observation algorithm is 12.01 kW, which is slightly higher than that tracked by the traditional method. As shown in Figure 12. Besides, the maximum oscillation amplitude is only 0.06 kW, much lower than that of the traditional method.

![Figure 11. Output power of traditional perturbation and observation method](image)
Figure 12. Output Power of perturbation and observation method with variable step based on power prediction

(1) For high-power and high-voltage photovoltaic micro-grid power generation system, both of the two algorithms can finish the maximum power tracking task well under the circumstance of changing illumination intensity and temperature change. The enhanced perturbation and observation method significantly improves the tracking accuracy and achieves higher output power.

(2) It can be seen from the output curve that the output waveform of the improved perturbation and observation method is smoother and the oscillation amplitude is smaller. It helps to solve the problem of oscillation in the traditional method and reduce the loss of power.

(3) The contradiction between tracking accuracy and reaction speed is eliminated. Under the condition that the changes of environment are evident, the speed of reaching the maximum power point again is increased, and the output precision is closer to the maximum power point.

The above simulation results proved the advantages of the perturbation and observation method with variable step based on power prediction, which remedied the defects of the traditional method and dramatically advanced the steady-state and dynamic performance of the system.

3.3. Energy Management Strategy of Energy Storage System

The major functions of energy storage system are to suppress the fluctuation of photoelectric power and act as backup power supply. Therefore, the management and control of energy storage system includes the stabilization control of photoelectric power and the charging and discharging control of battery.

It is required that energy storage units should ensure continuous power supply for critical loads and charge and discharge electricity reasonably to ensure their service life. The flow chart for the charging and discharging control of energy storage system is shown in Figure 13.

Figure 13. Flow chart for the charging and discharging control of Energy Storage System
(1) When the power generated by the photovoltaic power generation system exceeds the demand of loads, the photovoltaic power generation system supplies power to the loads directly, and the extra power is charged to the battery.

(2) When the power generated by the photovoltaic power generation system can’t satisfy the demand of loads, the shortage of power provided by the photovoltaic power generation system is supplied by the battery.

(3) When the power generated by the photovoltaic power supply system is close to the demand of loads, there are two different situations. If the internally stored energy of energy storage units is low, the energy storage units needs to be charged to reach the set capacity. If the internally stored energy of energy storage units is higher than the set capacity, the energy storage units needs to be discharged to satisfy the electricity balance of system and ensure sufficient adjustment space for the energy storage units.

In the photovoltaic system, the characteristic curve of photovoltaic cells is non-linear on account of the influence of temperature and illumination intensity. The big fluctuation of output power in the photovoltaic arrays will affect the design, scheduling and control of the whole power grid. The project solves the problem of power fluctuation by adding energy storage system into battery, so as to maintain the voltage stability of DC bus. Through the cooperation of MPPT and bidirectional DC/DC converter, the energy storage and release of the battery are carried out for suppressing the fluctuation of photovoltaic output power and controlling its change rate, shown in Figure 14.

![Figure 14. Control strategy of power stabilization](image)

The control method of double closed loops is adopted to stabilize the photoelectric power and the outer loop is a controlling one for power. \( P_{pv} \) is a value got through low-pass filter and \( P_{pv\_s} \) is the given value of grid-connected power. The working reference power of battery is \( P_{b\_ref} = P_{pv} - P_{pv\_s} \). \( e \) is the error between the actual power of battery \( P_b \) and \( P_{pv\_s} \). \( I_{b\_ref} \) is the reference current of battery through PI regulator. The inner loop is a controlling one for current, and it tracks the reference current value \( I_{b\_ref} \) given by the outer loop through checking the actual working current \( I_b \) of battery. It can be seen in Fig. 14 that the clipping link is used after the PI regulator of the outer loop to limit the working voltage of the battery.

4. Control Technology of the System

In accordance with the implementation plan of the project, a portable and intelligent power generation simulation system based on microgrid of 5kw is designed, including solar power generation system, 10kwh energy storage device and control systems like two sets of load distribution apparatus (DC and AC), sun-chasing system, maximum power tracking and controlling, energy management system and so on. The system is used to supply electricity to the computers, mobile phones, electric kettles, air conditioners, experimental equipment and other electrical appliance in the laboratory.

4.1. Information Collection of the System

The data of the system working for one day are observed through the interface of the energy management system, including the generated power of photovoltaic system, the discharge power of energy storage system, load power, SOC of energy storage and so on. The curves for the generated power of photovoltaic system and the load power are shown in Figure 15.
4.2. Comparison of Photoelectric Power between This System and Traditional System

The sun-chasing system and the MPPT module are added in our system. Photovoltaic panels can rotate any angle in the three-dimensional space to find the best point of light receiving.

The power curve of the system is obtained directly by the energy management system, while the photoelectric power of the traditional system is fitted the simulation software. The comparison results are shown in Figure 16. It can be seen from Fig. 16 that the power generation performance of this system is obviously superior to that of traditional power generation.

5. Control Technology of the System

In order to satisfy the demand of emergency electrical power supply in some special occasions, a design scheme of portable and intelligent photovoltaic generation system based on microgrid is put forward in the project. The sun-chasing control technology is introduced to the system. The photoelectric tracking is combined with the sun-viewing trajectory tracking algorithm to make the solar panels obtain the maximum illumination intensity and realize the maximum utilization of solar energy. The traditional algorithm is improved in terms of MPPT module, and the perturbation and observation method with variable step based on power prediction is adopted to make the photovoltaic power generation system achieve maximum power output under certain illumination intensity. The energy storage device and energy management system are added to enhance the power supply capacity of portable power source and ensure smooth and stable power supply quality.
Through experimental verification of the developed power-supply system, the design scheme of the project has been fully realized, and the expected design objectives have been achieved. The control functions are complete and the control effects are favorable. The modules of the project can be transferred and installed to specialized vehicles and ships, and the capacity of solar power generation and energy storage devices can be expanded according to our needs to form a portable and intelligent photovoltaic power generation system based on microgrid.

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**References**
[1] I Szeidert, IFilip, FDragan. et al. Issues regarding the usage of MPPT techniques in micro grid systems [J]. IOP Conference Series: Materials Science and Engineering, 2018, 294 (1).
[2] Zhang Jiyang, Li Da, Yang Ping, et al. Analysis on the Development Trend of Photovoltaic Power Generation [J]. Renewable Energy Resources, 2014, 32 (02): 127-132.
[3] Liu Hongpeng, Zhu Hang, Wu Hui, et al. A New Voltage-mode Control Method for Photovoltaic Grid-connected Inverter [J]. Proceedings of the CSEE, 2015, (21): 5560-5568.
[4] Bai Shuhong. Predictive Power Control of a New Type of Photovoltaic Inverter [J]. Acta Energiae Solaris Sinica, 2014, 35(02): 230-236.
[5] A.S.Oshaba. E.S.Ali. S.M.Abd Elazim. PI controller design for MPPT of photovoltaic system supplying SRM via BAT search algorithm [J]. Neural Computing and Applications, 2017, 28(4): 651-667.
[6] Guan Mingjie, Wang Kunpeng, Zhu Qingyuan. et al. A High Efficiency Boost Converter with MPPT Scheme for Low Voltage Thermoelectric Energy Harvesting [J]. Journal of Electronic Materials, 2016, 45(11): 5514-5520.
[7] Ning Pei, Zhou Huiyuan, Hu Jiaxin, et al. MPPT Strategy Based on Improved Perturbation and Observation Method with Variable Step [J]. Telecom Power Technology, 2019, 36(01): 17-20.