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Optimization and Simulation of Photovoltaic MPPT Control Strategies

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Abstract: Power generation based on solar photovoltaic principle has developed rapidly in recent years due to its advantages of no pollution and inexhaustible resources. The output characteristics of solar photovoltaic are susceptible to external environmental factors, therefore, the maximum power point needs to be tracked in real time so that the PV system works continuously at the maximum power point. In order to improve the speed and stability of the PV system tracking and reduce the power loss in the steady state, the perturbation and observation (P&O) method which is used commonly in Maximum Power Point Tracking (MPPT) control method is selected for analysis in this paper. In view of the shortcomings of its existing control methods, this paper will analyze and compare the algorithms based on three perturbation and observation strategies: fixed-step, variable-step and artificial neural networks. The simulation results indicate that the perturbation and observation method of variable-step and neural network track strategy are relatively fast, and the neural network control strategy is the most stable after tracking to the maximum power point.

1. Introduction

The exploration of new energy resources is of great strategic significance to energy security and supply diversification, and plays a positive role in economic growth, pollution prevention, energy conservation and emission reduction. It is a significant energy strategy for sustainable development of all countries in the world. Solar energy is the most essential source to provide a clean environment and a better gain in economic[1]. Solar power generation technology is a way of generating electricity by converting solar energy directly into electricity without other energy conversion. Photovoltaic (PV) is currently considered the most popular renewable energy[2-4] due to its many advantages. Solar photovoltaic systems are attracting a lot of attention in the field of new energy generation because of their characteristic of environmental friendly, reproducible and convenient. However, the output characteristics of solar power generation are easily affected by the external environment[5], which is still far from sufficient for large-scale application. Particularly it has the high production costs, low power conversion[6-8] and nonlinear I-V and P-V characteristics. So there is still more room for improvement in power generation efficiency. Typical solar system efficiency is within 9% and 17%[9].Therefore, a more reasonable structure of the solar power system and the adoption of a suitable MPPT strategy can effectively improve the conversion efficiency of solar energy, maximize the use of renewable resources and achieve better economic and ecological benefits while protecting the environment. Conventional P&O MPPT is the most common tracking strategy in many industrial applications due to many reasons such as; simplicity, low cost, reduced number of required sensors, and direct operation[10]. This paper will focus on the analysis of the perturbation and observation (P&O) method strategy, which has simple structure and few measured parameters[11]. The MPPT approach allows the PV module to function at its maximum power point by controlling the switching converter[12].The simulation analysis and comparison of the algorithms of the P&O method strategies of fixed-step, variable-step and artificial neural network will be carried out to realize optimization of the PV system performance in any radiation and temperature conditions that the solar panels undergo[13].

2. MPPT Control Strategies of Photovoltaic System

2.1. Photovoltaic System Derived from Fixed-Step P&O Method

How to improve the output efficiency of photovoltaic array needs to be studied emphatically. Among the commonly used MPPT methods, the hardware selection of the conductivity increment method is complicated, and it is difficult to select the appropriate step size[14]. Therefore, the perturbation and observation method is selected in this paper, which has excellent local optimization ability[15]. The principle is to compare the two output powers before and after the disturbance is applied, and define the change direction of the perturbation according to the change direction of the power. The specific control flow is shown in Figure 1. In the conventional P&O, the power (P) is computed using the measured values of the voltage (V) and current (I) of the PV array[16]. The system continuously samples and records the output current and voltage parameters, calculates the output power, and then calculates ΔU, ΔP. When the applied disturbance $\Delta U > 0$, and $\Delta P > 0$, continue to apply forward disturbance. When the applied disturbance $\Delta U > 0$, and $\Delta P < 0$, reverse disturbance is applied instead. When the applied disturbance $\Delta U < 0$, and $\Delta P > 0$, continue to apply the reverse disturbance. When the applied disturbance $\Delta U < 0$, and $\Delta P < 0$, apply forward disturbance instead. After constant repetition of the perturbation, the output power will be closer to the maximum power point and eventually achieves its tracking. The speed of convergence to a maximized power point depends on the step size[17].

The perturbation and observation method has clear logic and is simple to implement, but its output voltage is easy to fluctuate. In addition, it suffers from the low tracking speed and high steady state oscillations that forms the main shortcomings of these methods[18].So it is important to select a reasonable step size.

2.2. Photovoltaic System Derived from Variable-Step P&O Method

The MPPT strategy used in the solar electric generating system is the fixed-step perturbation and observation method, but the selection of the disturbance step size becomes a big problem. If a larger step size is chosen, the tracking accuracy will be sacrificed, and the oscillation problem is very obvious. The system will not stabilise at the maximum power point and eventually oscillate around it, resulting in power loss. If the tracking accuracy is to be improved, the disturbance step size must be reduced, but this will increase the time for the system to track to the maximum power point, and it is difficult to meet the control time requirements[19]. For the sake of solving this problem, the system adopts variable-step perturbation and observation method to improve the defect that the accuracy and speed cannot be given consideration. The disturbance step is set as $\text{deltaD} = \text{aK} + \text{b} \Delta \text{P}$, where deltaD is the change amount of duty ratio. K is calculated from the difference among the output power P, output voltage V and angular velocity ω obtained from the first and second sampling, as $\frac{dP}{dV}$ or $\frac{dP}{d\omega}$. ΔP is equal to $P_{max} - P$, where P_{max} is the maximum output power recorded by the system in a stable environment. P_{max} restarts recording after certain changes in light intensity, temperature and other conditions, and a and b are constants.

When the system power has further distance with the maximum power point, the slope of each point on the power curve is larger and the deltaD is also larger, so the system will use a larger step to approach the maximum power point fast. After approaching the maximum power point, the power curve will become gentle, and the deltaD will decrease. The system should be capable of tracking the maximum power point more accurately.

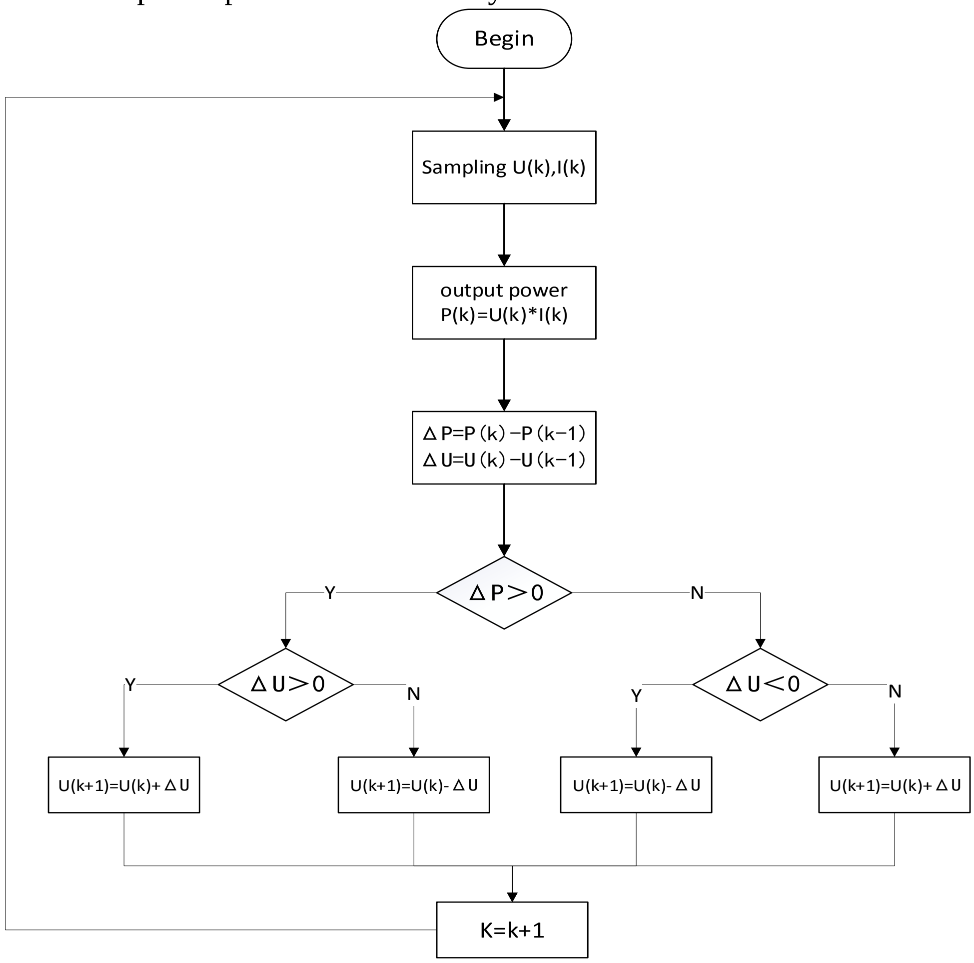

Figure 1: Flow chart of P&O method.

2.3. Photovoltaic System Optimized by Artificial Neural Network

After the above simulation experiments, a large amount of data has been accumulated, which can provide a basis for the optimization of the system using artificial neural network. The artificial neural network which is composed of a large number of neurons (also known as nodes) connected with each other is usually used as simulation of the structure and function of the human brain nervous system. The nodes are connected and performs calculation. They modify their own parameters according to the external information. It mainly adjusts the connection weights of each neuron through network training, model the input data of the input layer, and store the learned knowledge in the adjusted connection weights. Finally, the network is able to solve practical problems[20].

The structural design process of a neural network includes the determination of the numerical value of neurons in the input and output layers, the numerical value of neurons in the hidden layer and the transfer function of each layer. The weights of the neural network are obtained through training, and the goal of which is to achieve a certain threshold for the sum of the squared errors of the sample output and the network output [21]. The realization process of neural network needs to be learned first. The network weights are determined through the learning samples, and then the recognition is carried out.

Neural network can approach continuous nonlinear function arbitrarily, and can deal with some residual nonlinear factors in information. It is more suitable for some complex processes with unclear mechanism knowledge and inference rules. The neural network has a fast running speed, which includes the reception, conversion and output of information in the whole process of processing information. Due to the distributed processing within the network, it has a high tolerance for data including noise and measurement error.

When selecting the output node, in order to facilitate the specific application of the model, first quantify the parameters and select the data corresponding to the initial sample. The selection of the number of hidden layer units has a direct relationship with the number of output output units, which is a relatively complex problem. At present, there is no unified answer from the development of BP network theory. In the actual calculation process, it can be selected according to $n_1 = \sqrt{n+m+a}$, ($\boldsymbol{n}$ is the numerical value of input neurons, $\boldsymbol{m}$ is the numerical value of output neurons, and $\boldsymbol{a}$ is a constant between 1 and 10), and $n_1 = log_2 n$. Whether the number of hidden layer nodes is appropriate can be determined by the size of the error rate. Similarly, since the final calculation result is a binary value, the selection of output nodes is different according to different samples.

3. MPPT Simulation Analysis of Photovoltaic System

3.1 System simulation of fixed-step P&O method

The simulation model of the solar electric generating system as shown in Figure 2. The PWM generator that implements the MPPT is shown in Figure 3, and the tracking is implemented by the fixed-step perturbation and observation method. The parameters of each element in the system boost circuit are set as inductance L=1.2 MH, capacitors C_1 and C_2 are respectively 10 μF and 452 μF and output resistance R=20 Ω.

The system simulation duration is 2 S, and the standard environmental conditions for a solar power system are set at a light intensity of 1000 W/m^2 and a temperature of 25 ℃. At 1S, the light intensity increases to 1400 W/m^2 and the temperature increases to 30 ℃ at 1.5 S. The duty cycle perturbation is set to 0.001. The power tracking and duty cycle variations are shown in Figure 4 and Figure 5.

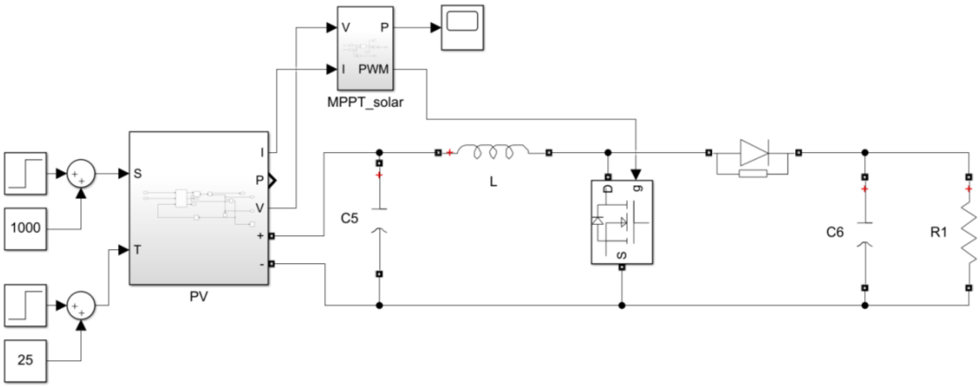

Figure 2: Simulation model of solar electric generating system.

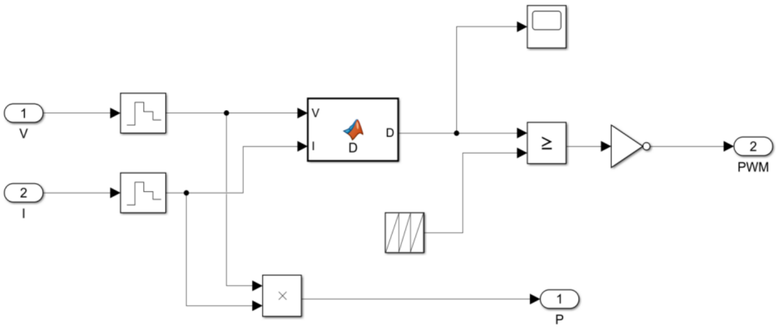

Figure 3: PWM generator based on fixed-step perturbation.

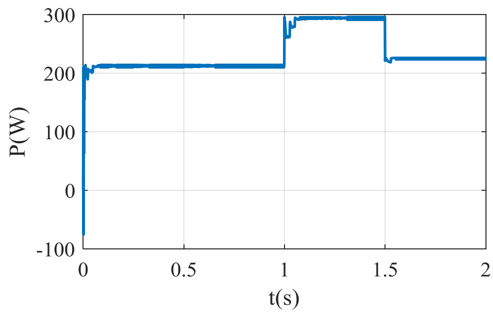

Figure 4: Power tracking chart.

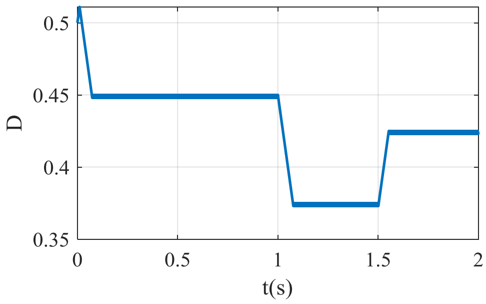

Figure 5: Duty cycle change chart.

When the light intensity S=1000 W/m ²and the temperature T=25 ℃, the output power is about 213 W and the duty cycle is about 0.45. When the light intensity S=1400 W/m ²and the temperature T=25 ℃, the output power is about 295 W and the duty cycle is about 0.37. When the light intensity S=1400 W/m ²and the temperature T=30 ℃, the output power is about 225 W or so, and duty cycle is about 0.42 or so. It can be seen that the solar cell output power is positively correlated with light intensity and negatively correlated with temperature. However, regardless of changes in light intensity and temperature, the controller is able to track the maximum power point within a short period of time and remain at maximum power output, improving the energy efficiency.

3.2 System Simulation of Variable-Step P&O method

The PWM generator optimized for the solar electric generating system as shown in Figure 6 is built in Simulink, and the variable-step perturbation and observation method is adopted. The simulation duration of the system is 2 *S*, and the light intensity and temperature settings are consistent with the above.

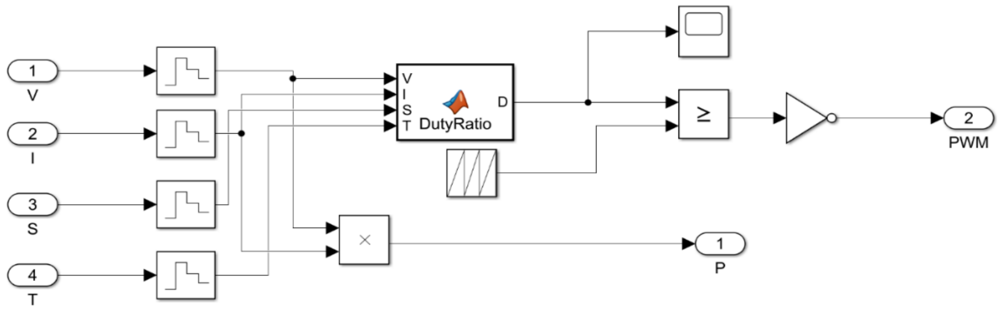

Figure 6: PWM generator based on variable-step perturbation.

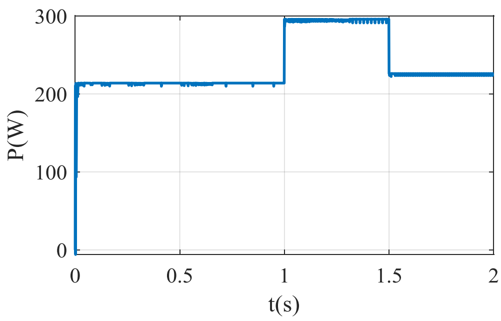

Figure 7: Power tracking chart.

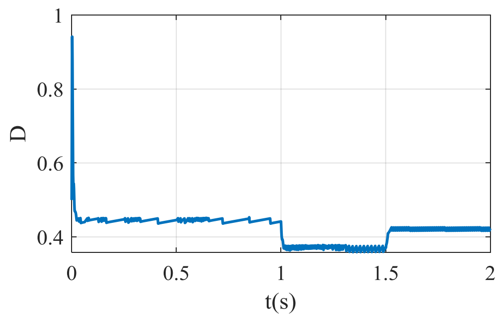

Figure 8: Duty cycle change chart.

When the light intensity S=1000 W/m ²and the temperature T=25℃, the output power is about 213 W and the duty cycle is about 0.45. when the light intensity S=1400 W/m ²and the temperature T=25℃, the output power is about 295 W and the duty cycle is about 0.37. when the light intensity S=1400 W/m ²and the temperature T=30 ℃, the output power is about 225 W or so, and duty cycle is about 0.42 or so. The steady-state results are basically consistent with the fixed-step perturbation and observation method. However, it is obvious from the figure that the variable-step method improves the response speed of the system tracking and locates the numerical range of the maximum power point more quickly.

3.3 System Simulation of Artificial Neural Network Optimization

Figure 9 is a PWM generator based on ANN in the solar electric generating system established in Simulink. The changes of system power tracking and duty cycle are shown in Figure 10 and Figure 11. The system simulation duration is 2 *S*, and the other settings are consistent with the previous ones.

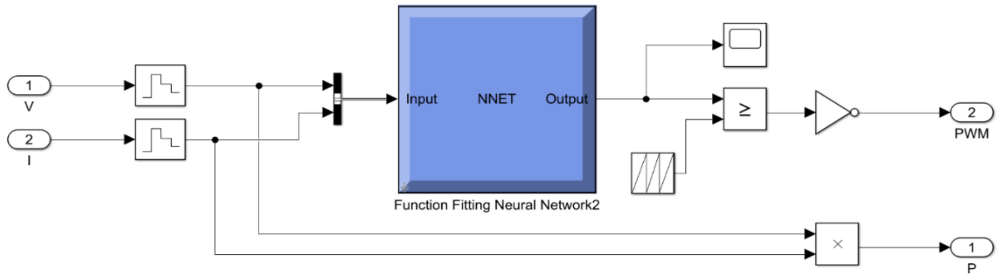

Figure 9: PWM generator based on ANN.

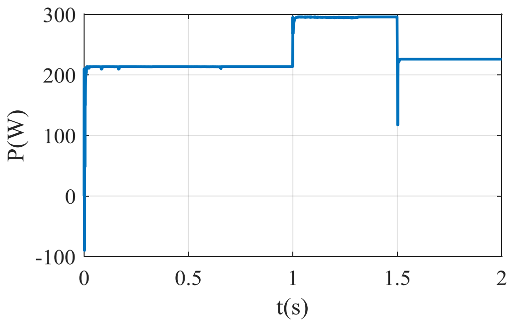

Figure 10: Power tracking chart.

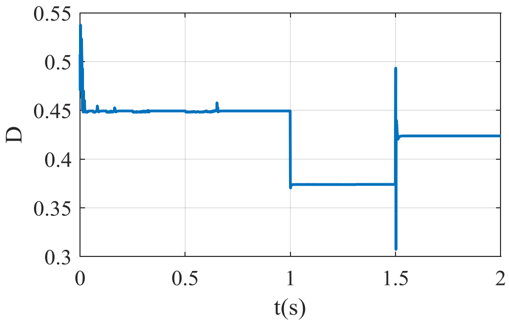

Figure 11: Duty cycle change chart .

Similarly, under the control variable method, the numerical values of the illumination intensity and temperature are set to be the same as those of the above fixed-step and variable-step simulation. The simulation results of the output power and duty cycle of the power generation system based on the artificial neural network are basically consistent with the simulation results of the fixed-step method, which verifies the feasibility of tracking the maximum power point by the artificial neural network.

3.4 Comparison and Analysis of Three Control Strategies

After the simulation analysis of three different strategies of the solar electric generating system, perturbation and observation method based on fixed-step and variable-step and artificial neural network, the simulation waveform of the three control strategies are compared and analyzed. The simulation duration of the system is 2 *S*, and the illumination intensity and temperature are the same as the above.

Figure 12 is a comparison chart of maximum power tracking. Under the control of fixed-step method, the system takes about 0.079 *S*, 0.077 s and 0.035 *S* to track the maximum power point for three times, and there is generally 2-5 W fluctuation after stabilization. Under the control of variable-step method, it takes about 0.015 *S*, 0.013 *S* and 0.011 *S* for the system to track the maximum power point for three times, and there is 2-5 W fluctuation after stabilization. However, compared with the control strategy of fixed-step, the fluctuation time is significantly reduced. Under the control of artificial neural network, it takes about 0.015 *S*, 0.019 *S* and 0.011 *S* for the system to track the maximum power point three times. After stabilization, there is an occasional fluctuation of 1-3 W. Comparing the three control schemes, the variable-step method and the neural network control scheme track relatively fast. The neural network control scheme is the most stable after tracking to the maximum power point, and there is no fluctuation in most of the time.

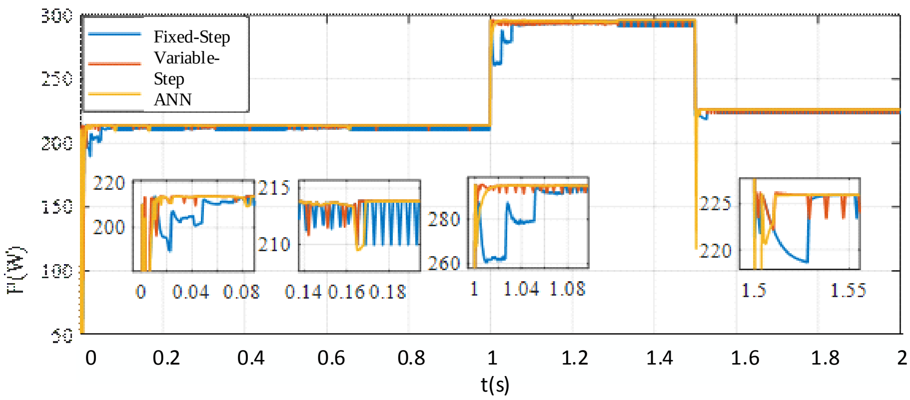

Figure 12: Power tracking comparison chart.

4. Conclusions

In this paper, the MPPT control strategy of solar electric generating system is studied, and the modeling and simulation analysis of solar electric generating system are carried out. This paper introduces the perturbation and observation method, which is commonly used in MPPT. Three perturbation and observation methods, such as fixed-step, variable-step and artificial neural network, are discussed and simulation models are established, and then the comparison and analysis of the three algorithms are carried out. Through the modeling and simulation analysis of photovoltaic power generation, it can be seen that the variable-step method and the ANN are relatively fast to track, and the ANN control scheme is the most stable after tracking to the maximum power point, and there is no fluctuation in most of the time. So the ANN control scheme has more advantages in steady-state accuracy and tracking speed.

In this paper, some traditional MPPT strategies are studied, and the research on variable-step perturbation observation method and artificial neural network optimization methods need to be further researched to achieve more perfect MPPT strategies.

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