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Research on DC Boost Type of Photovoltaic Power Generation System

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Abstract. For DC boosting photovoltaic power generation system, this paper mainly focuses on the theory studies, system construction and algorithm design from three aspects, such as photovoltaic array model and output characteristics, structure and principle of boost system, principle of maximum power point tracking and control method. According to the single peak of the P-U curve and the principle of maximum power point tracking, the maximum power point tracking scheme using the impedance transform function of the boost circuit and the adaptive algorithm is determined. Through the study and analysis of the control strategy of the conventional adaptive algorithm introduced the optimal gradient method, an improved adaptive algorithm that fuses the fixed voltage method, the fitting curve method and the optimal gradient method is proposed. The simulation system is established to verify the simulation. The corresponding experimental results prove the validity of the designed photovoltaic power generation system and the improved adaptive algorithm, which improve the speed and accuracy of maximum power point tracking, and solve the wrong judgment of maximum power point

1. INTRODUCTION

As a non-renewable energy source, fossil energy is dying up and has been polluting the environment while renewable energy sources is widely distributed and does not pollute the environment, which is the ideal alternative energy source for the moment. Among them, solar energy has been widely used as a typical representative.

Photovoltaic power generation can directly convert solar energy into electrical energy. However, the photoelectric conversion efficiency of photovoltaic cells is relatively low, and their output power is nonlinear due to the effects of sunlight intensity and temperature. The key to ensuring the efficiency of the entire photovoltaic power generation system is to ensure that the photovoltaic cells are always operating at their maximum power point. [1]

This article will study the DC-boost type photovoltaic power generation system, conduct theoretical research and design on each link, and focus on solving the problem of optimal control of maximum power point tracking for photovoltaic power generation, which can improve the power quality of photovoltaic power generation and increase the efficiency of photovoltaic power generation.

2. The DC boost type of PV generation system structure

In 1839, the French scientist AE Becquerel first discovered the "photovoltaic effect". When sunlight hits a photovoltaic cell, the cell absorbs light energy, generates a "photovoltaic voltage", and when it is loaded, it will form a "photocurrent", which can output power and convert solar energy into electricity.

2.1. Photovoltaic cell model and output characteristics

2.1.1. Photovoltaic cell equivalent model. Photovoltaic cells are the power source of photovoltaic power generation systems. The output power of single photovoltaic cells is relatively low and cannot be directly used as a power source. However, if a number of single photovoltaic cells are connected in series and parallel to form a photovoltaic array, that is, a common photovoltaic panel, so that a large enough electric power can be output.

When the light intensity and the ambient temperature are certain, the solar photovoltaic cell is neither a constant voltage source nor a constant current source, but is a non-linear DC power source. [2] The equivalent circuit is shown in Figure 1, the equivalent mathematical model is as follows:

$$\mathrm{I} = I_{ph} - I_o\left[e^{\frac{q(U+IR_S)}{nkT}} - 1\right] - \frac{U+IR_S}{R_{sh}} \quad (1)$$

Where I is the PV cell output current; $U$is the PV cell output voltage; I_o is the reverse saturation current of the PN junction; I_{ph} is the photocurrent and the illumination is constant as the constant current source; q is the electron charge,$\mathrm{q} = 1.6 \times 10^{-19}\mathrm{C}$; k is the Boltzmann constant,$\mathrm{k} = 1.38 \times 10^{-23}\mathrm{J/K}$; T is the thermodynamic temperature; n is the curve constant of the PN junction;R_s, R_h is the intrinsic resistance of the photovoltaic cell.

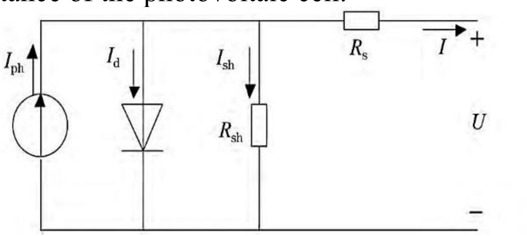

Figure 1. Equivalent circuit model of PV cells.

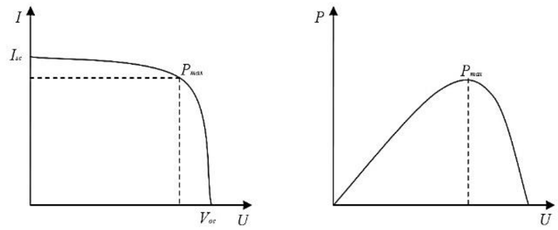

Figure 2. U-I and U-P characteristic curve.

2.1.2. Photovoltaic cell output characteristics. According to the U-I and U-P characteristic curves of photovoltaic cells, the photovoltaic cell is a non-linear DC power supply. Its power characteristic curve is a single-peak curve, and the power is determined by the light intensity and temperature. [3] As the photovoltaic cell voltage rises, the power rises to the power peak and then decreases to zero. Photovoltaic cell power peak, also known as the maximum power point is called 'P_{max}'.

2.2. System structure design

The DC-boost photovoltaic generation system studied in this paper is mainly used to power small DC circuits. The block diagram of the system is shown in Figure 3. Since the output voltage of the PV array is smaller than the DC-side voltage, it needs to be up-converted. So we choose Boost converter in this article. The output of the PV array is connected to the input of the DC circuit through the output of the Boost converter. [3] The control circuit controls the Boost converter through the sampling of the output voltage U and the output current I of the PV array to achieve the maximum power point tracking.

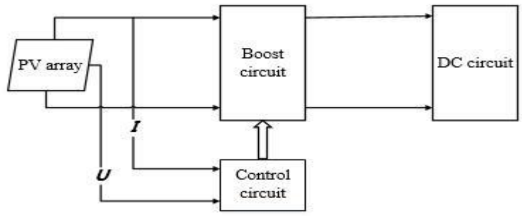

Figure 3. Block diagram of PV system.

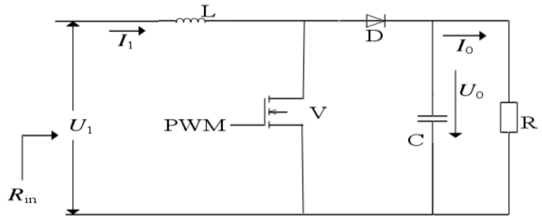

Figure 4. Boost circuit diagram.

2.2.1. Boost circuit principle. Boost circuit is mainly composed of inductor L, capacitor C, diode D and switching device V, Circuit diagram shown in Figure 4.

Boost is divided into two processes: charge and discharge. Charging process: The switching device is closed, the current flows through the inductor, and the switching device, forming a loop. Under the action of the direct current, the inductor stores energy. Discharge process: The switching device is disconnected, and the current flowing through the inductor is not abrupt, but is discharged through the new circuit to charge the capacitor. The voltage across the capacitor rises to achieve boost. [4]According to the law of energy conservation and assuming that the boost converter circuit is an ideal circuit, that is, there is no energy loss, the input and output power are equal, and output voltage and current calculation formula is:

$$U_o = \frac{T}{T_{off}} U_I = \frac{1}{1-D} U_I \quad (2)$$

$$I_o = (1 - D) I_I \quad (3)$$

Among them, T is the opening and closing cycle of the switching device, D is the duty cycle.

2.2.2. The principle of Boost circuit to achieve the changes in the output point of photovoltaic array. External light intensity, ambient temperature and load will affect the output power of photovoltaic cells, and by adding external devices to adjust the external light intensity and temperature control of the output power of the PV array is obviously not desirable. The use of DC conversion circuit, only need to use fewer components of the power electronic devices can achieve the PV array operating point regulation. According to the formula(2) and (3), the equivalent input impedance Zin of the boost circuit is calculated as:

$$Z_{in} = \frac{U_I}{I_{I_I}} = \frac{U_o}{I_o} (1 - D)^2 = Z(1 - D)^2 \quad (4)$$

From equation (4), we can see that when the resistance of the load Z is a constant value, the value of the equivalent impedance Zin can be achieved by adjusting the duty cycle D of the boost circuit, and then the output point of the PV array can be adjusted by changing the duty cycle. [5] Based on the adjustment of the operating point of the PV array, the maximum power point tracking algorithm is used to control the operation of the boost circuit so as to realize the tracking control of the maximum power point of the PV array.

3. Optimal Control of Photovoltaic Maximum Power Point Tracking

3.1. Maximum power point tracking control principle

Photovoltaic cells are a non-linear power supply whose output voltage and current are affected not only by light intensity and temperature, but also by the nature and condition of the load. In the photovoltaic cell voltammetry curve, the intersection of photovoltaic cell output characteristic curve and the load characteristic curve is the operating point of the photovoltaic cell. If the working point is at the maximum power point, the system is in a state of match and the electricity generated by the photovoltaic cells is fully utilized. On the contrary, the electrical energy it generates is not fully utilized. On the Volt-ampere characteristic curve of the photovoltaic cell, a tangent is made at the maximum power point, and the slope of the tangent is the dynamic equivalent impedance of the photovoltaic cell operating at the maximum power point. Commonly used maximum power point tracking control method.[6]

According to the principle mentioned above, that is, Boost circuit to achieve the PV array output operating point changes, the boost conversion is configured between the photovoltaic cell and the load. The input impedance of the circuit is adjusted by controlling the duty ratio of the switching device, that is, the equivalent load of the photovoltaic cell. Its value is matched with the dynamic equivalent impedance when the photovoltaic cell operates at the maximum power point, and the photovoltaic cell outputs the maximum power so as to achieve tracking of the maximum power point.

3.2. Maximum power point tracking control method

MPPT technology can usually be divided into indirect approximation control method, direct sampling control method and artificial intelligence control method. Common methods include constant pressure method, hysteresis comparison method, disturbance observation method, conductivity increment method, etc. [7]

This paper focuses on the analysis of an adaptive algorithm that introduces the optimal gradient method. The optimal gradient method is an optimal problem calculation method based on the gradient method. Its basic principle is to use the negative gradient direction as the search direction for each iteration, and to gradually approach the minimum value of the function.[8] Then, the maximum power point tracking for the PV array should select the positive gradient direction and gradually approach its maximum value.

The iterative method of the maximum power point tracking algorithm using adaptive algorithm is:

$$U_{k+1} = U_k + a * d_k \quad (5)$$

Where a is a non-negative constant, U_{k+1} and U_k are the output voltages of the PV array at the k+1 and k moments respectively, and d_k is the differential of the output power at the K moment about the output voltage.

Compared with the conventional conductance increment method, the conventional adaptive algorithm that introduces the optimal gradient method automatically adjusts the step size of the perturbation according to the slope of the characteristic curve of the curve P-U, thereby gradually approach the maximum output point of the photovoltaic cell and avoid excessive oscillation near the maximum power point, which causes power loss. However, in practical applications, when using the optimal gradient method to track the maximum power point, the problem of misjudgment at the maximum power point may occur due to sudden light changes [9].

In this paper, according to the actual state of changing light and temperature in the PV array operating environment, the curve fitting and comparison are introduced to improve the algorithm. In this algorithm, according to the principle, that is, voltage at the maximum power point is constant, $0.78U_{oc}$ is selected as the starting search point, avoiding wasting too much time in the area away from the maximum power point at the beginning of the search; a voltage is selected before and after U_k and its corresponding power are calculated, then fit by these three points and find the maximum power point P_{max1}, by determining whether the formula $|(P_{max1} - P_{max})P_{max} \leq 0.01|$ is established to determine degree of coincidence between the fitting curve and the actual PV cell's P-U characteristics, when the formula is established, the optimal gradient method is used to optimize the maximum power point.

4. SYSTEM SIMULATION AND ANALYSIS

In order to verify the working condition of the DC boost PV system described above and the effect of maximum power point tracking, a photovoltaic system model was built on the Matlab/Simulink simulation platform for simulation analysis. The simulation model is showed in Figure 5.

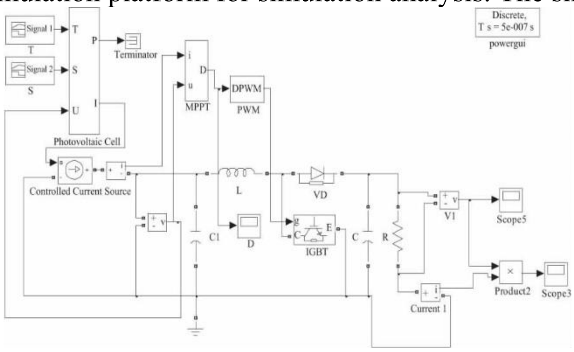

Figure 5. Simulation Model of PV System

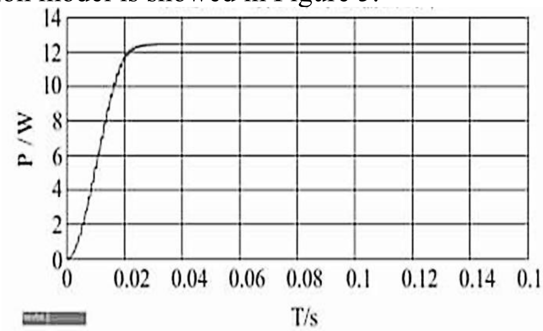

Figure 6. Output power at 1000 W/m2.

According to the results in Figure 6, when the system performs maximum power point tracking at a given light intensity ,for example at 1000 W/m2, the output power stabilizes at around 0.03s, and the vibration at the maximum power point is greatly reduced and tends to be stable. The results of the maximum power point tracking performed under different light intensities and different temperature is showed in Figure 7-8.When the simulated light intensity increased from 1000 W/m2 to 1600 W/m2, the system quickly tracked the new maximum power point in about 0.01s. When the maximum power point is tracked under different external temperature conditions and the external temperature rises from 25°C to 30°C, the system can also quickly track the new maximum power point.

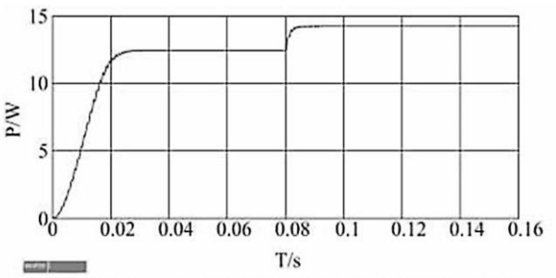

Figure 7. Output power changes at different light intensities.

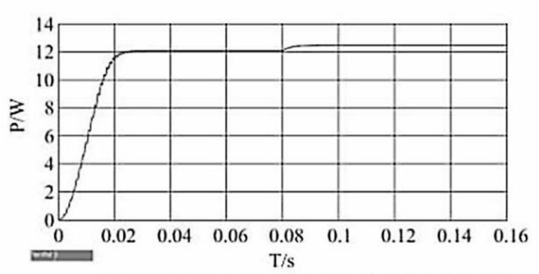

Figure 8. Output power changes at different temperatures.

In summary, the photovoltaic power generation system can work well. The improved adaptive algorithm greatly improves the tracking speed due to the use of the fitting curve method and avoids the misjudgment problems caused by environmental changes, which increases the tracking accuracy.

5. Conclusion

This paper focuses on DC boost photovoltaic power generation system, and conducts detailed theoretical research and system design work from three aspects: photovoltaic array, booster circuit, and maximum power point tracking. According to the analysis and research on the output characteristics of photovoltaic arrays, this paper proposes an improved adaptive MMPT algorithm, combining the fixed voltage method, the fitted curve method, and the optimal gradient method. This method uses the fixed voltage method for rapid positioning at the initial stage, and then the output characteristic curve of the photovoltaic cell is fitted by a numerical calculation method, and then using the optimal gradient method to accurately track the maximum power point ,which not only improves the tracking speed, but also avoids the problem of misclassification of the maximum power point ,which is caused by the traditional optimal gradient method when the light intensity mutates, and effectively improves the PV system's photoelectric conversion efficiency.

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