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Analog Control Algorithm for Maximum Power Trackers Employed in Photovoltaic Applications

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Abstract

Tracking the Maximum Power Point (MPP) of a photovoltaic (PV) array is usually an essential part of a PV system. The problem addressed by Maximum Power Point Tracking (MPPT) techniques is to find the voltage V_{MPP} or current I_{MPP} at which a PV array should operate to generate the maximum power output P_{MPP} under a given temperature and irradiance. MPPT control methods such as the perturb and observe method and the incremental conductance method require a microprocessor or DSP to determine if the duty cycle should be increased or not. This paper proposes a simple and fast analog MPPT method. The proposed control scheme tracks the MPP very quickly and its hardware implementation is simple when compared with the conventional techniques. The new algorithm can successfully track the MPP even in the case of rapidly changing atmospheric conditions. In addition, it has higher efficiency than ordinary algorithms.

Key words: Analog MPPT, Maximum power point tracking, MPPT, Photovoltaic, Renewable energy

I. INTRODUCTION

Photovoltaic (PV) generation is becoming increasingly important as a renewable energy source due to its many advantages such as incurring no fuel costs, pollution free operation, requiring little maintenance, no noise emissions, etc. Due to the rapid growth in semiconductor and power electronics techniques, PV energy is increasingly being noticed in electrical power applications. It is important to operate PV energy conversion systems near the MPP to increase the output efficiency of PV arrays. The typical current-voltage and power-voltage characteristics of a PV array are shown in Fig. 1. Its V-I and V-P characteristic curves specify a unique operation point at which the maximum possible power is delivered. The problem addressed by MPPT techniques is to find the voltage V_{MPP} or current I_{MPP} at which a PV array should operate to generate the maximum power output P_{MPP} under a given temperature and irradiance [1], [2].

The boost converter for solar power conversion should have the ability to automatically track the MPP in order to achieve the maximum power conversion efficiency of a PV array. The basic principles of conventional MPPT techniques are as follows: In the current source region of a PV array, the duty cycle of the boost converter has a tendency to decrease in order to move to the MPP. On the contrary, the duty cycle has a tendency to increase to move to the MPP in the voltage source region of a PV array. Most of conventional techniques are just different types of implementations of the principles mentioned above. MPPT control methods such as the perturb and observe (P&O) method [3], [4] and the incremental

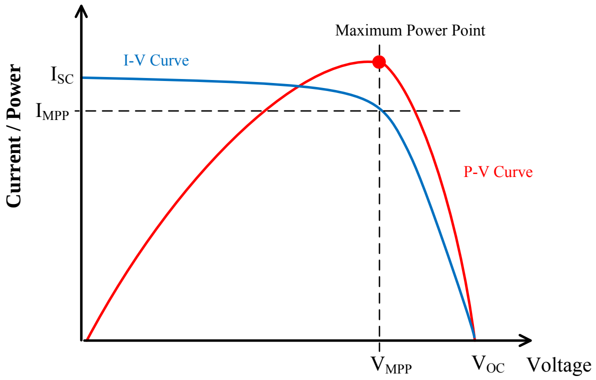

Fig. 1. V-I characteristic of a photovoltaic array.

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conductance method [5] require a microprocessor or DSP to determine if the duty cycle should be increased or not. Therefore, these techniques are very complex and expensive to implement [6]. The ripple correlation control [7] discerns the operating region with the sensed ripple voltage and current of a PV array. However, this technique employs three multipliers and hence is a bit complex.

This paper proposes a simple and fast MPPT method employing an analog control scheme. Experimental results show that this method can track the MPP well under a given temperature and irradiance.

II. REVIEW OF CONVENTIONAL MPPT TECHNIQUES

A. Perturb and observe

In MPPT, the P&O method is the most commonly used among the various MPPT algorithms because it is easy to implement. From Fig. 1, it can be seen that incrementing (decrementing) the voltage increases (decreases) the power on the left side of the MPP and decreases (increases) the power on the right of the MPP. Therefore, if any voltage perturbation increases the power, it should be continued to reach the MPP. Contrarily, if any voltage perturbation decreases the power, it should be reversed. This process is repeated periodically until the MPP is reached. The system then oscillates near the MPP. The oscillation can be minimized by reducing the perturbation step size. However, a smaller perturbation step size makes the MPPT speed slower.

P&O methods can fail to track the MPP under rapidly changing atmospheric conditions, as illustrated in Fig. 2. Starting from operating point A, if the atmospheric conditions stay approximately constant, the decreasing perturbation ΔV in the PV voltage V will move the operating point to B and the perturbation will be reversed due to the decrease in power. However, if the irradiance increases and shifts the power curve from $P1$ to $P2$ within one sampling period, the operating point will move from A to C. This means that the increase in power and the decreasing voltage perturbation are kept the same. Consequently, the operating point diverges from the MPP and the steadily increasing irradiance will keep the MPP diverging [8].

B. Incremental Conductance

The incremental conductance (IncCond) method is based on the fact that the slope of a PV array power curve (Fig. 1) is zero at the MPP, positive on the left side of the MPP, and negative on the right side as follows:

$$\begin{cases} \Delta I/\Delta V = -I/V, \text{ at } MPP \\ \Delta I/\Delta V > -I/V, \text{ left side of } MPP \\ \Delta I/\Delta V < -I/V, \text{ right side of } MPP \end{cases} . \tag{1}$$

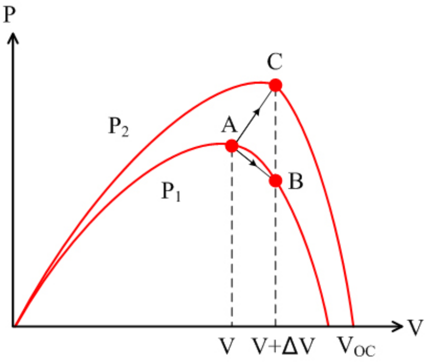


Fig. 2. Divergence of P&O.

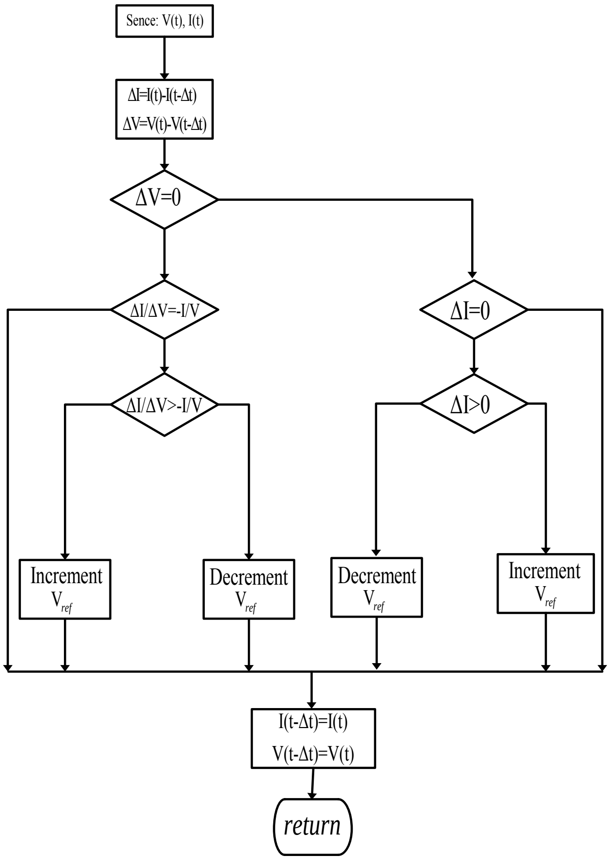


Fig. 3. IncCond algorithm.

Thus, the MPP can be tracked by comparing the instantaneous conductance (I/V) with the incremental conductance ($\Delta I/\Delta V$), as shown in the flowchart in Fig. 3. If it is assumed that V_{ref} is the reference voltage at which the PV array is forced to operate, it becomes V_{MPP} at the MPP. Furthermore, when the atmospheric conditions change, V_{ref} is decreased or increased to track the new MPP. In the meantime, the increment size determines how fast the MPP is tracked. Namely, a bigger increment size can achieve faster tracking performance.

However, it might prevent the MPPT from accurately

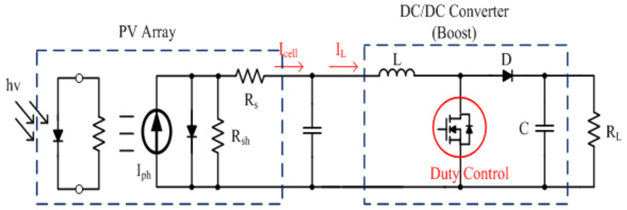


Fig. 4. Configuration of PV system.

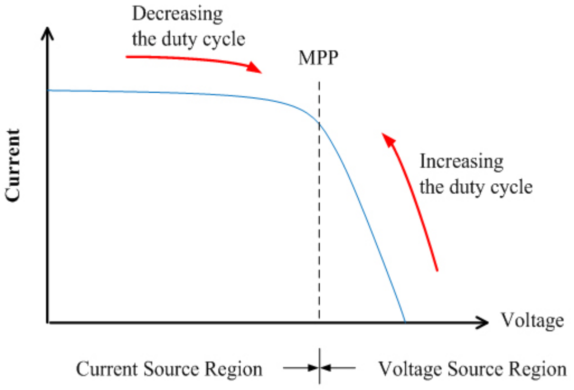


Fig. 5. The principle of MPPT using boost converter.

tracking the MPP and cause the tracking power point to oscillate near the MPP. Thus there exists a tradeoff between the tracking speed and accurate MPPT [8].

III. PROPOSED MPPT ALGORITHM

A. The effects of the MPPT's duty cycle on a PV Array

Fig. 4 shows the system configuration of a PV system. The power flow is controlled by varying the on/off duty cycle of the switch in the DC/DC converter. When the duty cycle is increased, the current through the inductor is increased. Therefore, the operating voltage is decreased according to the V-I characteristics of the PV array, as shown in Fig. 5. On the contrary, when the duty cycle is decreased, the current through the inductor is decreased and the PV voltage is increased.

As a result, it can be seen that increasing the duty cycle increases the power on the right side of the MPP (the current source region) and decreasing the duty cycle increases the power on the left side of the MPP (the voltage source region).

B. Operating principle of the proposed scheme

As shown in Fig. 6, the proposed control scheme consists of a multiplier, a peak power detector with a reset, a comparator with a offset voltage and a D F/F. The D F/F will finish the duty cycle for the control system. Fig. 7 shows the four operating modes of the proposed MPPT. Initially, the output voltage of the PV array remains at the open circuit voltage V_{OC}. At the beginning of the operation shown in Fig. 7(a), the $\bar{Q}$ of D F/F is supposed to have the value of 'High'. Therefore, the switch M_1 is turned on. The current and output power of the PV array will be increased to move forward to the MPP. Before passing over the MPP, the CLK to change the status of $\bar{Q}$ is not generated due to the offset voltage of the comparator. If the MPP is passed over, then the output of the peak detector holds the value of the MPP and the output power of the PV array will be decreased. As a result, at point A where the summing value of the multiplier output and the offset is less than the value of the MPP, the CLK signal becomes 'High,' as shown in Fig. 7(b). Consequently, the peak detector output is reset, $\bar{Q}$ becomes 'Low' and switch M_1 is turned off. If switch M1 is turned off, the PV array current will be decreased and hence the PV array will move to the voltage source region while passing over the MPP, as shown in Fig. 7(c). If the PV array reaches point B, then the CLK signal becomes 'High,' as shown in Fig. 7(d).

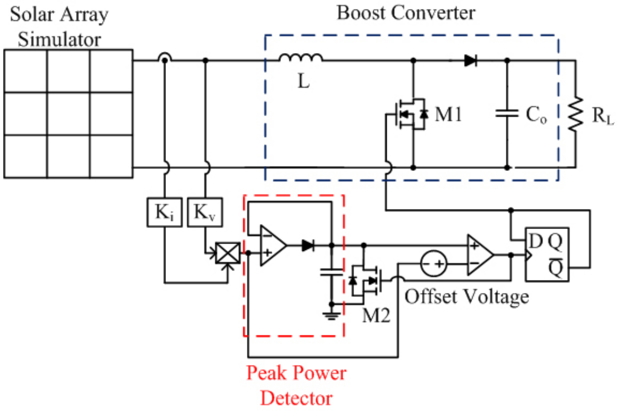
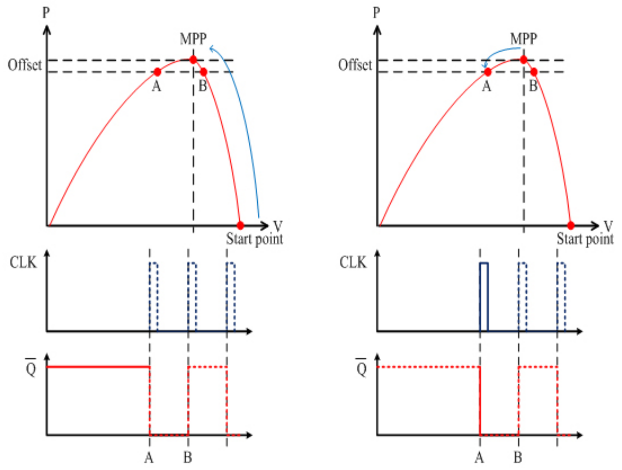


Fig. 6. Configuration of boost converter with proposed MPPT.

Consequently, the peak detector output is reset, $\bar{Q}$ becomes 'High' and switch M_1 is turned on. If switch M1 is turned on, the PV array current will be increased and hence the PV array will move to the current source region while passing over the MPP. Thus, the MPP is being tracked with back and forth movement between points A and B

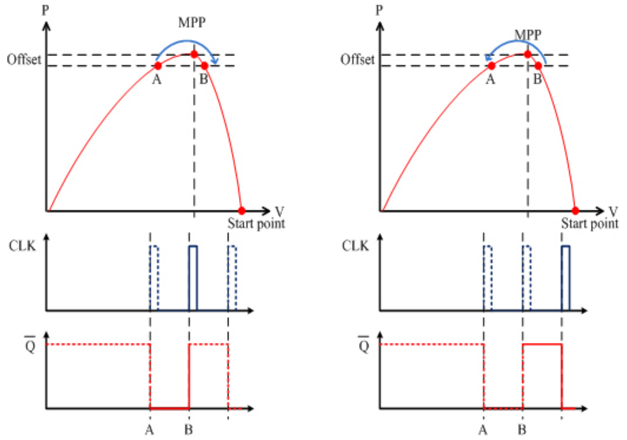
IV. EXPERIMENTAL RESULTS

To verify the validity of the proposed MPPT algorithm, a laboratory prototype is implemented with the specifications and parameters listed in Table 1. The solar array simulator for the experiment is an Agilent E4350B. In this case, the open circuit voltage is 64.2V, and the MPP is achieved with a PV voltage of 50V. Fig. 8 shows the behavior of the proposed MPPT algorithm during the startup of the boost converter. The PV voltage at the initial instant, when the converter is disabled, corresponds to the open circuit voltage (64.2V). When the system is enabled, the PV voltage and current move from the starting value toward the maximum power



(a) Mode 1.

(b) Mode 2.



(c) Mode 3.

(d) Mode 4.

Fig. 7. Four operating modes of proposed MPPT.

point (50V, 2A) in about 54us. Fig. 9 shows the steady state waveforms of the voltage and current at the maximum power checking test by setting the smallest offset value. The waveforms from top to bottom are the power P_{cell}, the current through cell I_{cell} and the voltage through cell V_{cell}. The waveform of the generated power, $P_{cell} = V_{cell} \times I_{cell}$, calculated by utilizing a math-function of the oscilloscope itself is also shown to track the maximum power. As can be seen in the power waveform, because the operating points keep coming and going the 'MPP – Offset' point, P_{cell} operates like wave. The offset voltage determines the power ripple. The output power ripple is:

$$P_{cell\_ripple} = \frac{V_{offset}}{(V_{MPP} \times K_v) \times (I_{MPP} \times K_i)} \times P_{MPP} \tag{2}$$

where K_v : voltage V_{cell} sensing gain
K_i : current I_{cell} sensing gain

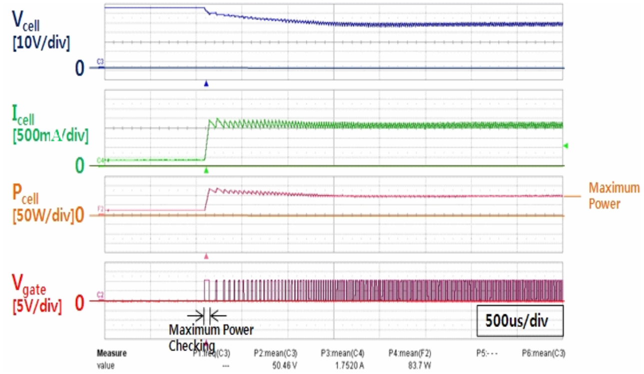


Fig. 8. Startup transient waveforms.

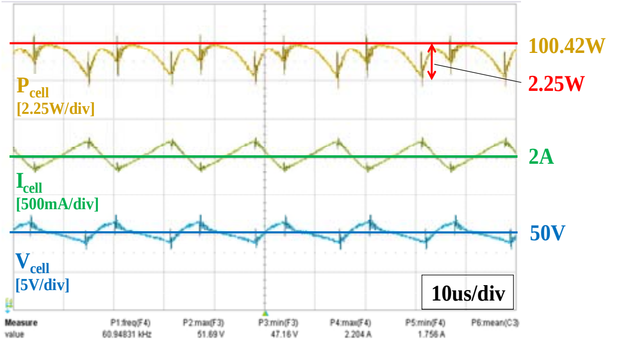
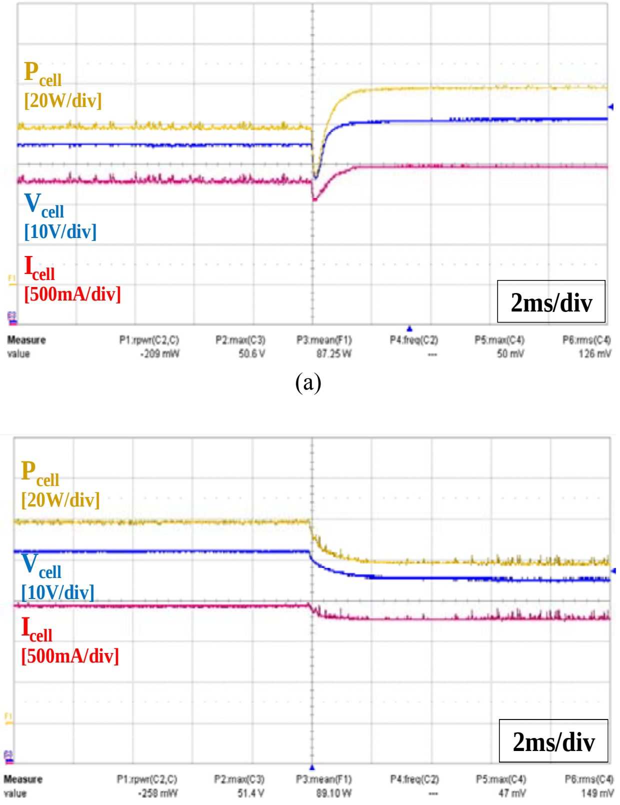


Fig. 9. Experimental results of maximum power point tracking.



(a)

(b)

Fig. 10. Transient waveforms of the boost converter when power is subject to change (a) from 80W to 100W and (b) 100W to 80W.

TABLE I

PARMETERS FOR SOLAR ARRAY SIMULATOR AND BOOST CONVERTER

Parameters for solar Array Simulator		Parameters for boost converter and controller	
V_{oc}	64.2[V]	L	1.50[mH]
I_{sc}	2.26875[A]	C_o	220[uF]
V_{mp}	50[V]	R_L	200[Ω]
I_{mp}	2.00841[A]	Offset Voltage	0.16V
Max. Power	100.4205[W]	K_v	0.167
		K_i	0.43

The experimentally measured value of the power ripple is 2.25[W], which is similar to the calculated result, with the parameter values, of 2.23[W]. The settling power level during the MPPT control is equal to the maximum power level. This shows that the successive tracking to the maximum power point is achieved. The MPPT efficiency is defined as follows: P_{max} is a preprogrammed known value, and the values of P_{actual} can be read off of the simulator. The MPPT efficiency of the proposed method is $99.53[W]/100.4205[W]\times 100 = 99.11[\%]$. With the proposed MPPT control, the converter operates with high efficiency under the maximum power point tracking.

The proposed MPPT algorithm it the case of a sudden insolation change of the maximum P_{cell} from 80W to 100W and from 100W to 80W is simulated, as shown in Fig. 10. As shown in this figure, it can quickly track the MPP within 2ms even during an abrupt insolation charge. Moreover, the tracked power coincides well with the MPP at the PV cell. Therefore, it can be seen that the proposed algorithm features fast tracking dynamics and good regulation performance.

Since the proposed method is very simple, it is possible to make an IC chip. The major functions of the MPPT IC are sensing/measuring the PV voltage and current, MPPT algorithm implementation (including PV power calculation, tracking the maximum power dynamically and ensuring that the required PWM output is supplied to the gate drive circuit of the switching MOSFET) and DC–DC conversion using the boost topology. If the proposed MPPT configures the analog control scheme, it is complicated by discrete components. A small offset value makes it possible for the solar cells to draw power more effectively in the proposed MPPT. However, producing an offset value that is less than 0.1V at the analog circuit is particularly difficult and a noise problem can occur. However, the offset value can be minimized in the IC.

Conventional MPPT systems have already been installed in modules using a microcontroller [9-11]. Therefore, all of the MPPT ICs have been designed by using the VHDL hardware description language included in the A/D converter. The hardware implementation of the proposed control scheme is very simple because it does not use digital control, unlike the conventional MPPT ICs.

V. CONCLUSIONS

The purpose of a MPPT is to adjust the solar operation voltage close to the MPP under changing atmospheric conditions. In this paper, a simple method which combines one-switching cycle control is used to track the MPP of a PV array. The implementation of the MPPT control is not based on a DSP controller. Since the proposed method is very simple, it is possible to make an IC chip.

The operating points of the proposed method keep coming and going 'MPP-Offset' point. If the offset value is very small, this converter operates with high efficiency under the maximum power point tracking. The maximum power point tracking operation has been confirmed through experimental results.

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