

Research on Photovoltaic MPPT based on Improved Sliding Mode Extremum Seeking Control

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Abstract

In order to improve the efficiency of photovoltaic power generation system and solve the problem of maximum power point transfer caused by changes in the external environment, a photovoltaic maximum power point tracking (MPPT) strategy based on the improved sliding mode extremum seeking control (SMESC) is proposed. While realizing the real-time tracking of maximum power point of photovoltaic system, the chattering existing in the traditional SMESC is suppressed through the adaptive adjustment of sliding mode surface parameters, and the better tracking effect is achieved. In addition, the simulation model of photovoltaic power generation system is built based on MATLAB/Simulink platform, and the MPPT effects of PSO algorithm, SMESC algorithm and improved SMESC algorithm are compared and studied. The simulation results show that the MPPT method based on the improved SMESC can realize the real-time tracking of the optimal working point when the external light intensity and temperature change, and avoid the influence of chattering compared with the SMESC algorithm, which has better control effect.

Keywords

MPPT; Sliding Mode Extremum Seeking Control; Photovoltaic Power Generation System; Chattering Suppression.

1. Introduction

Photovoltaic system is a power generation system that uses the photovoltaic effect of semiconductor materials to convert light energy into electric energy. Its energy source is clean, safe and renewable solar energy, and the power generation process will not cause pollution and damage to the ecological environment. It is one of the new energy sources with great development potential[1].

Photovoltaic cell is the core module of photovoltaic power generation system. Under a certain uniform light and ambient temperature, there is a nonlinear relationship between the output voltage and output current of the circuit inside the photovoltaic cell, and there is a separate maximum power point. Through the control algorithm to regulate the output voltage and carry out maximum power tracking technology, the photovoltaic cell can obtain the maximum working efficiency.

In the application, under the preset fixed light intensity and temperature conditions, the determined output voltage is set for the photoelectric system generally according to experience. However, in the actual working process, whether the light intensity changes or the ambient temperature changes, the actual maximum power point will deviate from the preset working point, thus reducing the photoelectric conversion efficiency of the battery. In order to keep the

photovoltaic cells operating at the maximum power point to improve the photoelectric conversion efficiency, scholars have proposed a variety of MPPT control methods, but different algorithms have different applications, and also have their own advantages and disadvantages. Therefore, the research on MPPT control technology using different strategies still has extensive development space. At present, common control strategies at home and abroad include classic algorithms such as constant voltage tracking (CTV)[2], perturbation and observation (P&O)[4], as well as emerging algorithms such as fuzzy logic control (FLC)[6], neural networks (NN)[7], particle swarm optimization algorithm (PSO)[8].

From the current research status, MPPT has always been a very active research field[9]. It is necessary to explore how to improve the accuracy, real-time and practical economy of the method for the scene of significant changes in light intensity and ambient temperature under the condition of uniform sunlight.

In fact, MPPT of photovoltaic system is an excellent extreme value search problem. Considering that the extremum seeking control (ESC) algorithm has the advantages of model independence, high accuracy, simple structure and small amount of calculation, sliding mode extremum seeking control (SMESC) algorithm is applied to MPPT control of photovoltaic system in this study. In order to avoid the buffeting effect of SMESC itself, a buffeting suppression strategy based on adaptive adjustment of sliding surface parameters is proposed to design the unipolar MPPT control system under uniform and variable illumination, which can reduce the calculation amount of the algorithm and improve the accuracy of MPPT control.

2. Modeling of Photovoltaic Cells

Photovoltaic cell is a semiconductor device based on PN junction, which uses photoelectric effect to realize the conversion from solar energy to electric energy, and is the core part of the whole photovoltaic system. In engineering, ideal model or diode equivalent circuit model is often used to study and analyze it. Ideally, as shown in Fig 1, the photovoltaic cell model can be simplified into four parts: photo generated current source, parallel diode and series parallel resistance.

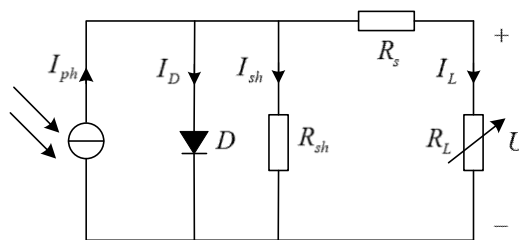


Fig.1 Diode equivalent circuit model of photovoltaic cell

According to the model, Kirchhoff's law can be applied and to obtain

$$I_L = I_{ph} - I_o \left\{ \exp \left[\frac{q(U + I_L R_s)}{A k T} \right] - 1 \right\} - \frac{U + I_L R_s}{R_{sh}} \tag{1}$$

Where I_L and U are the output current and voltage of the photovoltaic cell respectively; I_{ph} is the current of the photogenerated current source, which is determined by the radiation intensity of the light, the installation angle and area of the photovoltaic panel and other factors; R_{sh} and R_s are the parallel resistance and series resistance of the built-in electric field of the

photovoltaic cell respectively, indicating the internal loss of the cell; I_{sh} is the current flowing; I_D is the current flowing through the equivalent diode inside the photovoltaic cell, which I_o is its reverse saturated current; $q = 1.6021892 \times 10^{-19} C$ is the unit charge; A is the constant of PN junction curve, with a value range of 1~2; $k = 1.3086 \times 10^{-23} J/K$ is Boltzmann constant and T is ambient temperature.

According to the above mathematical model, the simulation model of photovoltaic cells is built in MATLAB/Simulink platform, and the P-V output characteristic curve of photovoltaic modules under different light intensity and ambient temperature can be obtained, as shown in Fig.2.

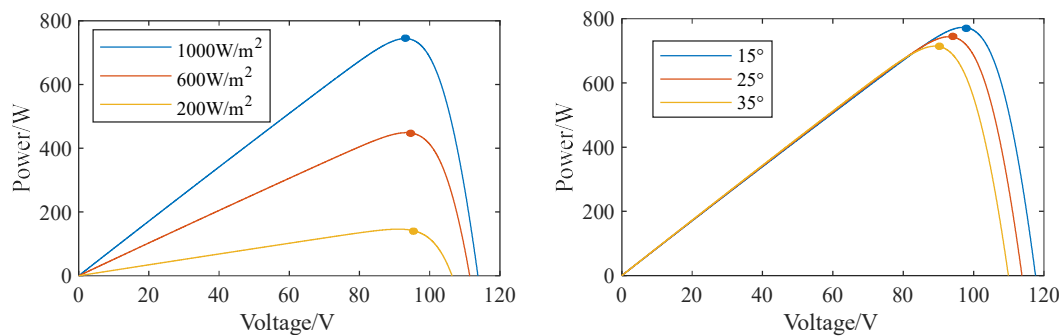


Fig. 2 (a) P-V output characteristic curve under different light intensities at 25° (b) P-V output characteristic curve under different temperatures at 1000 W/m^2

When the ambient temperature and light intensity are constant, the P-V characteristic curve of photovoltaic cells has a single peak characteristic, that is, the output power of photovoltaic cells is mainly determined by the output voltage, and there is a maximum point, the so-called maximum power point. When the ambient temperature is constant, the maximum power point voltage decreases and the maximum output power increases with the increase of light intensity; When the light intensity is constant, the maximum power point voltage decreases and the output power decreases slightly with the increase of temperature. It can be seen that the change of light intensity and ambient temperature will lead to the change of maximum power point voltage, and the influence of light intensity on maximum output power is particularly significant. In practice, the intensity of sunshine in a day is always changing according to the change of the sun's orientation, and the ambient temperature is also greatly affected by the sunshine, so the maximum power point also changes over time. If a fixed output voltage is used, it is obvious that it cannot meet the expectation of maintaining the best working state. In order to improve the power generation efficiency, it is necessary to adopt the maximum power point tracking strategy to make the photovoltaic array always work at the maximum power point.

3. Design of MPPT Control Strategy based on Improved SMESC

3.1. Principle of SMESC

The SMESC is an optimization algorithm combining the sliding mode control and extremum search principle. By designing the sliding mode surface and using its discontinuous control law, the system state is forced to move along the switching surface to realize the online search and tracking of the extreme points of the dynamic system. It has the advantages of simple structure and easy implementation[10]. The control block diagram of the SMESC is shown in Fig.3.

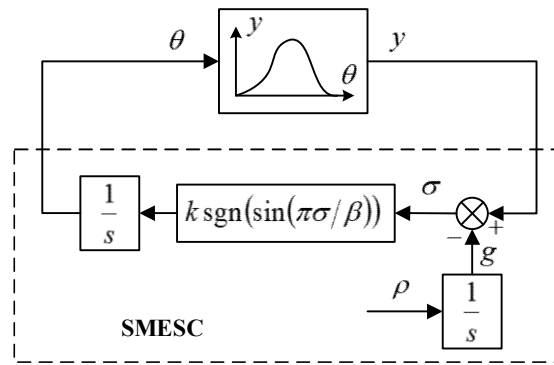


Fig.3 Control schematic diagram of SMESC

Where k, β, ρ are the control parameters of the algorithm, which are positive constant. The SMESC has a series of parallel sliding mode surfaces, which are determined by the switching function $\eta = \sin(\pi\sigma/\beta) = 0$. As long as the gradient of the system satisfy $|\dot{\phi}(\theta)| > \rho/k$, that is $\eta\dot{\eta} < 0$, the sliding mode surface of the system exists and can be reached.

The seeking process of SMESC system can be divided into three stages according to whether the system trajectory is on the sliding mode surface:

- 1) The arrival phase: the process of the system trajectory from any initial position to the sliding surface;
- 2) The sliding stage: the difference between the cost function and the reference function remains constant, and the system converges to the extreme point;
- 3) The steady-state stage: when the current valence function reaches the extreme point, it loses the ability to continue monotonically increasing or decreasing, and the system trajectory will break away from the sliding surface and finally oscillate and stabilize near the extreme point.

3.2. Design of Improved SMESC without Oscillation

According to the analysis in the previous section, it can be seen that when the SMESC reaches a neighborhood of the extreme point, because the forced motion cannot continue, the system will leave the sliding mode surface and make reciprocating motion in the neighborhood, finally forming a steady-state oscillation, and the amplitude of the steady-state oscillation is positively correlated with the value of ρ/k and β . Due to the control accuracy requirements, the value of ρ/k determines the size of the $\Theta_{(\delta_l, \delta_r)}$ neighborhood, and its value has been required to be set as small as possible, while the value of β cannot be set too small in order to prevent the dislocation of the sliding surface. If the parameters of sliding mode surface can gradually decrease after the system reaches the steady-state stage, the amplitude of steady-state oscillation will be smaller and smaller while preventing the sliding mode motion from dislocation. Based on this idea, this paper designs a method of adjusting parameters online to suppress the oscillation in the steady-state stage. When the system has not reached the sliding mode for the first time or is sliding on the sliding mode surface, the value of β is set to be large to meet the convergence condition of the sliding mode surface. When the system is out of the sliding mode surface, β will change according to the following formula,

$$\beta = \beta_0 + \beta_m e^{-k_\beta |\sigma - \sigma_i|} \quad (2)$$

so as to reduce the oscillation amplitude and suppress the steady-state oscillation. In this formula, β_0, β_m and k_β are preset constants. When the system has not reached the sliding

mode, σ_i is equal to σ_0 , which is the initial value of σ . When the system reaches the sliding mode, it is updated to the current value of σ when the sliding motion starts. According to this strategy, there will be $\beta = \beta_0 + \beta_m$ in the initial stage and sliding motion stage, and then as the sliding motion disappears, the difference between σ and σ_i becomes larger and larger, resulting in gradual attenuation to $\beta = \beta_0$. The system block diagram of applying the steady-state oscillation suppression control strategy to the SMESC algorithm is shown in Fig.4.

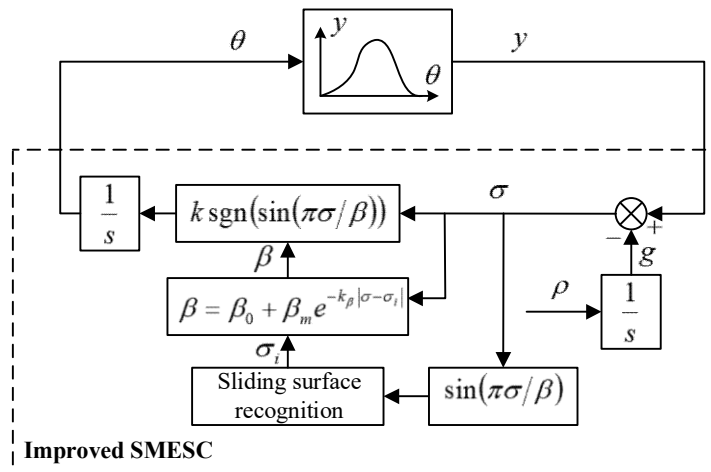


Fig.4 Control principle block diagram of improved SMESC

3.3. Photovoltaic MPPT Control Strategy based on Improved SMESC

MPPT technology makes the impedance of photovoltaic array match the equivalent impedance by adjusting the duty cycle of DC-DC converter. The DC-DC converter between the photovoltaic array and the load or energy storage terminal can adjust the DC voltage generated by the photovoltaic array to adapt to the load or energy storage module.

The DC voltage and current output by the photovoltaic battery pack is used as the input of the MPPT controller, and the output is the duty cycle. The MPPT control module implements the improved SMESC algorithm, determines the optimal duty cycle by searching the maximum power point voltage, and inputs it to the pulse width modulation to drive the DC-DC circuit to change the input resistance in the circuit, so as to control the maximum power output of the photovoltaic array and ensure that the system operates at the optimal working point. The proposed MPPT control topology of photovoltaic system based on improved SMESC is shown in Fig.5.

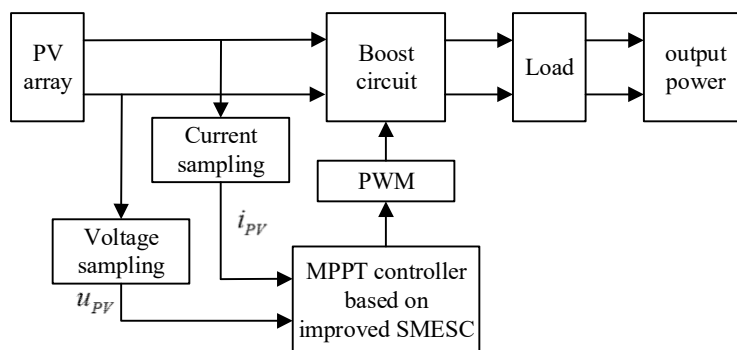


Fig.5 MPPT control topology of photovoltaic system based on improved SMESC

4. System Simulation and Result Analysis

A photovoltaic simulation system consisting of photovoltaic array, MPPT controller, boost circuit and load, as shown in Figure 4, is built on the MATLAB/Simulink simulation platform. In order to verify the effectiveness of the improved SMESC algorithm used in this paper, PSO, SMESC and improved SMESC algorithm are simulated in MPPT system, and their optimization efficiency and convergence speed are analyzed. The parameters of SMESC algorithm are set as $k = 2500, \rho = 5000, \beta = 30$, the parameters of improved SMESC are set as $k = 2500, \rho = 5000, \beta_m = 30, \beta_0 = 1, k_\beta = 0.05$, the particle number of PSO algorithm is set to 10, the maximum number of iterations is 150, and the learning factor is set to $c_1 = c_2 = 1.2$. In the simulation experiment, when the simulation time is up to 0.5s, the working condition changes from light intensity of $1000 W/m^2$, temperature of 35° to light intensity of $200 W/m^2$, temperature of 15° . According to the model, the maximum power voltage changes from 89V to 95.25V, and the maximum power value changes from 714.5W to 152.4W. The simulation results are shown in Fig.6.

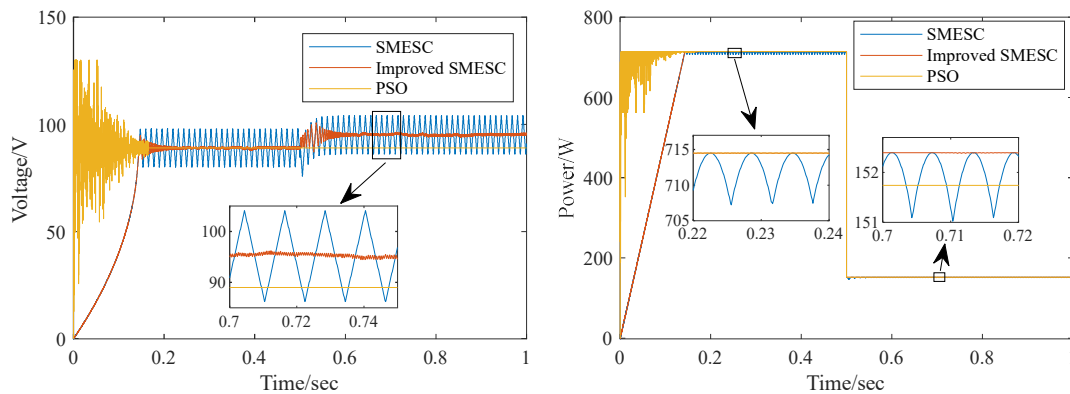


Fig.6 (a) Tracking effect of optimal working voltage under different algorithms (b) Output power of photovoltaic system under different algorithms

It can be seen from Fig.6 that under the initial conditions, PSO, SMESC and the improved SMESC algorithm can effectively search for the best operating point, and the search results of SMESC finally oscillate near the best operating point, while PSO and the improved SMESC algorithm make the system stable at the maximum power. When the system working condition changes suddenly, SMESC and improved SMESC can respond in real time and search for the new optimal working point, while PSO algorithm cannot search again as the number of iterations reaches the upper limit. To restart the search, restart mechanisms need to be designed. However, the restart mechanism is often set according to the threshold discrimination, and can only be transferred when the extreme point is offset by a sufficient amount, which cannot achieve the effect of real-time search for the best working point. To sum up, the improved SMESC algorithm can realize the real-time tracking of the best working point, and avoid the influence of chattering compared with SMESC algorithm, which has better tracking effect.

5. Conclusion

In this paper, the SMESC algorithm is applied to the MPPT control strategy design of photovoltaic system to realize the automatic tracking of the maximum power point when the maximum power point of photovoltaic array is transferred, so as to ensure that the system always works in the maximum power state. In order to avoid the influence of the chattering

phenomenon of traditional SMEC, this paper proposes an improved SMESC method that suppresses the chattering through the adaptive adjustment of sliding mode surface parameters, maximizes the advantages of ESC algorithm in MPPT problem, and greatly improves the utilization rate of photovoltaic energy, which has high practical value.

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