Maximum Power Point Tracking With Ripple Current Orientation for Photovoltaic Applications

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***Abstract*— Experimental tests reveal that the rippled current and voltage of a photovoltaic (PV) panel are always out of phase when the peak of the current is less than the current at the maximum power point (MPP), but begins to deviate once the current peak goes beyond the MPP. This paper proposes an efficient MPP tracking (MPPT) method by ripple current orientation based on the detected phase deviation of the PV voltage and current. By continuously detecting the phase difference, the PV panel can be operated at the MPP under constant atmosphere condition and can quickly move to the new MPP when the operating condition has been changed. A laboratory PV system with a microcontroller and a phase detection circuit is set up to verify the feasibility and effectiveness of the MPPT control strategy.**

***Index Terms*— Maximum power point tracking (MPPT), photovoltaic (PV) panel, ripple current orientation.**

I. Introduction

SOLAR electricity, which converts light energy from the sun into electrical power, has become one of the most important renewable power sources since last decades due to and rapid developments in manufacturing of photovoltaic (PV) cells and power electronic techniques as well as the consciousness of environmental protection [1]. The main design objective of a PV system is to obtain the maximum power generated by PV cells. Therefore, a power conversion circuit is required to maximize the conversion power as well as to regulate the voltage from the PV panel into an appropriate level for the following stage [2], [3]. In general, a dc-to-dc power electronic converter with pulsewidth modulation is used to operate the PV system at the maximum power point (MPP) under extremely variable irradiant conditions [4].

Up to now, a variety of methods for MPP tracking (MPPT) have been proposed [5]. Among which, the methods with the fractional open-circuit voltage or the fractional short-circuit current are the most simple but can only operate the PV system at the vicinity of the MPP [6]. On the other hand, the method with perturbation–observation can find the true MPP, but operate the PV system around the MPP under a constant irradiation condition. The method with incremental conductance can overwhelm this problem by resorting to higher complexity in tracking control [7]. Some of them are featured with easy implementation, and some are superior in tracking accuracy [8], [9]. The higher tracking accuracy, however, resorts to sophisticated control with complex computation [10]. Alternatively, the MPPT method with ripple correlation control (RCC) makes use of the high-frequency ripple current, voltage, or power when a PV panel is connected to a power electronic converter [11]–[14]. Instead of data sampling and averaging, the RCC method observes the phase commutation between the PV power and current. Using a simple analog circuit, the RCC can track the MPP quickly with satisfied accuracy.

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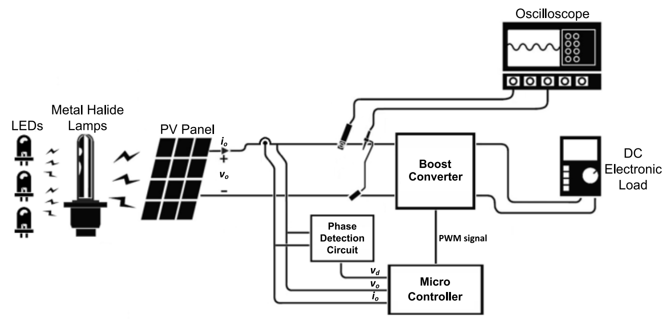


Fig. 1. Arrangement of PV power system.

However, experimental tests indicate that the phase difference between the PV current and voltage deviates gradually, so that the measurement of the incremental PV power is difficult and thus the detection of phase commutation [15]. Moreover, the phase commutation may not happen exactly at the MPP, leading to deterioration in operating efficiency. To solve the problem of the RCC method, a resemble MPPT method named as ripple current orientation is developed with the perspective of phase deviation between rippled current and voltage from the PV panel. Instead of multiplying and averaging for power calculation, the proposed approach uses directly the rippled current and voltage from the PV panel. With a simple detection circuit, the PV current can quickly be oriented to that at the MPP.

II. Arrangement of Experimental PV System

Fig. 1 shows the arrangement of a small-scale PV power system for experimental tests. The PV panel is illuminated by the several halide and LED lamps to have a stable and adjustable irradiance level. A boost converter is connected with the PV panel to draw a rippled current and voltage. The generated power from the PV panel can be regulated by adjusting the duty ratio of the boost converter with a microcontroller. A dc electronic load is used to emulate the

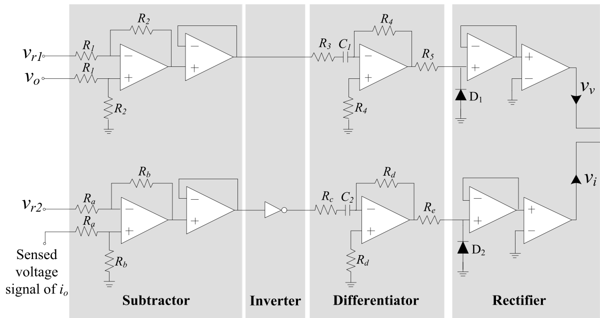
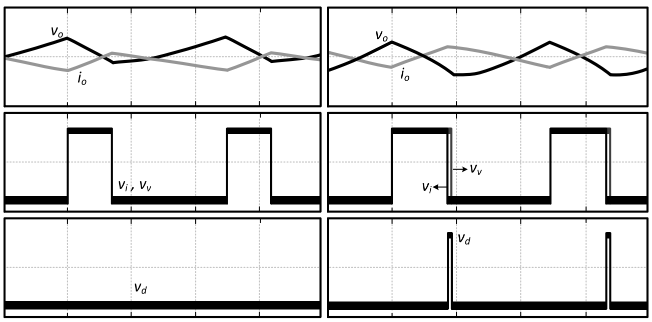
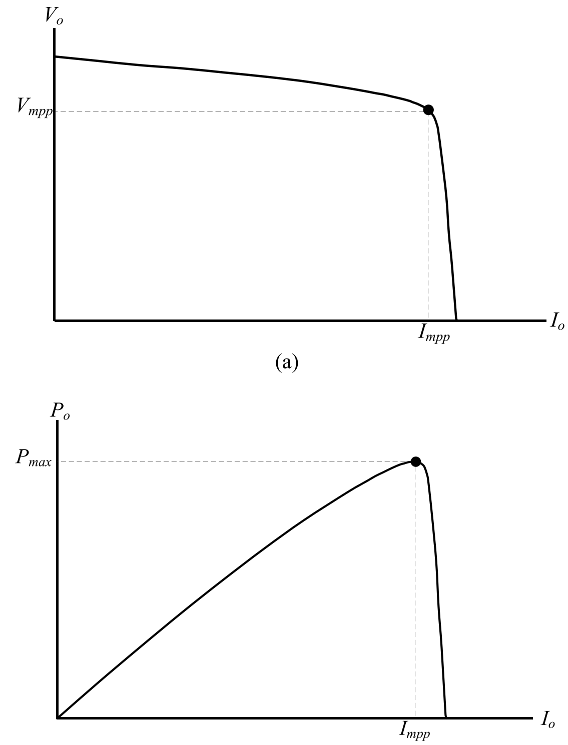


Fig. 2. Detection circuit of phase difference between PV voltage and current.



(a) (b)

Fig. 3. Illustration of detective signal detection. (a) $I_o < I_d$. (b) $I_o = I_d$.



(b)

Fig. 4. Static V–I and P–I characteristic curves. (a) V–I characteristic curve. (b) P–I characteristic curve.

consumed power. The voltage v_o and current i_o from the PV panel are measured by sensor circuits and simultaneously observed by an oscilloscope.

Fig. 2 shows the phase detection circuit designed to scrutinize the phase deviation between the PV current i_o and the voltage v_o. The generation of the detective signal from the detection circuit is shown in Fig. 3. The levels of the sensed voltage and current from the PV panel are first reduced into signal level by subtractors. The current signal is then inverted so that will be in phase with the voltage signal before phase difference begins to deviate. Subsequently, the triangular voltage and current are turned into quasi-rectangular signals by differentiators. To facilitate the detection, both signals are rectified by diodes and comparators into two rectangular waves, v_v and v_i. Consequently, an XOR gate generates a detective signal, v_d. When a phase difference between v_v and v_i is identified, a high-state v_d is generated, implying that the peak of the PV current reaches the MPP current.

III. Dynamic Characteristics of PV Panel

The static voltage–current (V–I) and the static power–current (P–I) curves as shown in Fig. 4 are obtained by operating the PV panel with a dc. A unique point with the maximum power can be found as the product of the PV voltage and the PV current reaches its maximum. The PV current and voltage at the MPP are denoted by I_{mpp} and V_{mpp}, respectively.

The PV panel, when connected to a boost converter, outputs essentially a triangular current. In other words, the boost converter draws a rippled current along with a rippled voltage and a rippled power from the PV panel. Experimental results reveal that both V–I and P–I dynamic characteristics follow the static ones of the PV panel while the peak of the PV current is less than the MPP current. Once the peak current goes beyond the MPP current, the PV voltage starts to lag to the current, leading to hysteresis contours in the dynamic characteristics [15].

Fig. 5 shows two exemplar cases of the different average PV currents drawn by the boost converter from the PV panel. In Fig. 5(a), the peak of the PV current is less than the MPP current. In a switching cycle, the PV voltage descends as the PV current ascends, and vice versa. The PV power stays always in phase with the PV current, but out of phase with the PV voltage. However, when the peak current exceeds the MPP current, as shown in Fig. 5(b), the PV voltage and power waveforms begin to distort. The valley of the voltage is not coincident with the peak of the current but with a phase deviation. Both PV power and voltage lag the PV current by a phase. By converting these waveforms into V–I and P–I curves, the dynamic characteristics become hysteresis contours, as shown in Fig. 6.

IV. Basic Concept of MPPT With Ripple Current Orientation

From the perspective of the dynamic characteristics of the PV panel with a rippled current, the occurrence of the hysteresis contour can be a decision point. By which, one can identify that whether the peak of the rippled current exceeds the MPP or not. At the moment that the peak of the PV current just exceeding the current at the MPP, the phase between the