A Low Cost Maximum Power Point Tracking Technique for the Solar Charger

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Abstract – **In this paper, a simplified maximum power point tracking technique for the solar charger is presented. Main advantages of the proposed charger include low cost and optimized charge time. The maximum power point tracking method is used to deliver the maximum power from PV array to the battery thereby reducing the charge time. Moreover, the proposed technique which tracks the maximum power point by adjusting output current helps reduce the quantity of required number of sensors for the charger. The experimental protype was implemented by using an 80W PV array, a buck converter and a digital signal processor to verify the feasibility of the proposed method.**

Index Terms – **Solar Charger, Maximum Power Point Tracking, Low Cost, Optimized Charge Time.**

1. Introduction

As the concerns of conventional energy source exhaustion and environmental pollution increase, attempts are being made to replace fossil fuels with non-conventional energy sources in various sectors. In vehicular transportation field, automotive industry is undergoing a revolution in the design of its electrical system. This is the result of increasingly sophisticated engine as well as the introduction of new electrically controlled functions. Using rooftop photovoltaic (PV) arrays is an effective way to aid in providing additional power which can power the ventilation system or air conditioning system in vehicles. The advantage of using rooftop PV arrays is that even when the car is parked under sunlight, the arrays can produce electric energy to charge the battery and then power the systems to cool down the atmosphere inside the car. In daily life, people are now increasingly dependent on mobile devices such as cell phone, laptop, music player and etc. However, since the most of these devices rely on an internal rechargeable battery, their functionality is lost when the battery is discharged. In order to meet the need for recharging battery when accessing to the ac source is not convenient, PV arrays can be good candidates to replace the grid for charging the battery. However, there are several drawbacks in using PV arrays as an energy source for the charger such as high fabrication cost, low energy conversion efficiency and long charge time. Thus, when the PV array is used for charging the battery as an auxiliary energy source, the PV system need to be low in cost and it is important to charge the battery within a short period of time.

In this paper, a maximum power point tracking technique which reduces the complexity and the cost of the solar charger is proposed. Also the low cost MPPT method is used together with the constant current control to reduce the charge time.

2. Proposed solar charger with reduced number of sensors

Fig.1 shows the block diagram of the proposed solar charger which employs a low cost MPPT technique. An 80W PV array is used as an energy source which has the open-circuit voltage of 21.2[V] and short-circuit current of 4.9[A]. A 12V 40Ah lead-acid battery is used to store energy from the PV array. A buck converter is employed to step down the PV output voltage and to charge the battery. The control algorithm is separated in two modes: MPPT mode and current control mode (CCM). The MPPT technique is implemented by maximizing the charge current I_{out} at the output of buck converter (Fig.1). The CCM is employed to limit the charge current when the current obtained by the MPPT is higher than the rated charge current of the battery. With the proposed method the number of the sensors in the system can be reduced because the sensors at the input of the buck converter are not required. It helps reduce the complexity and cost of the system and also provides the flexibility in selecting the PV array for the charger since the no sensors associated with PV array are employed.

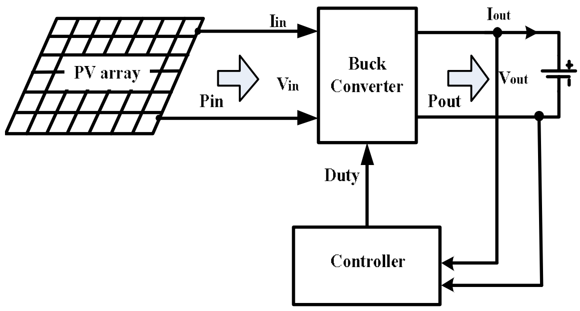

Fig. 1 The block diagram of the proposed solar charger

3. Principle of the low cost maximum power point tracking technique

The purpose of MPPT techniques is to automatically find the voltage or current value at maximum power point at which the PV panel should operate and generate maximum power, even in varying operating condition [1]. Generally, MPPT algorithms are based on the fact that the slope of the PV panel power curve is zero at the MPP, positive on the left of the MPP, and negative on the right. However, if the algorithms is used for the battery charge application, four sensors are required in total: two for measuring PV output current and voltage, the other two for measuring charge current and battery voltage. In order to reduce the number of sensors and to deal with the circuit simplification and low cost issues, the MPPT technique which only uses the output current is applied [2].

From Fig.1, by assuming there is no loss and by applying the power balance principle, we have:

$$P_{out} = P_{in} \tag{1}$$

It is clear that the change of power at the input of the converter has to be equal to the change of power at the output.

$$dP_{out} = dP_{in} \tag{2}$$

In addition, battery can be considered as a voltage-source since the terminal voltage changes slowly. Therefore, the value of dV_{out} is approximately equal to zero in a short period of time. So,

$$dP_{out} = V_{out} dI_{out} \tag{3}$$

The equation (3) can be rewritten as (4) by dividing by dD.

$$\frac{dP_{in}}{dD} = V_{out}\frac{dI_{out}}{dD} \tag{4}$$

From equation (4), it can be noticed that the derivative dI_{out}/dD can be used to track the MPP instead of dP_{in}/dD.

4. Design of the charge controller

4.1 Equivalent circuit of a solar cell

The characteristic equation of a PV arrays can be is described as in (5):

$$i_{pv} = I_{pv} - I_s\left[\exp\left(\frac{v_{pv}-R_s i_{pv}}{V_T\eta}\right)-1\right]-\frac{v_{pv}+R_s i_{pv}}{R_p} \qquad (5)$$

Where, R_s and R_p are series and shunt resistances, respectively, I_{pv} is the light induced current, η is the diode ideality factor, I_s is the saturation current of the solar cell and V_T is the thermal voltage.

In order to reduce the complexity of circuit analysis, linearization technique is used to derive a further simplified equivalent circuit of the solar cell at single operating point. The linearized model can be described by the tangent line at a certain point on the I-V curve.

$$i_{pv} = g\times\left(v_{pv}-V\right)+I; \qquad g=\left.\frac{\partial i_{pv}}{\partial v_{pv}}\right|_{(V,I)} \qquad (6)$$

Thus the simplified equivalent circuit model of the solar cell can be represented by a voltage source and a series resistor as in Fig. 2, where $R_{eq} = -1/g$ and $V_{eq} = V - I/g$.

4.2 Converter modeling and controller design

For the control of battery charge current, the control-to-inductor current transfer function is derived. Fig.2 shows the overall circuit of the system. The battery is modeled by using an R-C series circuit, where Rb and Cb represent the equivalent series resistance and the equivalent capacitance of the battery respectively.

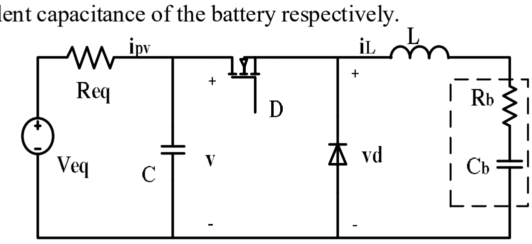

Fig. 2 The equivalent circuit of the solar charger

Using the small-signal technique, the control to output current transfer function is obtained:

$$G_{id}(s)=\frac{sC_b\left[V\left(1+sC\,R_{eq}\right)-I_L\,R_{eq}\,D\right]}{\left(s^2LC_b+sC_bR_b+1\right)\left(sC\,R_{eq}+1\right)+sD^2\,R_{eq}\,C_b}$$

The control to output current transfer function for designing the controller is obtained with the following parameters: V = 20 [V]; D = 0.6; L = 1250 [µH]; C = 470 [µF]; C_b = 96000 [F] and R_b = 20 [mΩ]. This transfer function has the crossover frequency at f_c = 2.2 [kHz] and the gain at the low frequency band is G_o = 11[dB]. The PI compensator is designed to have a zero at $f_c/10$ (220 [Hz]) and its transfer function is as follows:

$$G_c(s)=\frac{0.28s+397}{s}$$

5. PSIM simulation result of the MPPT algorithm

PSIM simulation was performed to verify the proposed MPPT algorithm. The irradiation was kept constant at 800 [W/m2] and the temperature is 25°C.

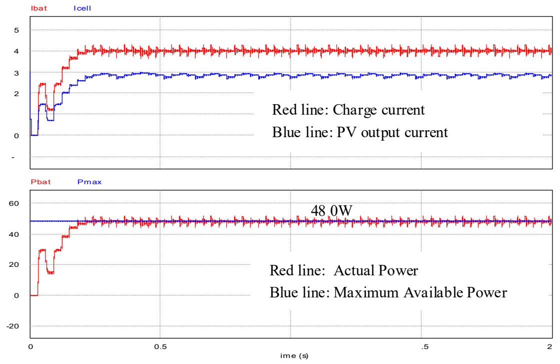

Fig. 3 PSIM simulation result of MPPT algorithm

6. Experimental results

The MPPT algorithm and the battery charging method described above was experimentally tested with a PV array and a 12V, 40Ah lead-acid battery. The switching frequency of buck converter was set at 60 [kHz]. The MPPT cycle is set at 30ms and duty step dD was 0.005.

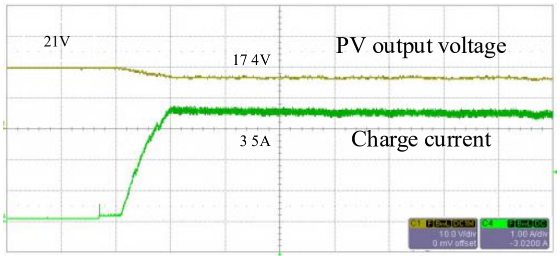

Fig. 4 The MPPT result under the constant irradiation

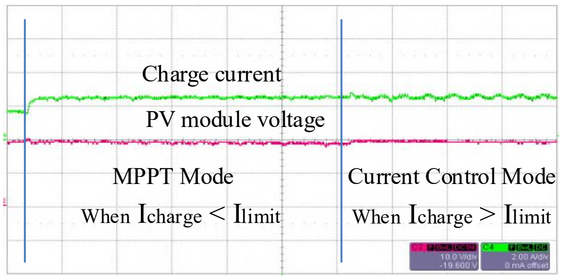

Fig. 5 Mode change in the charge algorithm

7. Conclusion

In this paper, a low cost solar charger was proposed and its feasibility was proved by the experiments. By the proposed MPPT technique the number of the sensors can be reduced, thereby reducing the complexity and the cost of the solar charger. The proposed system can be used for the rooftop solar system of the vehicle and the auxiliary charger for the portable electronics.

Reference

[1] Trishan Esram and Patrick L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", IEEE Transactions on Energy Conversion, Vol. 22, No. 2, June 2007.

[2] D. Shmilovitz, "On the Control of Photovoltaic Maximum Power Point Tracker via Output Parameters", IEE Proc.-Electr. Power Appl., Vol. 152, No. 2, March 2005.