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On a hybrid MPPT control scheme to improve energy harvesting performance of traditional two-stage inverters used in photovoltaic systems

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ABSTRACT

How to promote the energy harvesting performance of traditional two-stage inverters used in photovoltaic (PV) systems is a critical issue in the PV applications. This paper reviews the prevalent maximum power point tracking (MPPT) techniques and the difficulties and performances of using different stage inverter architectures. Based on the findings of the reviews, this study proposes a new hybrid MPPT algorithm to speedily track the MPP of the PV arrays. The algorithm can be used in a single-phase two-stage PV inverter, where the direct current (dc) sensors for tracking the MPP are not required. A current mode control with a phase-locked function is also proposed to combine with the hybrid MPPT method and implemented in the PV inverter. A grid-tied PV power conditioning (PVPC) system with a capacity rating of 4 kW was constructed as a test sample system. An extensive series of experiments were conducted to examine the basic performance for tracking the dynamic MPP of PV array provided by the proposed method. The test results show that the proposed hybrid MPPT method could produce more energy of 2.72% than the traditional P & O method. Moreover, the comparative experiments for several kinds of microprocessor- and digital signal processor (DSP)-based commercial inverters using different MPPT methods were also conducted. Experimental results demonstrate that the commercial inverter equipped with the proposed hybrid MPPT algorithm has a better energy harvesting performance comparing to other commercial inverters with various MPPT methods. The developed hybrid MPPT algorithm and control scheme are promisingly in energy harvest and are ready to use in the commercial PV systems.

1. Introduction

Solar energy can be directly converted into direct current (dc) electricity through photovoltaic (PV) array. However, the current-voltage (I–V) properties of PV array exhibit a nonlinear characteristic that varies under environmental conditions. This fact makes accurately tracking the maximum power point (MPP) of PV array more difficult [1–3]. To improve the operation of PV generation system in real time, the problem of the nonlinear electrical characteristics of PV array influenced by many environmental factors should be resolved. Therefore, it is necessary to develop a simple and fast MPPT algorithm for PV generation system. Many kinds of the maximum power point tracking (MPPT) algorithms were proposed and further applied to the dc-dc converters of PV systems [4–42]. Table 1 summarizes the comparison of the maximum power point tracking (MPPT) algorithms. The simplest method is the fixed duty cycle method [12]. It does not require any feedback and only adjusts the load impedance to track the MPP. However, the tracking speed of this method is slow and the tracking factor (TF) for the output power is the lowest of 85.5% with low tracking accuracy among these methods. The dynamic performance of the MPPT process with the fixed duty cycle method is poor and the steady-state oscillation at MPP for PV system is large. On the other hand, the constant voltage method is based on the empirical rule, indicating that the ratio of the voltage at MPP to the open-circuit voltage of PV arrays operating under a standard atmospheric condition is between 70% and 80% [13–16]. From the field-test data, the variation of such a voltage ratio in the PV system is very small even when the intensity of solar radiation changes, but it varies when the

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Table 1
The comparison of the maximum power point tracking (MPPT) algorithms.

Refs. #	MPPT Algorithm	Implementation	Tracking Speed	Tracking Factor (%)[a]	Tracking Accuracy	Dynamic Performance	Steady-state Oscillation
[12]	Fixed Duty Cycle	Very simple	Slow	85.5	Low	Poor	High
[13–16]	Constant Voltage	Simple	Slow	91.9	Low	Poor	Low
[17,18]	System Oscillation	Simple	Slow	90.8	Low	Poor	High
[12,19–21]	Temperature	Simple	Rapid	98.2	High	Good	Practically zero
[22,23]	Perturb and Observe (P & O)	Simple	Fast	95.6	High	Poor	Low
[24–27]	Modified P & O	Complex	Fast	97.2	High	Good	Low
[12]	P & O based on PI	Medium	Fast	98.3	High	Good	Practically zero
[23,28,29]	Hill Climbing (HC)	Simple	Slow	91.2	High	Poor	High
[29,30]	Particle Swarm Optimization (PSO)	Medium	Fast	98.1	High	Good	Practically zero
[31–33]	Incremental Conductance (IC)	Medium	Fast	95.8	High	Good	Low
[12,34,35]	IC based on PI	Medium	Fast	98.3	High	Good	Practically zero
[12,36]	Beta Function	Medium	Fast	98.5	High	Good	Practically zero
[37,38]	Ripple Correlation	Complex	Rapid	96.1	High	Good	Very Low
[39,40]	Fuzzy-logic-control (FLC)	Complex	Fast	96.1	High	Good	Low
[41]	Artificial Neural Network (ANN)	Complex	Slow	95.9	High	Poor	Low
[42], This study	Direct Prediction Method (DPM)	Simple	Rapid	99.5	High	Good	Practically zero

[a] The tracking factor (TF) is defined as the percent of energy extracted from the PV modules during the start-up step to achieve the MPP [12].

temperature changes. Hence, this method is only suitable to use in low temperature-varying regions. The advantage of this method is that it only requires a voltage sensor used to measure the voltage of the PV system, and an input current sensor is not required to measure the current of the PV system. Therefore, the constant voltage method is a simple control loop to reach the MPP tracking of the PV system. However, the ambient temperature affects the voltage ratio of the PV systems, resulting in a slow tracking speed and a low tracking factor of 91.9% with low accuracy. From the viewpoint of MPPT process, the dynamic performance of the constant voltage method is also poor with the low oscillations at the steady state of MPP.

Based on the maximum power transfer principle, a system oscillation method was proposed to determine the optimum point of operation [17,18]. The amplitude ratio of the oscillation to the average voltage at the MPP of the PV system is a constant value. Similar to the constant voltage method, this method only needs to measure the voltage of the PV system, and it does not require an input current sensor to measure the current of the PV system. It is simple to implement the system oscillation with analogical circuits to locate the MPP of PV panels. Further, it needs to use the double grid frequency of grid-tied converters or the additional low-frequency ripple to implement system oscillation in the MPPT process of the PV system. Before acquiring the system oscillation, the switching frequencies must be filtered in advance to avoid wrong switching and an increase of electromagnetic interference, resulting in the slow tracking speed and poor dynamic performance for the MPP tracking. Applying the system oscillation method to the MPP control procedure for the PV system, the tracking accuracy of this method is worse with a low TF value of 90.8% and the steady-state oscillation at the MPP is large. Therefore, it is not common to implement this method in the converter switching frequency and the MPPT algorithms [17,18]. In order to overcome the shortcomings of the temperature variations in the MPP tracking, a good approach was proposed, which used the temperature correction in the MPP algorithms [12,19–21]. For the temperature correction method, it adopted a low-cost temperature sensor to sense the ambient temperature, and then modified the MPP algorithm function to track the true MPP. This method was developed based on the constant voltage method, and therefore is simple to be implemented. Because it avoids the temperature variations in the MPP tracking, the performances of MPPT with the temperature correction method possesses the rapid tracking speed with good dynamic performance and the high accuracy with a high TF value of 98.2%. The steady-state oscillations at the MPP for this method are practically zero. However, the sensing of ambient temperature in practical implementations can be an issue, because of the irregular temperature distribution of the PV array. The calibrations of the temperature sensor cannot be accurately accomplished, and wrong temperature measurements for PV modules may appear.

The most prevalent method of MPPT algorithms is the perturb-and-observe (P & O) method, which is widely used in the control process of converters of PV systems [12,22–27]. The P & O method has an advantage of not requiring the information of solar panel characteristics [22,23]. It is simple to implement the P & O method to the MPPT algorithm of a converter and is fast to track the MPP of PV modules with high tracking accuracy and a high TF value of 95.6%. However, this method is unsuitable for the applications with rapidly changing atmospheric conditions, because the conventional P & O method takes more time to reach the MPP through a series of perturbations. There are low oscillations of PV modules at the MPP under steady-state controlling. Therefore, some studies have tried to improve the performance of MPPT algorithms via modifying P & O approaches [24–27], with making the structure of the converters more complex. By sensing the current of a capacitor placed in parallel with the PV arrays, for example, Bianconi et al. proposed a current-based technique [24]. This study developed a dual control technique such that the fast tracking of irradiation variations and disturbance rejection could be achieved. For practical PV systems, however, the dynamic interactions of the inverters adopted in the two-stage grid-connected PV system and its MPPT controller under wide working range may reduce the system performance. To solve this problem, Femia et al. [25] designed a proper compensation network, which can cancel out the PV voltage oscillations by dealing with the error signal between a reference signal provided by the P & O MPPT controller and the signal that was proportional to the PV array voltage.

Through the modified P & O method, the dynamic performance of MPPT algorithms is improved. However, the steady-state oscillation of PV modules at MPP using the P & O and modified P & O methods leads to little alterations due to the perturbations of the voltage [22–27]. A digital controller or a proportional integral (PI) controller can be used to solve this problem [12]. According to the difference between the estimated MPP and real one, the PI-based P & O method utilized a closed-loop control to alter the tracking strategy adopted by converters such that they were with the different step sizes of the voltage perturbations. The PI-based P & O method can also fast track the