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Battery Charger Based MPPT Technique For Photovoltaic Arrays

Minh-Huan Vo
Faculty of Electrical and Electronics Engineering, HCMC University of Technology and Education, Vietnam

ABSTRACT : *The solar cell battery charger based on the Maximum Power Point Tracking (MPPT) method using fractional open circuit voltage method is studied for mobile devices or IoT sensor nodes. The proposed technique is based on the operation principle of DC-DC buck converter to find the maximum power point from the solar cell, to optimize the charging process to the battery. The MPPT circuit is based on the characteristics of the various light density solar cell and electrochemical power of the lithium-ion battery with the constant current charging and constant voltage charging. Through the process of calculating, designing and simulating the system, the proposed solar battery charger shows 90% optimum charging power, 53% optimum charging time compared to the direct battery charger.*

KEYWORDS *Maximum Power Point Tracking; Buck Converter; battery charger; solar cell; fractional open circuit voltage*

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I. INTRODUCTION

Solar energy is one of the most important sources of renewable energy that has received a lot of attention in recent years. Solar energy is abundant, the largest amount available. The amount of solar energy that supplies the earth every day is enough to power the earth's energy needs for a year. Solar energy is clean and emits free, as it produces no pollutants or harmful natural products. Converting solar energy to useful energy has many applications in each field, especially in applications using power batteries in mobile devices such as sensor node in IOT applications [1].

Recently, the research and development of flat solar panels with lower cost. In the near future, the lower cost of power solar module units and solar power plants will be economically viable for the production and use of solar energy at big scale. At that time, handy battery-powered electronic devices can self-supply clean renewable energy sources to power themselves, increasing battery life.

The Maximum Power Point Tracker (MPPT) is used to detect the maximum point to achieve the maximum power level of the energy generated by the solar panels. The basic idea of MPPT algorithm is to find automatically voltage and current points at which the photovoltaic cells operate to achieve the maximum power output under given light and temperature conditions [2]. There are many different MPPT techniques which has researched and published so far. Here, the Hill Climbing technique using a microprocessor to increase or decrease the power around an extremely high power point is often used, however, this technique has to write a program for the processor or use a DSP chip specifically to track to the maximum power point. Thus, this technique will consume large power and much cost [3]. The MPPT technique using network fuzzy logic and neural nucleation is also commonly used because the MPPT technique is able to search with higher accuracy and faster peak response [2] [4]. Artificial neural network technique uses CPU, DSP, MatLab, to perform training and learn rules based on light intensity and temperature conditions to find the peak [4]. Open circuit voltage techniques are also commonly used to show the relationship between the voltages with the maximum power point and the open circuit voltage of solar cells [5] [6]. In various levels of heat and the light,, the open circuit voltage method is done by equation: $V_{MPP} = kV_{OC}$ method. Here k is a constant. k depends on the properties of the used solar cell. It is often calculated manually to determine the V_{MPP} and V_{OC} for energy cells at different degrees and intensity of luminance. The value of k ranges from 0.71 to 0.78 [2]. Using an electronic circuit track the maximum point will improve valuable power in the system. When the k value is known, the V_{MPP} may be calculated according to the V_{OC} by a simple analog circuit. So the open circuit voltage MPPT technique is simply include such as opamp, OTA circuit, electronic components compared to Hill Climbing including CPUs, DSPs, etc.

- ***THE BATTERY CHARGING PROCESS BASED ON BUCK CONVERTER***

Buck converter is a DC-DC voltage converter circuit whose output voltage is modulated according to PWM pulse from input voltage [7-8].

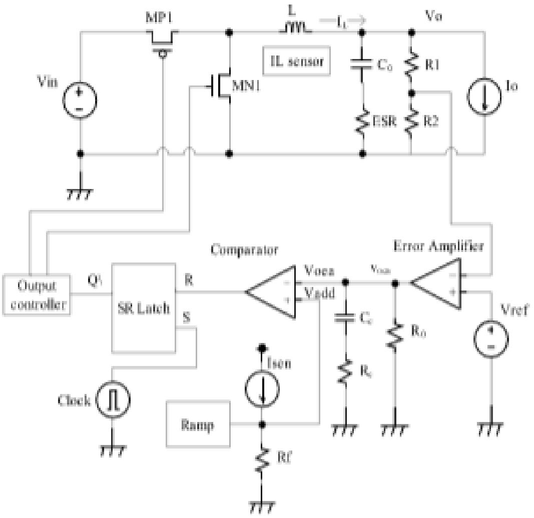


Figure 1. Conventional buck converter circuit designed in current mode [8]

Basically, the Li-ion battery charging process consists of constant current charging (CC) and constant voltage charging (CV). However, the CC process at buck converter has variable charging current [9].

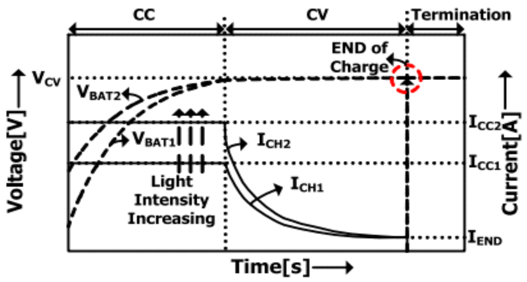


Figure 2: Li-ion battery charging process [6]

- **II.1 Current charging**

Considering the signal that controls the battery charging process V_{add}:

$$V_{add} = (I_{sen} + I_{ramp}) \times R_f \qquad (2)$$

In which, V_{add} adjusted by I_{sen} is the sensor current from the I_L current through the coil analyzed in the current sensor block. I_{sen} sensor current depends on I_L in ON cycle and I_{BIAS} ($\ll \alpha.I_L$) in OFF cycle of I_L.
During the T_{on} cycle, I_L increases gradually, V_{add} also increases gradually. If V_{add} is greater than V_{oea}, Reset = ‘1’ signal is created to the PWM circuit. This circuit controls transistor MP1 and turns off MN1, switches to T_{off}.
When the V_{bat} (or the V_O output voltage of buck converter) is low, the rising edge of the i_L has a steep slope, the decreasing edge has a very small slope, so the charge current will almost always increase.
When $V_{bat} \geq V_{sa}$ - V_{bat} (or $V_O \geq V_{IN}$ - V_O), the rising edge of i_L has a small slope and the decreasing edge has a steep slope, so the charge current almost always decreases. At this time, the battery voltage is approximately full, charging will continue with the charging process.

- **II.2 Voltage charging**

When V_{bat} ~ 80% V_{ref}, the OTA circuit makes V_{oea} decrease to 0 V. Because the charging current for the battery is stable at this time, the gradual decrease of the V_{oea} error signal shortens the cycle of the Reset signal to the SR latch circuit, causing the operating cycle of the current through the coil to be changed: T_{on} decreases and T_{off} increases. The above process causes the battery charging current to drop quickly to zero. Until the reset is ‘1’, the charge current becomes 0. The V_{ref} voltage will maintain the battery charge voltage during charging process.

- **Optimizing battery charging capacity with MPPT using the fractional open-circuit voltage method based on solar cell characteristics**

The solar cell voltage relative to maximum capacity is linearly dependent on the battery's open circuit voltage for different light intensities and temperatures:

$$V_{MPP} = k.V_{OC} \qquad (3)$$

In which, V_{MPP} is the voltage at the point of maximum power, V_{OC} is the open-circuit voltage of the battery depending on the ambient light temperature and intensity, and k is the voltage factor that is 0.71 to 0.78 depends on the properties of the solar cell. In the design circuit, k = 0.75.

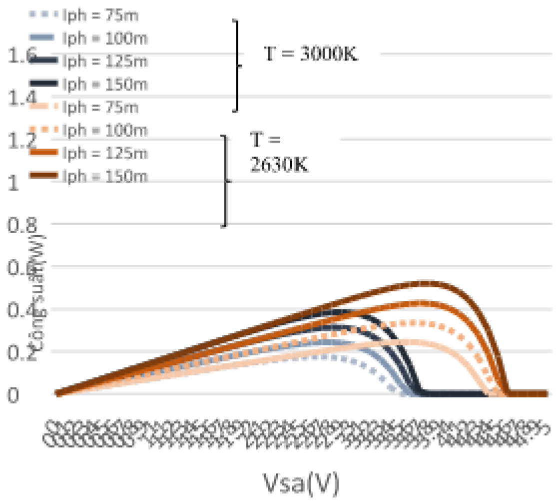


Figure 3: Solar cell power characteristics vary with temperature and light condition

When the ON cycle of the current passes through the coil, the current through the resistor R_f is I_1 has magnitude:

$$I_1 = I_{sen} - I_{MPPT} + I_{ramp} = K.I_L - \frac{(V_{SA} - k.V_{OC}).A_{V1(s)}}{R_2} + I_{ramp} \qquad (4)$$

R_2 is the resistance in the voltage-current transformer circuit (vtoi_real), A_{V1} (s) is the transfer function of the OTA block (the OTA circuit in the MPPT controller block):

$$A_{V1}(s) = \frac{V_{EA}}{k.V_{OC}} \approx g_m R_{O2} \frac{1 + sC_{C2}R_{C2}}{1 + sC_{C2}R_{O2}} \qquad (5)$$

Here, $R_{O2} >> R_{C2}$

Where, g_m is the tranconductance and R_{O2} is the output resistance of the OTA.

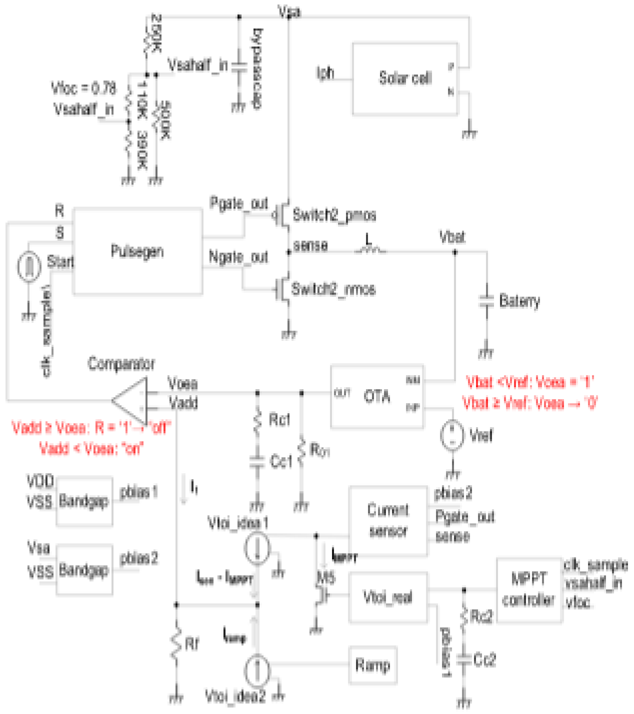
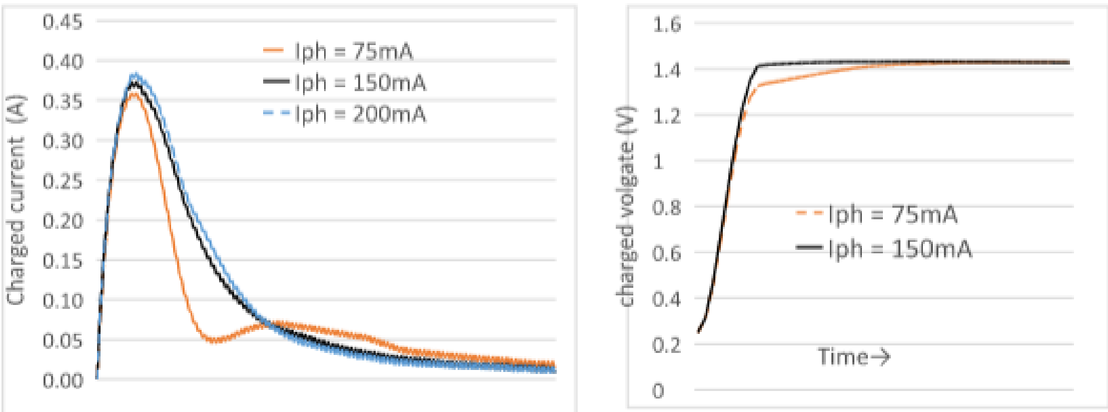


Figure 4: Diagram of the MPPT circuit

The current I_1 then forms the voltage signal V_{add}, which, together with V_{oea}, controls the charging process. At a light intensity level, the maximum power point of the solar cell is detected as follows: when $V_{SA} > k.V_{OC}$, the I_{MPPT} current increases. The V_{add} will decrease when I_{MPPT} increases or V_{add} will be inhibited by I_{MPPT} current during rising I_{sen}. Therefore, the I_{MPPT} current will last longer than the time of $V_{add} < V_{oea}$ or T_{on} cycle of the current through the coil is increased. The T_{off} decreases so the charging current for the battery increases. According to the current-voltage characteristics of the solar cell, the increased output current decreases V_{sa}. This process ends when $V_{sa} = k.V_{OC}$. At that time, the battery is charged to its maximum capacity from the solar cell. When lighting conditions is changed, CC current charging is optimized since V_{sa} tracks $k.V_{oc}$ so that the circuit reaches a new maximum power point.

IV. SIMULATION RESULTS



(a) (b)

Figure 5: Charged current (a) and charged voltage (b) when the light intensity is strong and weak, shown through two phases of charging current and charging voltage. The charging current is adjusted by MPPT while the charging voltage is constant.

The charging current is varied with different lighting conditions (I_{ph}) during charging by the buck converter based MPPT circuit. Maximum charging current is 359mA, 373mA and 385mA respectively with 75mA, 150mA and 200mA of light intensity. During the process, the battery voltage gradually increases. When the battery reaches approximately full voltage (1.4V), the charging current is adjusted less gradually, current charging process ends and charging voltage process takes place. We see that with lower luminous intensities, pressurization will take place earlier and vice versa.

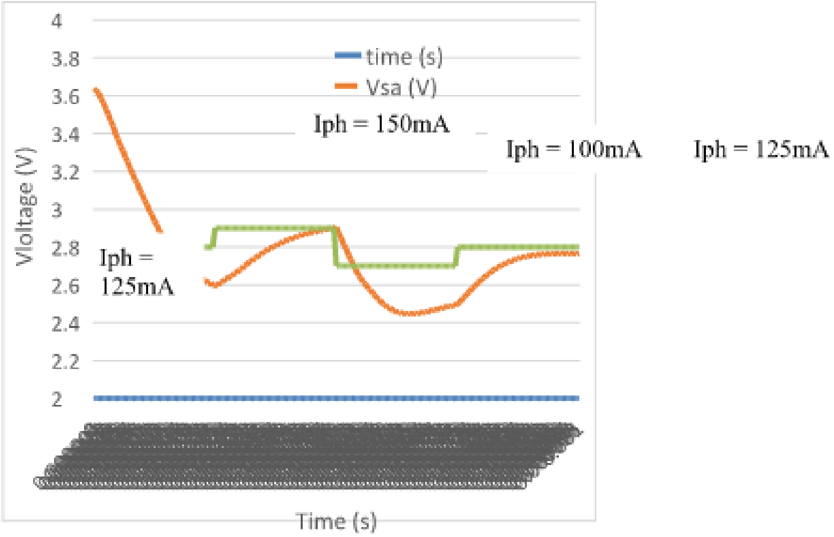


Figure 6: The MPPT circuit adjusts the MPPT current so that V_{SA} changes according to the maximum power point determined by $k.V_{OC}$, when the light intensity changes.

The I_{MPPT} current generated from the difference between V_{sa} and $k.V_{oc}$ will decrease V_{add}, increase the close cycle (T_{on}) of the lock transistor that charges current from the solar cell, thereby increasing the charge current to the battery. The increased charge current reduces the voltage of V_{sa}. This process is stable when $V_{sa} = k.V_{OC}$

Table 1: Comparison between the achieved power point and the desired power.

	Iph1	Iph2	Iph3	Iph4
V_{sa}	2,596	2,897	2,491	2,769
$k.V_{oc}$	2,8	2,9	2,7	2,8
P_0	0,3132	0,3851	0,243	0,3132
P	0,3047	0,385	0,2348	0,3123
%P	97,28608	99,97403	96,62551	99,71264

Here P_0 is maximum power level at $k.V_{oc}$. P is attained power level at V_{sa}.% P is attained power level of P relative to P_0.Based on the Table 1, it can be seen that the attained power level compared to the maximum power of the solar energy is almost maximized according to the light intensity.

Based on the results of Figure 7, we can see that the power achieved by MPPT method is always the highest compared to buck converter and direct charging. For example, at luminance I_{ph} = 200mA, the achieved power of the direct charging method is 0.28W, the conventional buck converter technique is 0.402W, and the proposed MPPT technique is 0.532W. The power gain of the MPPT technique is increased by 90% compared with the direct charging technique and 33% compared to the conventional buck converter technique.

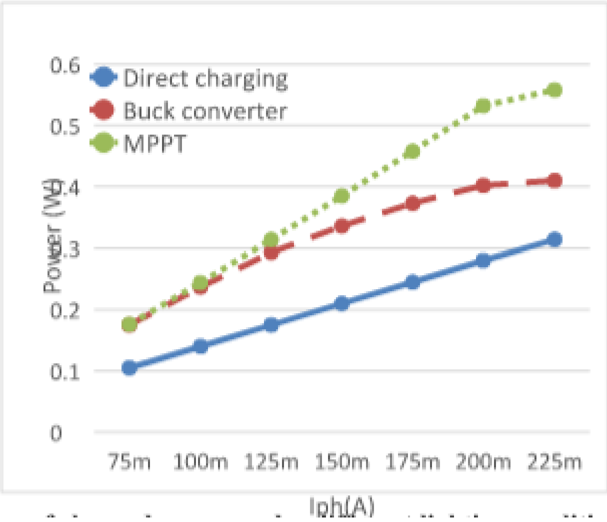


Figure 7: Comparison of charged power under different lighting conditions considering three cases: using MPPT, conventional buck circuit and direct charging.

When batteries is charged directly from solar cells, the solar cell output voltage depends on battery voltage $V_{sa} = V_{bat} << V_{oc}$. Originally, the charged battery has a low voltage which should keep the V_{sa} low and the charging current maximum. The solar cell's power point will then be located in the left-hand region of power profile. The battery charging process stops when V_{sa} increases to full charge voltage (V_{ref}).

In the process of battery charging, the MPPT is an optimized method based on buck converter circuit. At the beginning of the charging process, the solar cell output voltage V_{sa} is approximately V_{oc}. The battery charging current is very small (almost zero) because the transistor control the charging current in the off-state. The transistor is then turned on, increasing the charging current. The solar cell's power point will initially be located in the right-hand region of the power profile.

The difference between the method using buck converter and MPPT circuit is that the buck converter circuit has the charge current controlled by the full charge voltage of the battery as analyzed in the charging operation of the buck converter circuit. This is similar to direct charging, but increasing the charge current, gradually decreasing V_{sa} makes solar cells operate with power points at a higher level than direct charge.

Under constant light intensity, if the full voltage of the V_{ref} battery is approximately V_{oc} - V_{ref} difference voltage, the process of recharging the battery with the buck converter circuit can still reach the maximum power point like the MPPT method. However, when the light intensity changes, the maximum power point cannot be achieved. With the MPPT circuit, the charge current is controlled by the differential voltage V_{sa} - $k.V_{oc}$, or the magnitude of the I_{MPPT} current. The I_{MPPT} increases the charge current and reduces V_{sa}. V_{sa} is changed to $k.V_{oc}$ then stops. Therefore, V_{sa} is independent of battery voltage. When the light intensity changes, V_{sa} will be adjusted according to the above mechanism to achieve a new $k.V_{oc}$ value. Thus, the battery charging process is always at maximum power with all lighting conditions.

In addition, when the temperature changes, the V_{oc} and I_{sc} of the solar cell also change. The MPPT circuit still relies on the above mechanism to optimize the battery charging process.

Table 2 simulates and evaluates the MPPT technique and compares it with the direct charge technique. Time to charge a 3000F capacity battery at 1.4V is as follows:

Table 2: Comparison of charge time of MPPT and direct charge technique

Iph (mA)	75	100	125	150
MPPT	536.25	328	201.67	59.775
Direct Charge	674.75	467.25	328.75	109.16
Lower(%)	20.5	29.8020	38.65	54.758

According to the simulation results, at intensity I_{ph} = 150mA, direct charge time to fully charge the battery is about 109.16 minutes while MPPT technique is charged about 59.775 minutes. So the MPPT battery charger is about 53% faster charging time.

IV. CONCLUSION

The proposed MPPT circuit is added to a buck converter for optimizing the charging current. The system can adjust the charge current according to light, temperature conditions to transmit maximum power from Solar cells to Li -ion batteries. The constant voltage charging helps maintain the battery voltage to its full level and ends the charging process with optimal efficiency. From the simulation results, we see that the system is capable of optimizing charging power up to 90% , charging time is 53% more optimized than the direct charging method.

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REFERENCES

[1]. Huang-Chen Lee, *et al*, " Design of Multifunctional Wireless Sensor for In-Situ Monitoring of Debris Flows", *IEEE Transactions on Instrumentation and Measurement*, vol. 59, pp. 2958 – 2967, 2010

[2]. Trishan Esram; Patrick L. Chapman, "comparison of Photovoltaic Array Maximum Power Point TrackingTechniques", IEEE Transactions on Energy Conversion, Volume: 22, Issue: 2, Pages: 439 – 449 2007.

[3]. Hussam Al-Atrash; Issa Batarseh; Khalid Rustom, "Effect of Measurement Noise and Bias on Hill-Climbing MPPT Algorithms", IEEE Transactions on Aerospace and Electronic Systems, Vol. 46, pp. 745 – 760, 2010.

[4]. Haider Saif Agha; Zafar-ullah Koreshi; Mohammad Bilal Khan, "Artificial neural network based maximum power point tracking for solar photovoltaics", 2017 International Conference on Information and Communication Technologies (ICICT), 2017

[5]. Jawad Ahmad, "A fractional open circuit voltage based maximum power point tracker for photovoltaic arrays", 2010 2nd International Conference on Software Technology and Engineering, Volume: 1, pp. 247 -250, 2010.

[6]. Eun-Sub Lee, Chul-Mun Jung, Huan Minh Vo, Kyeong-Sik Min, School of Electrical Engineering, Kookmin University, "Compact and efficient Maximum Power Point Tracking circuit for portable solar battery charger", IEICE Electronics Express, June 25, 2011.

[7]. C. Leung, et al., "An integrated CMOS current-sensing circuit for low- voltage current-mode Buck regulator," IEEE Trans. Circuits Syst. 2, Vol. 52, No. 7, p. 394, July 2005.

[8]. Cheung Fai Lee, Phillip K. T. Mok, "A Monolithic Current-Mode CMOS DC-DC Converter with On-Chip Current Sensing Technique", IEEE Journal of Solid-State Circuits, Vol. 39, No. 1, January 2004.

[9]. M.Chen and G. A. Rincon-Mora, "Accurate, compact, and power- efficient Li-ion battery charger circuit," IEEE Trans. Circuits Syst. 2, vol. 53, no. 11, pp. 1180–1184, Nov. 2006.

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