Comparison of P&O and hill climbing MPPT methods for grid-connected PV converter

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Comparison of P&O and Hill Climbing MPPT Methods for Grid-Connected PV Converter

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***Abstract*-Maximum power point tracking (MPPT) techniques are employed in photovoltaic (PV) systems to make full utilization of the PV array output power which depends on solar irradiation and ambient temperature. Among all the MPPT strategies, perturbation and observation (P&O) and hill climbing methods are widely applied in the MPPT controllers due to their simplicity and easy implementation. In this paper, both P&O and hill climbing methods are adopted to implement a grid-connected PV system. Their performance is evaluated and compared through theoretical analysis and digital simulation. P&O MPPT method exhibits fast dynamic performance and well regulated PV output voltage, which is more suitable than hill climbing method for grid-connected PV system.**

I. INTRODUCTION

Photovoltaic (PV) generation is becoming increasingly important as a renewable source since it exhibits a great many merits such as cleanness, little maintenance and no noise. The output power of PV arrays is always changing with weather conditions, i.e., solar irradiation and atmospheric temperature. Therefore, a MPPT control to extract maximum power from the PV arrays at real time becomes indispensable in PV generation system.

In recent years, a large number of techniques have been proposed for tracking the maximum power point (MPP) [1-7]. Fractional open-circuit voltage and short-circuit current [1, 2] strategies provide a simple and effective way to acquire the maximum power. However, they require periodical disconnection or short-circuit of the PV modules to measure the open-circuit voltage or short-circuit current for reference, resulting in more power loss. Perturbation and observation (P&O) and hill climbing methods are widely applied in the MPPT controllers due to their simplicity and easy implementation [2-3]. P&O method involves a perturbation in the operating voltage of the PV array, while hill climbing strategy introduces a perturbation in the duty ratio of the power converter [2] and is more attractive duty to the simplified control structure [4]. Incremental Inductance (INC) method, which is based on the fact that the slope of the PV array power vs. voltage curve is zero at the MPP, has been proposed to improve the tracking accuracy and dynamic performance under rapidly varying conditions [2, 5]. However, the steady state oscillations still exist and the algorithm is a little more complicated comparing with P&O/hill climbing strategy.

Although P&O and hill climbing MPPT methods are the most commonly employed in practice, their performance is seldom compared. In this paper, both P&O and hill climbing methods are applied for the MPPT controller of a two-stage PV grid-connected converter system. Their performance is evaluated and compared through theoretical analysis and digital simulation. P&O MPPT method exhibits fast dynamic performance and well regulated PV output voltage, which is more suitable than hill climbing method for grid-connected PV system.

II. PV ARRAY MPPT

A. *PV array characteristics*

Generally, a PV module comprises of a number of PV cells connected in either series or parallel and its mathematical model can be simply expressed as [4, 6],

$$I_o = n_p I_{ph} - n_p I_{rs}[\exp(K_o \frac{V}{n_s}) - 1] \quad (1)$$

where I_o denotes the PV array output current, V is the PV output voltage, I_{ph} is the cell photocurrent that is proportional to solar irradiation, I_{rs} is the cell reverse saturation current that mainly depends on temperature, K_o is a constant, n_s and n_p are the numbers of series strings and parallel strings in the PV array respectively. The corresponding PV output power vs. output voltage curve can be obtained as shown in Fig. 1.

B. *The P&O and hill climbing MPPT algorithms*

Fig. 2 shows the P&O MPPT system, where “slope” is a variable with values either “1” or “-1”, denoting the perturbation direction [4, 7]. If there is an increase in the PV output power, the subsequent perturbation for reference voltage will be kept the same direction to reach the MPP, while the perturbation should be reversed at the case of a decrease in the PV output power. The MPPT algorithm provides a reference voltage, and a PI controller is followed to regulate the PV output voltage. In most applications, the maximum power point tracker is achieved by connecting a dc-dc converter between the PV array and load. The converter

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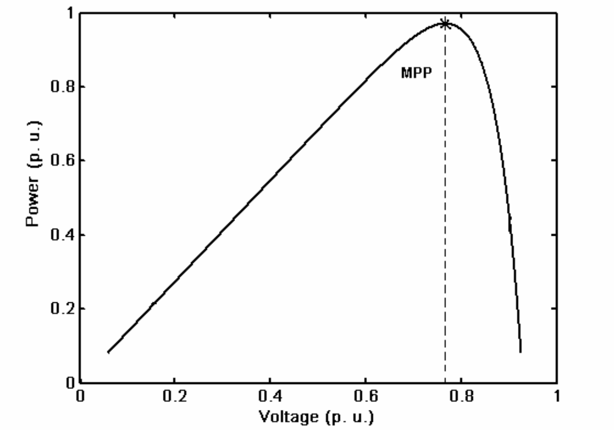
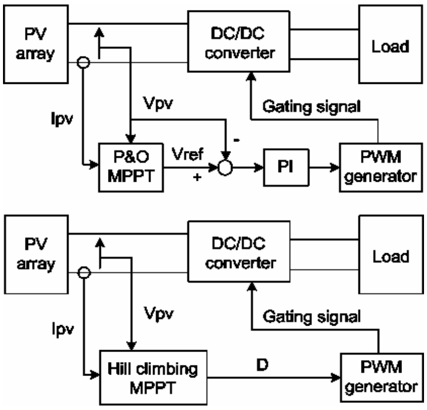
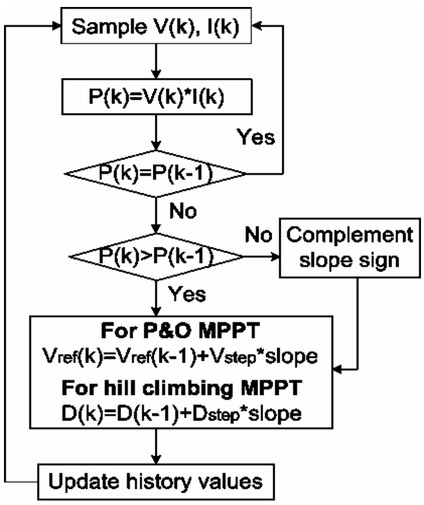


Fig. 1. Variation of the normalized power vs. voltage curve of a PV array



(a) Block diagrams



(b) The flowchart of MPPT control system

Fig. 2. P&O and hill climbing MPPT systems

duty cycle can be therefore directly controlled to reduce the system complexity. Such modified algorithm is termed as hill climbing MPPT method and is also illustrated in Fig. 2 [2].

III. Grid-connected Pv System Implementation

For the two-stage PV grid-connected system, a boost dc-dc

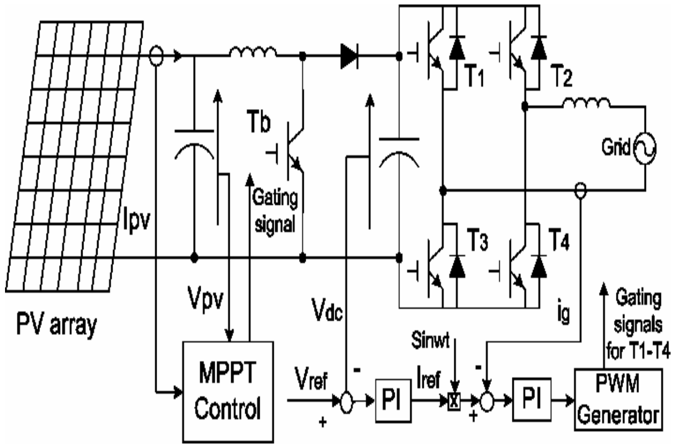


Fig.3. A two-stage PV grid-connected converter system

converter is usually employed as the front stage to shift the PV output voltage to a high level for the grid-connected inverter. Fig. 3 shows a simple MPPT PV system. It is composed of a boost converter and a single phase inverter. Thus, the control system consists of two parts, which are MPPT controller and inverter controller. The MPPT controller tracks the PV output power in real time through the regulation of the boost dc-dc converter. Both P&O and hill climbing strategies presented in Fig. 2 are adopted for such controller.

The inverter control system includes an outer dc voltage loop and an inner current loop. The dc voltage loop is used to keep the inverter dc bus voltage constant and it is achieved through a PI controller. The voltage error ($V_{ref} - V_{dc}$) is used by the PI controller to generate the amplitude of reference current I_{ref}. The current I_{ref} is multiplied by $\sin \omega t$ for synchronization with grid voltage. The measured inverter output current i_g is then regulated through a PI controller. The design of the grid-connected converter can be achieved by considering it a rectifier, and the corresponding control techniques are well documented [8, 9].

IV. MPPT Peformance Evaluation and Comparison

To verify the performance of the proposed modified variable step size INC MPPT algorithm, a MATLAB-SIMULINK model of the PV system shown in Fig. 3 is initially developed, and the specifications are illustrated in Table I. Ten pieces of GFM-120 Crystalline Silicon PV modules connected in series are used for PV array model in simulation with specifications listed in Table II.

The output power of the PV array mainly depends on solar irradiation and ambient temperature. The influence of the ambient temperature is slow and both two MPPT methods have no difficulties to track the maximum power point due the inherent iteration algorithm. However, the clouds sometimes move quickly in practice and the MPPT controller has to deal with such sudden change of the solar irradiation. Therefore, the performance of the two MPPT methods under sudden change of irradiation is investigated.

TABLE I
SPECIFICATIONS OF THE PV SYSTEM

PV module number	10 pieces
Dc bus reference voltage	380 V
MPPT sampling interval	20 ms
Switching frequency	10 kHz (dc-dc and dc-ac)
Grid voltage	220 V, 50 Hz

TABLE II
GFM-120 CRYSTALLINE SILICON PV MODULE SPECIFICATIONS

Open-circuit voltage	21.6 V
Typical operation voltage	17.3 V
Nominal output power	120 W

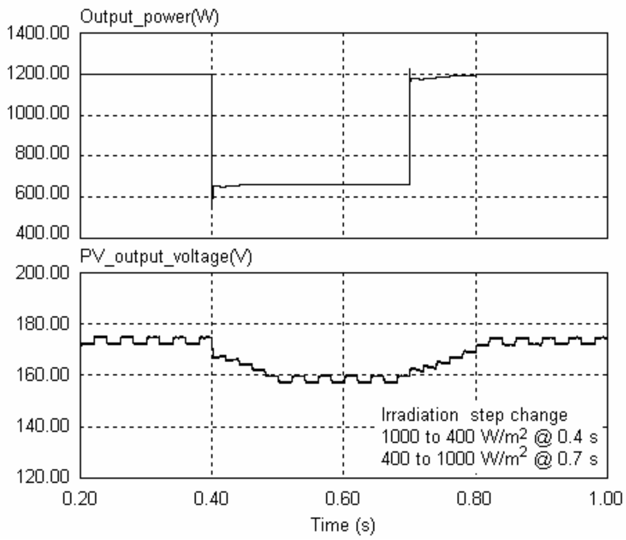


Fig. 4. The PV output power and voltage with P&O MPPT method

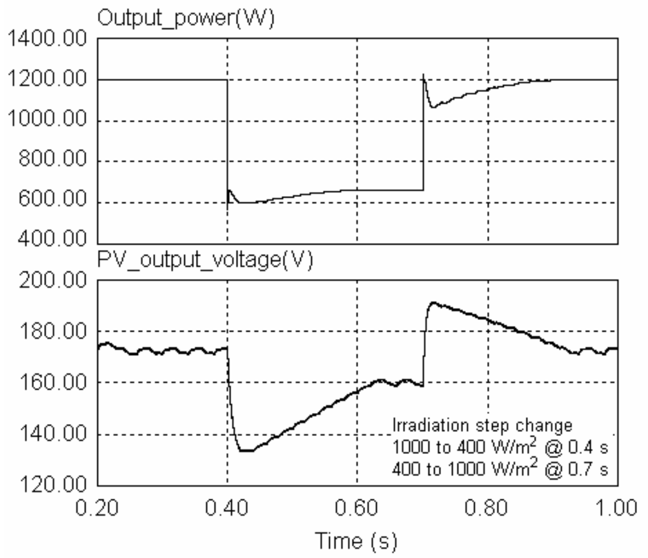


Fig. 5. The PV output power and voltage with hill climbing MPPT method

To facilitate comparison purpose, the voltage step size V_{step} (referred to Fig. 2 (b)) of P&O MPPT algorithm and the duty cycle step size D_{step} (referred to Fig. 2 (b)) of hill climbing MPPT algorithm are selected to ensure the same steady-state PV voltage ripple amplitude. The PV output power and voltage with P&O and hill climbing MPPT algorithms under solar irradiation sudden change conditions are shown in Fig. 4 and Fig. 5 respectively. The irradiation step changes were introduced at 0.4 s and 0.7 s. From Fig. 4 it can be seen that after 4 or 5 MPPT sampling intervals, the PV output voltage recovers, while it needs 11 or 12 cycles for hill climbing MPPT method in Fig. 5. Furthermore, the PV output voltage with P&O MPPT controller is well regulated and over/under voltage seldom occurs due to the PI controller.

Assuming the inductor current is continuous, the input voltage and output voltage of a boost dc-dc converter at steady state can be expressed as [10]:

$$V_o = \frac{1}{1-D} V_{in} \tag{2}$$

For the PV system, the output voltage of the boost converter (V_{dc}) is controlled as a constant and the PV array output voltage can be expressed as:

$$V_{PV} = (1-D)V_{dc} \tag{3}$$

When the irradiation suddenly changes, the PV array output voltage will vary as well. However, the boost converter output voltage is kept constant due to the inverter control. Thus, the variation of the PV array output can be expressed as

$$|\Delta V_{PV}| = |\Delta D| V_{dc} \tag{4}$$

where $|\Delta V_{PV}|$ and $|\Delta D|$ are the variations of PV output voltage and dc-dc converter duty cycle. And (4) can be reformed as

$$|\Delta D| = \frac{|\Delta V_{PV}|}{V_{dc}} > \frac{|\Delta V_{PV}|}{V_{PV}} \tag{5}$$

From (5), it can be seen that the variation of duty cycle is obvious than that of PV output voltage in percent. This is also suitable for the case of discontinuous current operation, due to the voltage step up characteristics. Therefore, P&O algorithm may exhibit a fast response than hill climbing algorithm under irradiation sudden change conditions. In Fig. 4 and Fig. 5, based on the same amplitude of PV output voltage ripples, the voltage step size V_{step} for P&O algorithm and duty cycle step size D_{step} for hill climbing algorithm are chosen as $0.0176 * V_{PV}$ and 0.009 respectively. And P&O MPPT controller demonstrates an obvious fast dynamic response than that of hill climbing MPPT controller. A larger duty cycle step size (0.03) is investigated for hill climbing MPPT controller to have a similar dynamic response as that in Fig. 4, and the PV output power and voltage are shown in Fig. 6. Both PV output power and voltage exhibit large ripples and the dc capacitor paralleled with PV array suffers severe under and over voltages. These deteriorate the PV converter system performance. Thus, P&O MPPT methods demonstrates fast dynamic performance and well regulated PV output voltage,

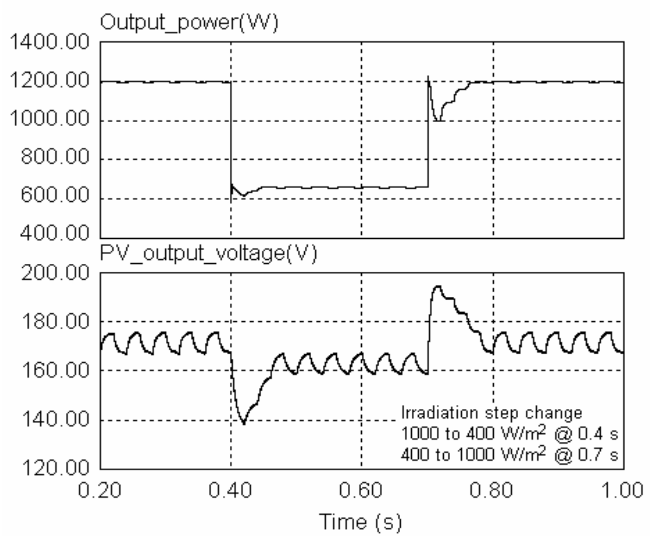


Fig. 6. The PV output power and voltage with hill climbing MPPT method and large step size

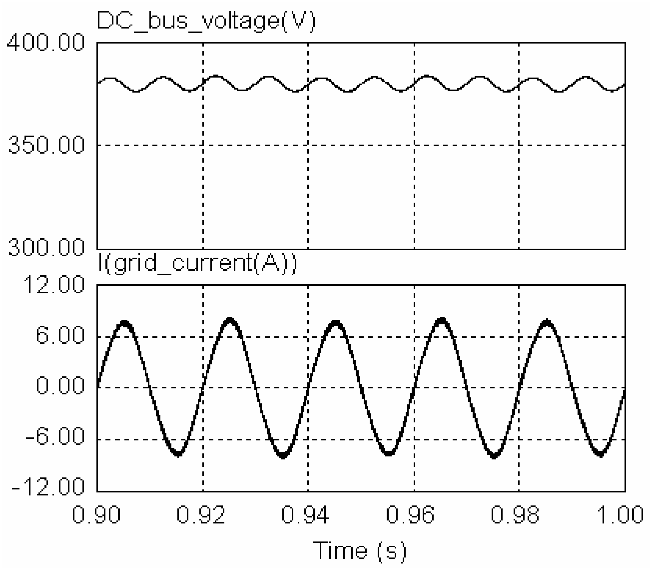


Fig. 7. The grid-connected converter dc bus voltage and output current with P&O MPPT controller

which is more suitable for PV grid-connected converter system. Hill climbing MPPT strategy shows features of simplicity and easy implementation, and the cost is therefore pretty low. It is more suitable for battery charger, where the fast dynamic response requirement is not necessary.

The grid-connected converter dc bus voltage and output current with P&O MPPT controller is shown in Fig. 7. The second harmonics inherently exist. The dc bus voltage is regulated around the reference 380 V and the converter current waveform is sinusoidal as well.

V. Conclusion

In this paper, a two-stage grid-connected PV system implementation is described. Both P&O and hill climbing methods are adopted for the MPPT controller. Their performance is evaluated and compared through theoretical analysis and digital simulation. P&O MPPT method exhibits fast dynamic performance and well regulated PV output voltage, which is more suitable for PV grid-connected converter system. Hill climbing MPPT strategy has characteristics of simplicity, easy implementation and low cost. It is more suitable for battery charger with which the fast dynamic response requirement is not necessary.

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