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# Research and development of maximum power transfer tracking system for solar cell unit by matching impedance

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ABSTRACT

Employing the theorem that matching impedance produces maximum power transfer, the current study develops a low-cost and highly efficient "maximum power point tracker for a solar cell unit," for the purpose of allowing a solar cell to achieve optimal power transfer under different solar intensities and temperatures. Circuit control takes a single-chip microprocessor as the core and the booster circuit design undergoes the solar cell charging operation even though the solar cell output voltage is lower than the rated storage battery voltage. Experiments conducted in this study prove that the tracker this study develops effectively enhances the utilization efficiency of a solar cell. When a solar cell is at an output voltage above 30% of the rated voltage, it can charge a storage battery. When it reaches above 80% of the rated voltage, its power conversion efficiency can reach above 85%. The charge and discharge management mechanism of the device also avoids excessive charge and discharge of the storage battery, and extends storage battery longevity.



## 1. Introduction

By adjusting the solar cell unit axial direction, the solar tracking system helps the solar cell unit possess the best receiving effect [1–8]. After the received energy is transformed as electric energy, it is delivered to the storage battery for charging or loading. If electric energy is required to perform parallel connection with an electricity system or supply general home appliances, an inverter is needed to transform the direct current (DC) to an alternative current (AC). To date, there are many highly efficient designs [9]. Nevertheless, the power transfer value of solar cell changes with solar intensity. The solar tracker acquires maximum solar power only when it is under the same light intensity, but it is unknown whether transformed electricity can be most efficiently utilized. As to the control of charge and discharge load, although the conventional relay-operated structure is simple, it cannot perform accurate load adjustment [10]. To achieve load control, many researches have adopted a microcontroller-based method to control solar transfer to achieve continuous control [11–14]. Circuit detection is typically employed to detect ever-changing electric signals, and further match with different arithmetic methods to control the charge and discharge mode, to acquire highest utilization efficiency of a solar cell.

The current study is based on the concept of maximum power transfer. Equal system impedance and load impedance achieve maximum power transfer, acquiring the highest utilization efficiency of a solar cell. The controller proposed by this study uses a microprocessor (microcontroller unit, or MCU) as the control core. Detecting power transfer change of solar cell units, achieves power impedance. Matching impedance is performed by pulse width modulation (PWM), achieving maximum power transfer without needing to use a complicated control circuit and arithmetic procedures. This method does not need to focus on the characteristic curve of the solar cell unit to undergo design. Instead, directly referring to the actual situation acquires maximum power transfer under this situation. Changing different solar cell unit by this method only requires performing simple software modification according to different specifications. Concerning using booster circuits to solve the problem of excessive low output voltage of a solar cell, even though it is under very low voltage output condition, charging can still be carried out for a storage battery, extending chargeable time and raising charging efficiency. Finally, through the charge and discharge management mechanism of a storage battery, charging voltage is controlled to be within the rated 120%, and discharge voltage to be within the rated 80%. Such a design effectively extends storage battery longevity. Apart from

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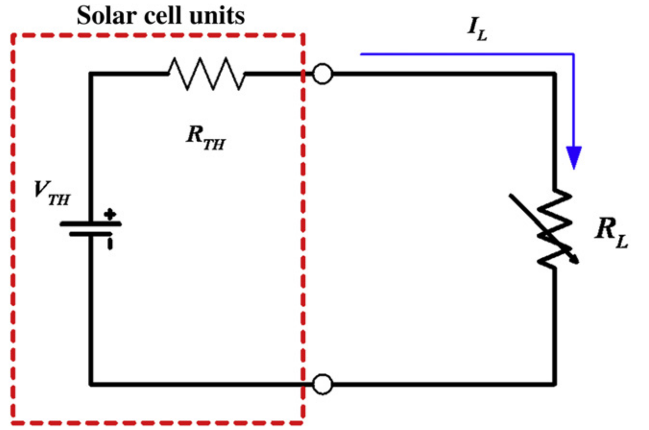


**Fig. 1.** Schematic demonstration of maximum power transfer for solar cell unit.

enhancing charging performance, the design also achieves environmental protection and decreases waste.

## 2. Related theories

The solar cell is a type of power, and its power transfer changes with solar intensity. Any changes of solar cell power transfer, also change its voltage and internal impedance. Circuit analysis is sometimes interested in determining the maximum power delivered to a load. By employing Thevenin's theorem, this work determines the maximum power a circuit can supply and the manner for adjusting the load in order to affect maximum power transfer.

Suppose that the given circuit is shown in Fig. 1. The power delivered to the load is expressed as:

$$P_L = I_L^2 \times R_L = \left(\frac{V_{TH}}{R_{TH} + R_L}\right)^2 \times R_L \tag{1}$$

We want to determine the $R_L$ value that maximizes this quantity. Hence, we differentiate the expression with respect to $R_L$ and equate the derivative to zero.

$$\frac{dP_L}{dR_L} = \frac{(R_{TH} + R_L)^2 V_{TH}^2 - 2V_{TH}^2 R_L (R_{TH} + R_L)}{(R_{TH} + R_L)^4} = 0 \tag{2}$$

which yields

$$R_L = R_{TH} \tag{3}$$

In other words, maximum power transfer takes place when the load resistance $R_L = R_{TH}$. Although this is a very important result, this study derives it using a simple network indicated in Fig. 1. When $R_L$ is adjusted to equal $R_{TH}$, the maximum power transfer for solar cell units can be acquired.

According to the above concept of maximum power transfer, the simplest way to achieve maximum power transfer is to use a group of variable resistors to achieve matching impedance ($R_L = R_{TH}$). This method achieves maximum power transfer of a solar cell under different solar intensities. Actual application of this theory would be restricted. The power transfer of a solar cell, no matter whether it is connected to a storage battery or a service load, still has load impedance. For example, for a storage battery load, the internal impedance ($R_B$) of the storage battery would change as affected by the charging situation. The maximum adjustment range of variable resistance would be limited in the range of $R_B \sim R_{VR} + R_B$. If internal impedance of the solar cell is outside of this range, the theoretical value of maximum power transfer will not exist. But the adjustable best situation under this condition can still be achieved. Manual adjustment of variable resistance cannot achieve automation with the constantly changing output impedance of the solar cell and storage battery. When solar cell output voltage is lower than storage battery voltage, the charge also cannot be achieved. To solve these problems, pulse width modulation (PWM) can be used to control the pulse width and change the impedance value by the side of the load. PWM only requires adjusting the pulse width moderately, and then the equivalent impedance by the side of the load can change to match with the internal impedance of the solar cell unit. This process achieves maximum power transfer of the above limitation condition. Using booster circuits, even though solar cell output voltage is lower than storage battery voltage, charging can still be undergone.

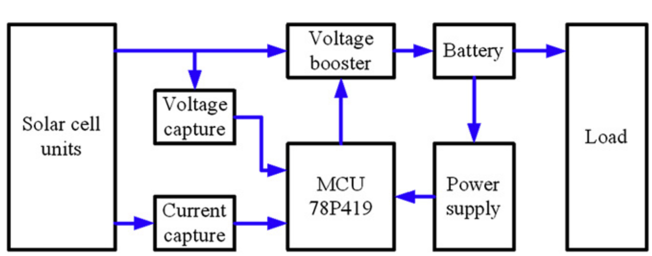


**Fig. 2.** Block diagram of control circuits.

## 3. Description of system and control circuits

Fig. 2 shows the circuit block diagram of the experiment in which the microprocessor (MCU) is the core, and circuits attain the voltage and current of the solar cell unit. The experiment calculates solar cell unit power and controls booster circuits using MCU, charging batteries even though the sunlight is very weak. This study conducts moderate battery voltage surveillance, and controls battery charge and discharge. Fig. 3 shows the complete control circuits, indicating their main operation as follows:

### *3.1. Signal sampling circuits for voltage and current*

In Fig. 3(a), block A shows the signal sampling circuits used in this study. The voltage sampling adopts voltage division between $R_1$ and $R_2$, taking the applicable range of the matched AD converter. The current sampling employs the voltage drop caused after the current goes through $R_{10}$. The voltage drop is converted to current value by Ohm's law, and further amplified by the reversing amplifier built-in MCU. For calculating electric power, the CPU calculates the measured voltage and current values after they have performed AD conversion, eventually acquiring the solar cell power transfer. PWM transfer adjustment uses power comparison. The current detected power rate is compared with that of the previous sampling time. By comparing the results, the PWM transfer is adjusted before storage battery charging, achieving matching impedance, and keeping power transfer at maximum value.

### *3.2. Driving and booster circuits*

In Fig. 3(a), block B shows the driving and booster circuits used in this study. The driving circuit conducts current amplification using a pair of bipolar junction transistors (BJTs). When n-channel metal-oxide-semiconductor (NMOS), which serves as a switch, increases its duties, the output voltage of storage battery drops, and rises contrarily. Using the driving current increases output ability and improves transient effect of the electric capacitor. Connecting the NMOS gate with resistance ($R_{15}$) reduces interruption by confused signals and maintains a stable output. Booster circuits are