Application Note

Buck Charger with MPPT and Boost Converter for Solar Powered Application Based on TPS61094

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ABSTRACT

Due to increase consumption of non-renewable energy for example, petroleum and the urgency of improving the ecological environment, energy harvesting, and solar energy, has become a hot topic in the world. More products choose solar as the power resource. The typical system powered by solar cell includes solar panel, energy storage element, similar to supercap or NiMH battery and the DC/DC device for charging the energy storage element from the solar panel, and others DC/DC to regulate output voltage. The result is specifically designed to the system powered by solar energy (less than 5 W). The Buck CC/CV feature ensures that the energy storage similar to super-cap or NiMH battery can be charged well. This result can nearly realize MPPT (Maximum Power Point Tracking) by using bi-directional buck or boost feature in TPS61094. And TPS61094 integrates a 60-nA ultra-low Iq boost converter to regulate output voltage no matter that the solar energy is strong or weak.

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1 Introduction of Solar Cell and MPPT

A solar cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. The common single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 V to 0.6 V. Individual solar cell devices are often the electrical building blocks of photovoltaic modules. The most commonly known solar cell is configured as a large-area p-n junction made from silicon.

Open circuit voltage and short circuit current are the most important parameters of solar panels. In general, its operating voltage and current vary with the load resistance (*Energy Harvesting From Single Cell Solar Panel for Li-Ion Battery Reference Design*). Figure 1-1 shows the operating current and voltage corresponding to different loads, which is the VI/VQ curve of the solar cell.

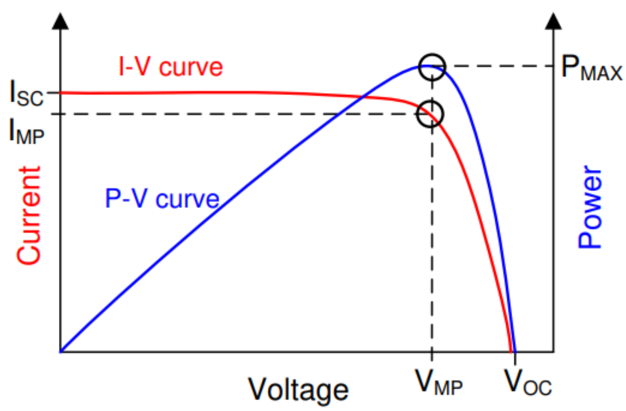

Figure 1-1. VI/VQ Curve of Solar Cell

Under different lighting conditions, the same solar panel has different maximum output power according to different loads. It's important to make the solar panel work at the maximum power point through adjustment. Maximum power point tracking is a technique used with variable power sources to maximize energy extraction as conditions vary. It maximizes energy extraction when conditions change. The central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on the amount of available sunlight, solar panel temperature and the load' s electrical characteristics. As these conditions vary, the load characteristic that gives the highest power transfer changes. The system is optimized when the load characteristic changes to keep power transfer at highest efficiency. This optimal load characteristic is called the maximum power point (MPP). MPPT is the process of adjusting the load characteristic as the conditions change. Circuits can be designed to present optimal loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems.

1.1 Traditional MPPT Solution

There are many ways to realize MPPT, such as perturb and observe, incremental conductance, current sweep, temperature method and constant voltage (*A survey of maximum PPT techniques of PV systems*). Different ways have their own advantages and disadvantages, and have different requirements for hardware and algorithms.

And the constant voltage way is one of the earlier strategies. It takes advantage of the fact that the maximum power point of the solar cell is almost on the same vertical line under the condition of constant temperature. A controller is used between the solar panel and the load to make the output voltage constant to realize simple MPPT function. It is suitable for applications with stable external environment (*Simulation and Hardware Implementation of New Maximum Power Point Tracking Technique for Partially Shaded PV System Using Hybrid DEPSO Method*). This application note is also using constant voltage to realize MPPT in system.

2 Typical System with Solar cell

2.1 General Introduction

This solution is mainly for some low-power system with solar panel and use one chip TPS61094 to achieve charging and discharge feature. It's really simple without external analog MPPT circuits as we've wanted to design a non-complex version of an MPPT with battery charging for our new generation solar product. The main suitable applications are tracker and fault indicator, etc.

2.2 Specific End Equipment

Asset trackers integrate numerous subsystems in a small space. Though the tracking modules can differ in style and features, they share similar digital interfacing challenges, such as reading in data from a variety of sensors or interfacing with a GPS module (*Optimizing Asset Trackers With Logic and Translation Use Cases*). The system is battery-powered, which requires higher power consumption and efficiency. Taking tracker as an example, this application note proposes a solution using solar panel as the power supply for the tracker and realize MPPT function with a single TPS61094. Figure 2-1 shows the typical system diagram.

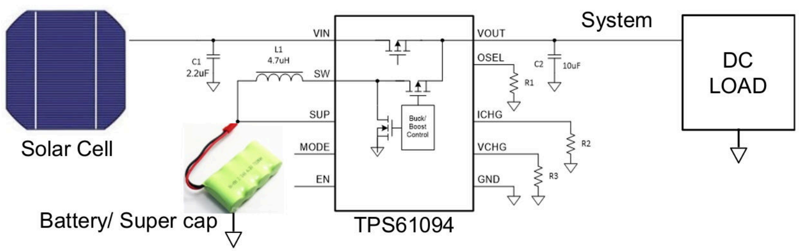

Figure 2-1. System Block Diagram of TPS61094 Power Supply

2.2.1 System Requirements

The system requirements are listed in Table 2-1.

Table 2-1. Tracker System Requirement

Parameters	Values
Output Voltage	3.3 V
Max Output Current	100 mA
Average Output Current	1 mA

Output power is the most important parameter in this system. The parameter determines the choice of solar panels, super capacitors, and MPPT target output voltage.

3 TPS61094 Solution

3.1 Supercap and Battery Design

An energy storage element is a necessary condition to realize this system, Supercap or batteries can be used here as energy storage elements. For this system, the capacity of the energy storage element needs to meet the power supply requirements of the system during the dark hours of the day. The choice of the supercap or batteries can be calculated by the following equation.

$$C = \frac{2tP_{average}}{\eta\left({U_{max}}^2 - {U_{min}}^2\right)} \quad (1)$$

Here select, η≈90%, according to the environment condition and system requirement. The supercap needs to be able to discharge at a constant power of 1 mA for 12 hours. Based on Equation 1, the super cap in the system needs to be more than 55 F.

3.2 Solar Panel Design

According to the requirement of the system, the solar panel needs to fully-charge the supercap with a constant current within 12 hours. And at the same time, it must meet the maximum power output of the rear stage. Combined with the output power, the power of the solar panel must be more than double of the output power. And it needs to be more than 10 mW in this system.

A 15×15 solar panel is used in this system. Actually, the average output power of a 15×15 solar panel should be much more than 6.6 mW. The V-P curve of the solar panel under different lighting conditions are shown in Figure 3-1.

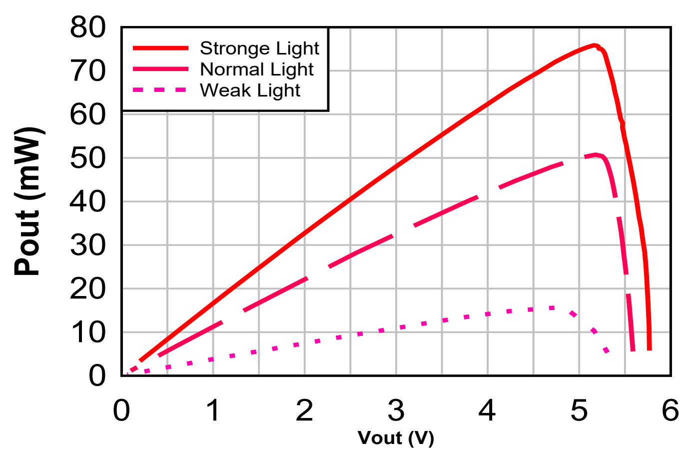

Figure 3-1. V-P Curve of Solar Panels under Different Environment

The maximum power point of the solar panel is basically stable at the same voltage. And the power of the solar panel is more than 10 mW most of the day. Combine with the system requirement, 4.8 V is used as the MPPT point.

3.3 TPS61094 Description and Operation

The TPS61094 is a synchronous bi-directional buck/boost converter with a bypass switch between input and output. When the TPS61094 works in buck mode to charge the supercap, the charging current and the charging termination voltage are programmable with two external resistors (R3 and R2). When the TPS61094 works in boost or supplement mode, it can boost the supercap and regulate output voltage to the programmed voltage, set by R1. Figure 3-2 shows the typical application of TPS61094.

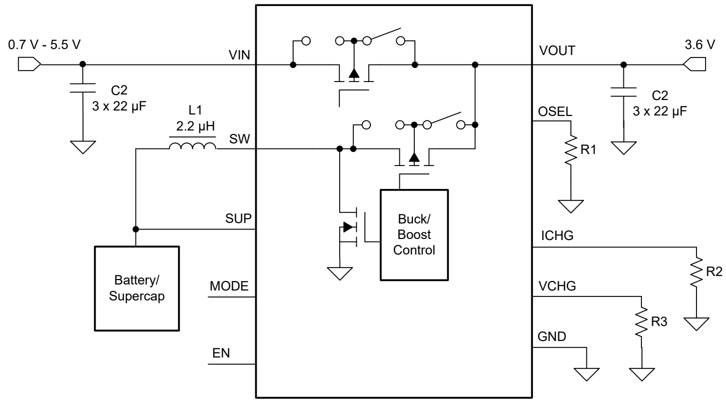

Figure 3-2. Typical Application of TPS61094

The TPS61094 has four operation modes: the auto buck or boost mode; the force buck mode; the force bypass mode and the true shutdown mode, set by the EN and MODE pins. Customers can choose the suitable mode based on their applications (*TPS61094 60-nA Quiescent Current Bi-directional Buck/Boost Converter with bypass Mode*).

3.4 System Solution

To realize MPPT function and shorten the time of system testing. Auto buck or boost mode is being used in this system. A smaller super cap is used on the testing board. Table 3-1 shows the setting in this test.

Table 3-1. Test Setting on EVM Board

Parameters	Values
Solar Panel	5.5 V 100 mW
Super Cap	3 F 2.7 V
Target Voltage	4.8 V
Charge Current	150 mA
Charge Voltage	2.7 V

The realization of the system mainly takes advantage of the characteristic that the voltage of the solar panel will drop when a large current is drawn. Combined with the auto buck-boost spec of TPS61094, the target voltage is 4.8 V and the charging current is 150 mA, which is higher than the Impp. Due to the characteristics of the solar cells, TPS61094 will switch between different modes quickly. This makes the output voltage fluctuate around the target voltage. And the output voltage is stable regardless of the light and the load. This solution realizes MPPT for not only battery charging but also post-stage power supply. The main operation mode of the system shows in Figure 3-3.

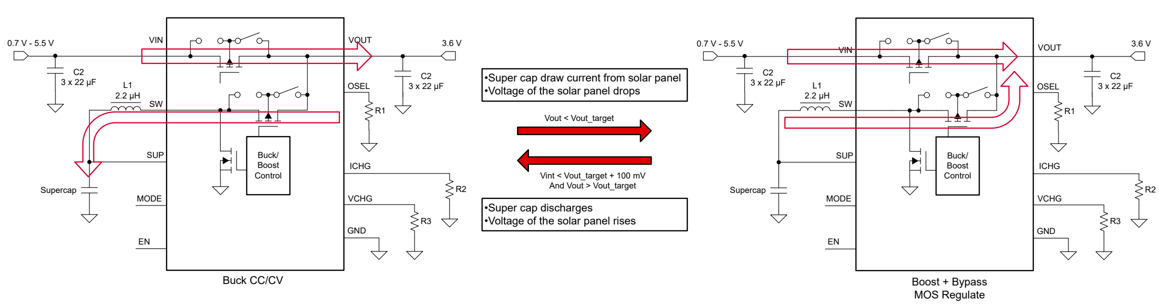

Figure 3-3. Main Two Operation States Transition

The TPS61094 works at buck mode first. There is a heavy load transient in the SUP pin and the solar panel cannot hold it, which makes the output voltage lower than the output target voltage (OSEL pin setting). The TPS61094 transfers from buck mode to supplement mode. The solar panel and SUP power source will supply the load together.

In supplement state, the input voltage will rise because the sup is not charged. And the output voltage will be higher than the output target voltage + 100 mV, meaning the solar panel can support the output load, the TPS61094 transfers from supplement to buck mode.

Figure 3-4 shows the waveform of the system. The yellow line shows the terminal voltage of the solar panel, the voltage is kept at around 4.8 V. The purple line shows the output voltage. A 47 uF electrolytic cap is added between the output and ground to filter out a 25 Hz switching ripple. The green line shows the current of the inductor. TPS61094 is in buck mode when the current is positive and in supplement mode when the current is negative. The result shows that this solution can successfully realize MPPT.

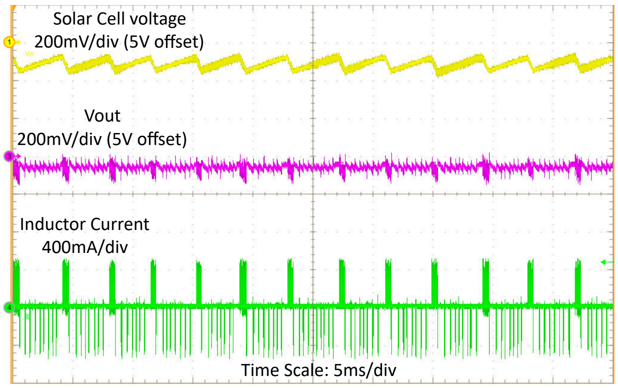

Figure 3-4. Typical Waveform to Realize MPPT

4 Test Report Based on TPS61094 Solution

4.1 Test Waveform

To meet the nature environment, system working waveforms are tested under different lighting and load conditions for comparison.

Figure 4-1 shows the supercap charging process under strong light conditions. When the device is enabled, super cap started to charge. The switch current shows the mode switch of TPS61094 and the solar panel voltage is regulated at 4.8 V(MPPT point). And the output voltage is stable.

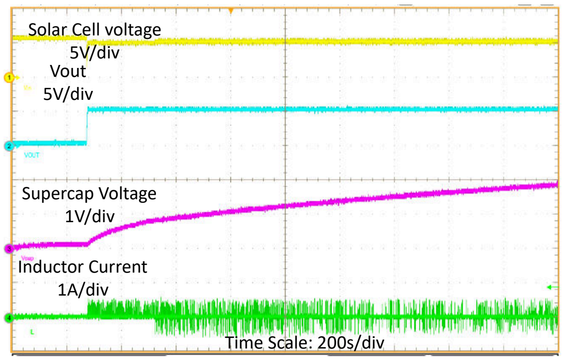

Figure 4-1. The Supercap Charging under Strong Light Conditions

Figure 4-1 shows the operation waveform under strong light and 20 mA load conditions.

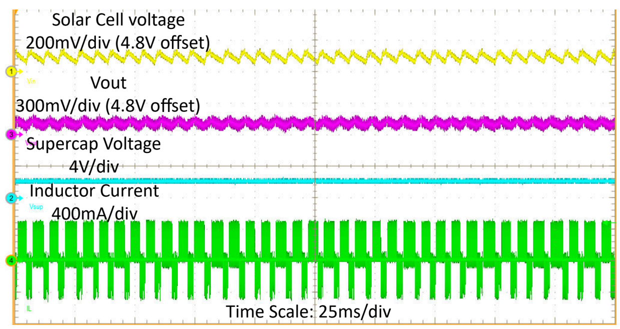

Figure 4-2. Strong Light and 20 mA Load Operation Waveform

5 References

1. Texas Instrument, *Energy Harvesting From Single Cell Solar Panel for Li-Ion Battery Reference Design*.
2. IEEE Xplore, *A survey of maximum PPT techniques of PV systems*, pp. 1–17, Ali, Ali Nasr Allah; Saied, Mohamed H.; Mostafa, M. Z.; Abdel- Moneim, T. M. (2012).
3. IEEE Xplore, *Simulation and Hardware Implementation of New Maximum Power Point Tracking Technique for Partially Shaded PV System Using Hybrid DEPSO Method*. 6 (3): 850–862, Seyedmahmoudian, M.; Rahmani, R.; Mekhilef, S.; Maung Than Oo, A.; Stojcevski, A.; Soon, Tey Kok; Ghandhari, A. S. (2015-07-01).
4. Texas instruments, *Optimizing Asset Trackers With Logic and Translation Use Cases*.
5. Texas Instruments, *TPS61094 60-nA Quiescent Current Bi-directional Buck/Boost Converter with bypass Mode* data sheet.