

An analog MPPT controller IC together with its application circuit

Fang Liu, Yan Han^{a)}, Yue Gao, and Jun Sun

*Institute of Microelectronics and Optoelectronics, Zhejiang University,
Hangzhou 310027, China*

a) hany@zju.edu.cn

Abstract: An analog integrated maximum power point tracking (MPPT) controller which is suitable for distributed MPPT (DMPPT) topology is presented in this paper. Without large numbers of external circuit components, the DC/DC converter together with its MPPT controller can be made small enough to be integrated into the junction box, which is practical and cost effective for DMPPT topology. Besides a negative feedback loop is used in the proposed system to make the output voltage of PV panel less susceptible to fluctuations of irradiation intensity and interference of switching noise. Meanwhile, an improved P&O algorithm is adopted to achieve a fast and precise tracking especially in fast changing weather conditions. Furthermore, the tracking precision is higher than 99.5% under different external environmental conditions.

Keywords: analog IC, MPPT controller, DMPPT, DC/DC converter, PV panel, PV array

Classification: Integrated circuits

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1 Introduction

With the depletion of conventional energy sources and the deterioration of the environment, the development of alternative energy is promoted. Solar energy, as one of alternative energy sources, has the potential to become a major source of power generation of the world. The PV market has also been growing fast over the past decade at a remarkable rate, and the world's cumulative installed PV capacity has reached 100 GW in 2012 and 138.9 GW in 2013 [1]. Currently, a centralized MPPT controller is embedded into the inverter to ensure that the output power of PV array is maximized [2, 3]. However, the array's overall efficiency is decreasing dramatically in the case of partial shading, and the hot spot may even destroy the PV panel, thus affect the output power of the whole PV array [4].

To mitigate the effect of partial shading and hot spot, a new topology called "DMPPT" is proposed and studied recent years [4, 5]. In this topology, a DC/DC converter performs independently MPPT for each PV panel, thus eliminates the mutual effect of different PV panels, and increases the overall output power of PV array. In consideration of costs and reliability, the number of discrete components should be as low as possible, especially in DMPPT topology.

A single chip together with a few discrete components solution is proposed recently [6, 7, 8]. The proposed IC like [6] uses ADCs and digital process, thus make it complicated and expensive. Papers [7, 8] present a chip without any ADCs, but the tracking algorithm is based on load current, which means the load must satisfy that the power is direct proportion to the current. However the load is not simply a resistor or a battery, a nonlinear load which is composed of other DC/DC converters is common in DMPPT topology. So the chip in paper [7, 8] is useless for DMPPT. Besides, there is no feedback in paper [7, 8], so the voltage of PV panel is susceptible to fluctuations of irradiation intensity and interference of switching noise, and has the potential to get away from MPP.

In this paper, an analog integrated MPPT controller is presented. The proposed chip is based on the voltage and current of PV panel, and has nothing to do with the load, thus the controller is suitable for DMPPT topology. Meanwhile, a negative feedback loop is used to immune the output voltage of PV panel from external interference. Furthermore, the improved P&O algorithm is adopted to achieve a fast and precise tracking in fast changing weather conditions. The proposed IC incorporates OPAMP, multiplier, oscillator, and other modules without any ADCs, and it's fabricated in CSMC 0.5 μm mix-signal CMOS process. The controller IC together with its application circuit has been fully realized and validated.

The outline of this paper is following. After a brief introduction of this paper, the proposed system architecture and the realization of MPPT controller IC are described in Sections 2 and 3, respectively. Simulation and experimental results are presented in Section 4. Finally, conclusions are summarized in Section 5.

2 System architecture

Fig. 1(a) shows the connection of the presented MPPT controller in a DC/DC converter. From the PV panel to the external load via a boost DC/DC converter which is controlled by MPPT controller, the power path is formed. In order to

maximize PV power, the controller tries to change the duty ratio of the pulse width modulated (PWM) signal which is provided to the boost converter by tuning the reference voltage (V_{ref}) of the system. V_{ref} is included in a negative feedback loop which is composed of two divider resistors R_1 and R_2 , an error amplifier (EA), a comparator, a driver and a MOSFET M_1 . With the aid of the negative feedback loop, the output voltage of the PV panel is forced to follow the change of V_{ref} , thereby achieving MPPT. In order to guarantee the stability of the feedback loop, a type III compensator network is added which is made up of C_3 , C_4 , C_5 and R_3 , R_4 , R_5 , as shown in Fig. 1(a). Among numerous DC/DC topologies, boost topology which is composed of inductor L_1 , diode D_1 and MOSFET M_1 as shown in Fig. 1(a) is selected because of its design simplicity and reduced voltage stress. Moreover, considering DMPPT topology, boost converter is easier to meet the requirements of high DC line voltage of the inverter. Also in Fig. 1(a), C_1 , C_2 are filter capacitors, and I_1 is a voltage regulator 7805 to provide the supply voltage of the MPPT controller. C_8 is a filter capacitor. The function of other chip-external elements is illustrated within the description of the chip realization in the following sections.

Fig. 1(b) shows the MPPT circuit used in DMPPT topology. It's noting that the load of each MPPT circuit is the output of other MPPT circuit, thus it's hard to determine the character of the load. So in order to shield the effect of load, the voltage and current of PV panel are measured in the proposed chip.

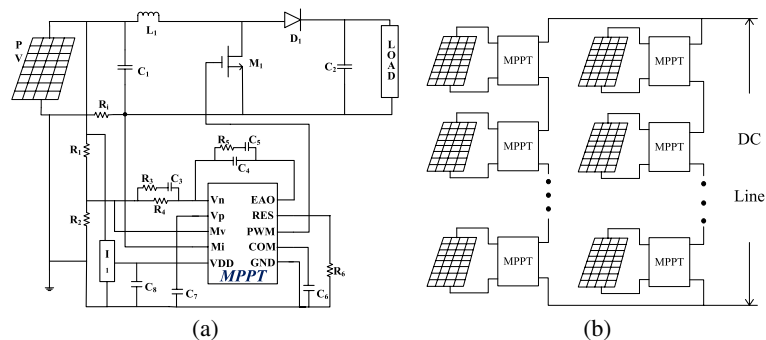


Fig. 1. The connection of the system: (a) MPPT controller in a DC/DC converter. (b) MPPT circuit in DMPPT topology

3 Realization of MPPT controller IC

Fig. 2 shows the internal realization block diagram of the proposed MPPT controller IC. This IC embeds a feedback loop module, a MPPT algorithm module, and other auxiliary modules. The feedback loop module contains an EA, a comparator, and a driver, adding external divider resistors and MOSFET together constitute the complete feedback loop. The MOSFET is driven by the driver which produces a PWM signal to realize the function of switch on and off. Powered by the supply voltage, the auxiliary module generates an internal bandgap voltage as well as the bias currents for other functional blocks. The external resistor R_6 shown in Fig. 1(a) is used as a part to produce current-bias. The oscillator is used to provide a chip clock of 100 kHz for MPPT algorithm module. It also provides a saw-tooth signal for the comparator of feedback loop module. Self-protection circuits are used to shut down the chip when it behaves anomalously and unpredictably. The MPPT

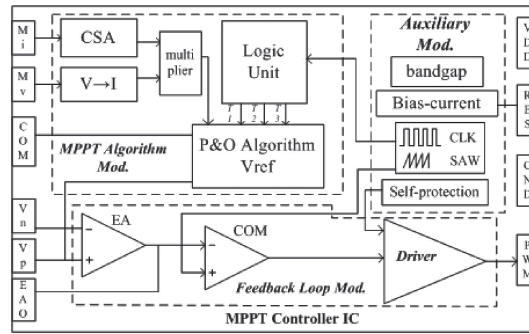


Fig. 2. Internal of MPPT controller IC

algorithm module, as the core module of this chip, is formed by multiplier, comparator, logic unit, and other blocks. In the following, the functions of the MPPT algorithm module are explained in more detail.

As shown in Fig. 2, the voltage and current of PV panel are sensed by divider resistors and current sense resistor (R_i shown in Fig. 1(a)). As R_i is small, the current signal must be amplified first through current sense amplifier (CSA). Limited by the narrow input range of traditional Gilbert multiplier, the proposed chip is preferred to current mode multiplier, which is based on MOS translinear loop. So the voltage and current signal of PV panel are transformed into current signal, and then used as the input of the current mode multiplier. As the output of the multiplier, the power of the PV panel is worked out in the form of voltage. In order to maximize this power, an improved P&O method is used in this chip, and the role of MPPT algorithm module is to adjust V_{ref} according to the tracking algorithm. A time interval called perturbing period is adopted to reduce the power consumption of perturbation. Fig. 3 shows the flow diagram and the circuit structure of P&O.

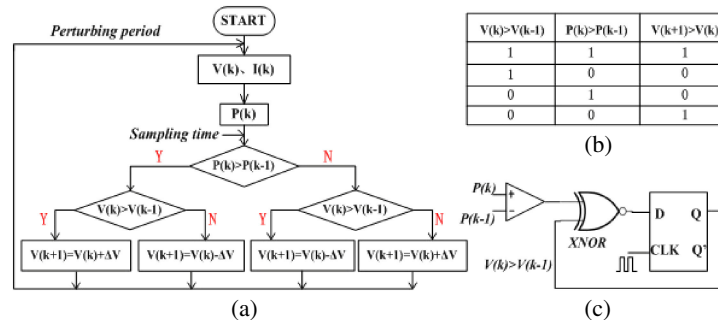


Fig. 3. Flow diagram and circuit structure of P&O: (a) Flow diagram of P&O. (b) Judging criteria of P&O. (c) Implementation of P&O.

At the beginning of the period, the power is stored in external capacitor C_6 as shown in Fig. 1(a). Then according to the judgment of last period, V_{ref} is perturbed, and the power of PV panel changes with it. Considering the settling time of the negative feedback loop after perturbation of V_{ref} , a time interval called sampling interval is needed, and it must be chosen greater than the settling time. After sampling interval, the power of PV panel before and after perturbation is compared. As shown in Fig. 3(b, c), the direction of perturbation next time is dependent on the

last direction of perturbation and the last power changing direction. When the next period is coming, the whole process above is repeated as shown in Fig. 3(a). So the logic unit in MPPT algorithm module needs to produce three periodic clock signals, namely perturbation period's starting signal T_1 , V_{ref} 's perturbing signal T_2 , and sampling interval's signal T_3 .

The novelty of P&O method proposed in this paper is that the step size is variable. The step size refers to the variation per perturbation of V_{ref} . As the P-V curve is a quasi parabola and the vertex of it refers to MPP, the larger the variation of V_{ref} is, the higher the tracking speed realizes, yet the lower the tracking precision achieves, and vice versa. As shown in Fig. 4(a), the step size is generated by adding two parts, namely fixed current source M_2 and variable current source M_3 , and the gate voltage of M_3 is controlled by the power of PV panel, thus the current changes with the PV power. The greater the power is, the smaller the current is. M_4 and M_5 act as MOS switch to charge and discharge the external capacitor C_7 to translate the current generated by M_2 and M_3 into V_{ref} . By this means, a higher tracking speed is achieved when the operating point is far away from MPP, and a higher tracking precision is achieved when the operating point is near the MPP. This method is useful especially in fast changing weather conditions where the MPP changes drastically. Also in Fig. 4(a), the control signals V_1 , V_2 are provided by the logic unit mentioned previously. M_6 and M_7 are dimensioned to form a discharge path for C_7 . Fig. 4(b) shows the signal timing of the variable step size circuit.

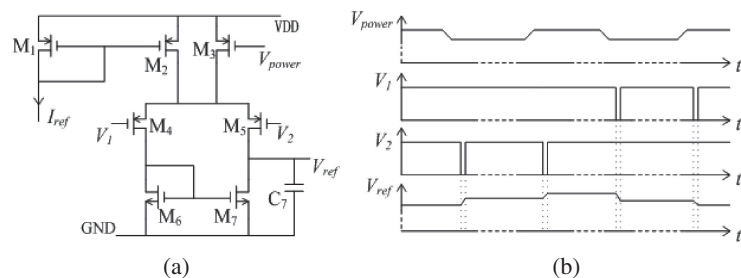


Fig. 4. Simplified circuit of perturbing V_{ref} and its signal timing:
(a) Circuit of perturbing V_{ref} . (b) Signal timing of the circuit.

Fig. 5 shows the microphotograph of a test chip which is fabricated in CSMC $0.5\mu\text{m}$ mix-signal CMOS process. The whole chip occupies an area of about $1.25\text{mm} \times 1.22\text{mm}$. There are only 16 functional pins in this chip and others are all test pins.

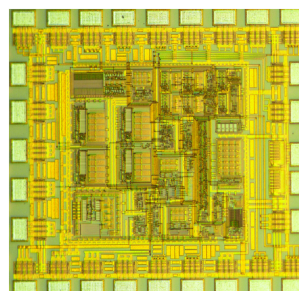


Fig. 5. Microphotograph of a test chip

4 Simulation and experimental results

In order to test the transient behavior, the MPPT controller together with its application circuit is operated under real outdoor conditions. The PV panel used for test is HQ020P(20 W), and the load is 3 SONGYUAN 12V 4.5AH sealed rechargeable batteries connected in series. Fig. 6(a) shows the voltage waveform of the PV panel when the tracking algorithm has achieved the MPP of the panel. It's noting that the voltage is stable after perturbation each time, and the panel is operated around MPP. The power consumption of the controller is about 16.5 mW.

As the irradiation of the sunlight and the temperature of the environment are hard to control, the tracking precision is worked out under simulation condition. The tracking precision is defined as $P_{\text{panel}}/P_{\text{MPP}}$. Fig. 6(b) shows the tracking precision when the irradiation ranges from 400 W/m² to 1000 W/m² and the temperatures are 0°C, 25°C and 40°C respectively. It can be observed that the tracking precision is always higher than 99.5% in different external environmental conditions. An overview of performance compared with the art-of-state is summarized in Table I.

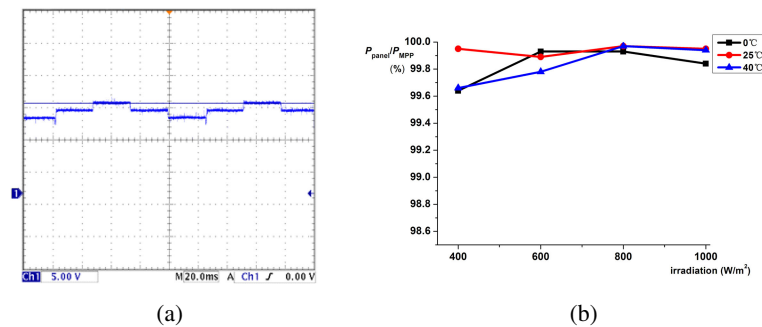


Fig. 6. Simulation and experimental results: (a) Transient behavior of the controller. (b) Tracking precision of the MPPT circuit

Table I. Performance summary.

Ref.	[6]/2013	[7]/2011	[8]/2013	This Work*
Process	ST BCD8 0.18 μm	AMS H35 0.13 μm	AMS H35 0.13 μm	CSMC 0.5 μm
Chip area	15 mm ²	0.441 mm ²	0.441 mm ²	1.525 mm²
MPPT algorithm	digital	analog	analog	analog
Suitable for DMPPT	Yes	No	No	Yes
Tracking precision	>99.8%	>99%	>99.5%	>99.5%

5 Conclusion

An analog integrated MPPT controller together with its application DC/DC circuit is proposed in this paper. Thanks to the improved MPPT algorithm and negative feedback loop, the PV panel can operate around MPP quickly and steadily. It's verified that the tracking precision is always higher than 99.5% in different external environmental conditions. The choice of 0.5 μm CMOS process and few external circuit components of the system bring a huge reduction of the system costs, thus make it cost effective for DMPPT topology.