Optimal Design of Photovoltaic MPPT Disturbance Step Length in a Rapidly Changing Environment

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Abstract. The traditional maximum power point tracking (MPPT) algorithm can not track the maximum power point (MPP) quickly and accurately in the environment of rapidly changing illumination amplitude. In this paper, based on the basic circuit model of solar cell, the small signal model between the disturbance step size of MPPT algorithm near the maximum power point and the intensity of light irradiance, ambient temperature, working voltage and working current is used, and then the MPPT duty cycle disturbance is modelled and analysed. The simulation results show that the model proposed in this paper clarifies the mechanism of the disturbance step size of MPPT algorithm in the environment of rapidly changing illumination amplitude. It also provides a theoretical basis for the design of subsequent disturbance step size.

1. Introduction

The output power of photovoltaic power generation has great randomness, especially the rapid change of solar radiation intensity caused by shadow changes the output characteristics of the PV array. The traditional MPPT algorithm can't adapt to the fast changing illumination conditions, and it is easy to cause the maximum power point (MPP) tracking deviation\cite{1}. This will affect the transmission efficiency of a photovoltaic system. The influence of rapid change of ordinance in photovoltaic power generation system is mainly reflected in the disturbance step size of duty cycle and judgment direction\cite{2}.

In this paper, based on the basic circuit model of solar cell, the small signal model between the disturbance step size of MPPT algorithm near the maximum power point and the intensity of light irradiance, ambient temperature, working voltage and working current is used, and then the MPPT duty cycle disturbance is modelled and analysed. The simulation results show that the model proposed in this paper clarifies the mechanism of the disturbance step size of MPPT algorithm in the environment of rapidly changing illumination amplitude. It also provides a theoretical basis for the design of subsequent disturbance step size\cite{3}.

2. Small signal model of boost circuit

The small signal model of boost circuit is obtained by the average switch modelling method, as shown in Figure 1.
In Figure 1, $V_o$ is the steady-state value of the output voltage of the solar cell, $\Delta V_o(t)$ is the variation of the output voltage of the solar cell, $I_L$ is the current steady value of the filter inductance L, $\Delta I_L(t)$ is the current variation of the filter inductance L, $\Delta d(t)$ is the disturbance of the Q duty cycle of the power switch, and $D$ is the steady value of the Q duty cycle of the power switch\(^{4-7}\).

Based on the mathematical modelling of boost circuit model, the transfer function of $\Delta V_o(s)$ to $\Delta d(s)$ can be derived:

$$G(s) = \frac{\Delta V_o(s)}{\Delta d(s)} = \frac{r_c V_B}{L C r_s s^2 + L s + r_c}$$  \hspace{1cm} (1)

3. Modelling and analysis of MPPT duty cycle disturbance

3.1. Analysis of optimization process

One of the disadvantages of the duty cycle disturbance method in MPPT is that it may misjudge the optimization under the condition of rapidly changing weather, because it is unable to judge whether duty cycle disturbance $\Delta d$ or radiation change $\Delta s$ causes a power change, as shown in Figure 2.

It is assumed that the system reaches MPP at time $kT_a$, and it should move to point A at time $(k+1)T_a$. Due to the radiation intensity, it will actually move to point B. The power change caused by $\Delta d$ is $\Delta P_d$, and the power change caused by irradiation change $\Delta s$ is $\Delta P_s$\(^{8-10}\).

According to the analysis in Figure 2, in order to make the system make a correct judgment, it is necessary to ensure that:

$$|\Delta P_d| > |\Delta P_s|$$  \hspace{1cm} (2)
Where the output power variation caused by duty cycle disturbance is $\Delta P_d$ (unit: W). The output power change $\Delta P_s$ (unit: W) caused by illumination amplitude change.

3.2. Optimal design of duty cycle disturbance

If the oscillation $(\Delta V_d, \Delta I_d)$ is far less than $(V_{MPP}, I_{MPP})$, the relationship between $\Delta I_d$ and $\Delta V_d$ at point $(V_{MPP}, I_{MPP})$ can be approximately as follows:

$$\Delta I_d \approx \frac{\partial i_{pv}}{\partial V_{pv}} |_{MPP} \Delta V_d + \frac{1}{2} \frac{\partial^2 i_{pv}}{\partial^2 V_{pv}} |_{MPP} \Delta V_d^2$$  \hspace{1cm} (3)

Let $\frac{1}{2} \frac{\partial^2 i_{pv}}{\partial^2 V_{pv}} |_{MPP} = H$ (H is a result of the second derivative of solar cell current to voltage at MPP, unit: AV)

The relationship between disturbance $\Delta d$ and corresponding steady state $\Delta V_d$ can be estimated by the transfer function given in equation:

$$\Delta V_d = G_0 \times \Delta d$$ \hspace{1cm} (4)

Where $G_0$ is the DC gain of the transfer function (unit: V)

Due to $\Delta V_d \ll V_{MPP}$, the power change $\Delta P_s$ caused by the change of irradiance $\Delta s$ meets the following requirements:

$$\Delta P_s = (V_{MPP} + \Delta V_d) \Delta I_s \approx V_{MPP} \Delta I_s = V_{MPP} \Phi \Delta s$$ \hspace{1cm} (5)

Where $\Phi$ is the material constant of solar cell (unit: $m^2/V$); $\Delta s$ is the variation of irradiance (unit: $W/m^2$).

Combined with the above formulas, it can be deduced that:

$$\left| \left( H V_{MPP} + \frac{1}{R_{MPP}} \right) G_0 \Delta d \right|^2 > V_{MPP} \Phi \Delta s$$ \hspace{1cm} (6)

After simplifying formula (6), we can get the following results:

$$|\Delta d| > \frac{1}{G_0} \sqrt{\frac{V_{MPP} \Phi \Delta s}{H V_{MPP} + \frac{1}{R_{MPP}}}} = \frac{1}{G_0} \sqrt{\frac{V_{MPP} \Phi \Delta s}{T_s}} = \Delta d_{min}$$ \hspace{1cm} (7)

Where $T_s$ sampling period (unit: s); $s$ is the average rate of irradiation change in $T_s$ time (unit: $W/(m^2 \cdot s)$).

The values of $H$, $V_{MPP}$ and $I_{MPP}$ are related to the variation of irradiance. Through formula (6), when the illumination amplitude changes rapidly, the MPPT algorithm can be optimized correctly by analysing the duty cycle disturbance ($\Delta d$ must satisfy the pass through formula (6)).

4. Experimental results and analysis

In this experiment, the open circuit voltage is set to $V_{oc} = 21.7V$, and the maximum power point output current is set to $I_{MPP} = 4.4A$. According to the requirements of output voltage and output
power, 58 SP75 blocks are needed. Under standard conditions, the maximum output power is 4.3KW, and $R_{MPP} = 56 \Omega$.

Fig. 3a shows the output power waveform of irradiance intensity increasing from 850 W/m$^2$ to 1000 W/m$^2$ at the rate of 20 W/(m$^2$·s). Figure 3b shows the output power waveform of irradiance intensity decreasing from 1000 W/m$^2$ to 850 W/m$^2$ at the rate of 20 W/(m$^2$·s). It can be seen from Figure. 3 that the MPPT algorithm of photovoltaic power generation system can quickly and accurately track the maximum power of the system under the condition of illumination change, which overcomes the problems of misjudgement of optimization, long optimization time and power loss caused by output oscillation when the illumination changes rapidly.

In Figure. 4a shows the photovoltaic output voltage waveform of irradiance intensity increasing from 850 W/m$^2$ to 1000 W/m$^2$ at the rate of 20 W/(m$^2$·s). Figure. 4b shows the photovoltaic output voltage waveform of irradiance intensity decreasing from 1000 W/m$^2$ to 850 W/m$^2$ at the rate of 20 W/(m$^2$·s). It can be seen from Figure. 4 that the output voltage of MPPT algorithm of photovoltaic power generation system oscillates narrowly near the maximum power point voltage with the amplitude of about 1%, which has good tracking performance. Due to the use of P&O algorithm to achieve the optimization, at the maximum power point $\Delta P / \Delta V = 0$, the algorithm still needs to give the duty cycle disturbance, causing the output voltage near $V_{MPP}$ narrow amplitude oscillation.
From the above simulation and experimental results, it can be seen that the MPPT algorithm duty cycle disturbance optimization design model established in this paper provides a method to avoid the optimization misjudgement, which ensures the reliability and tracking accuracy of MPPT algorithm in the case of rapid changes in illumination. It has high practicability and provides a theoretical basis for duty cycle disturbance optimization design.

5. Conclusion
In this paper, the mathematical model of duty cycle disturbance step size near MPP of solar cells is established, and the basis for optimal design of duty cycle disturbance step size is obtained when the illumination changes rapidly. The mechanism of the influence of disturbance step size on MPPT optimization performance is revealed, and the reliability, accuracy and rapidity of MPPT optimization algorithm are realized when the illumination changes rapidly. The experimental results show that the MPPT algorithm disturbance step size optimization design method has good dynamic tracking ability and steady-state control accuracy when the illumination changes rapidly. It verifies the correctness of the disturbance step size mathematical model and the disturbance step size optimization design basis. It has a certain guiding role for the MPPT optimization algorithm duty cycle disturbance step size design under the condition of illumination change Application value.

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