Solar charging solution provides narrow-voltage DC/DC system bus for multicell-battery applications

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Introduction

Solar-powered systems typically must operate from a very wide input-voltage range due to the large variations in a solar panel's output voltage. This wide operating range limits the system's ability to consume maximum power from the solar cell under all light conditions. The ideal solar charging application operates the solar cell at its maximum power point (MPP) while simultaneously limiting the input-voltage range of the system. This goal is achieved by integrating a narrow-voltage DC/DC (NVDC) battery-charging architecture with a solar-charger design. The narrow voltage range for the system power bus provides higher system efficiency, minimizing battery charging times and extending battery run times.[1] This article shows the NVDC charging architecture in a solar charging application and introduces a circuit that provides acceptable charger operation under several operating conditions, such as battery overtemperature, a discharged battery, a fully charged battery, and a system-current overload.

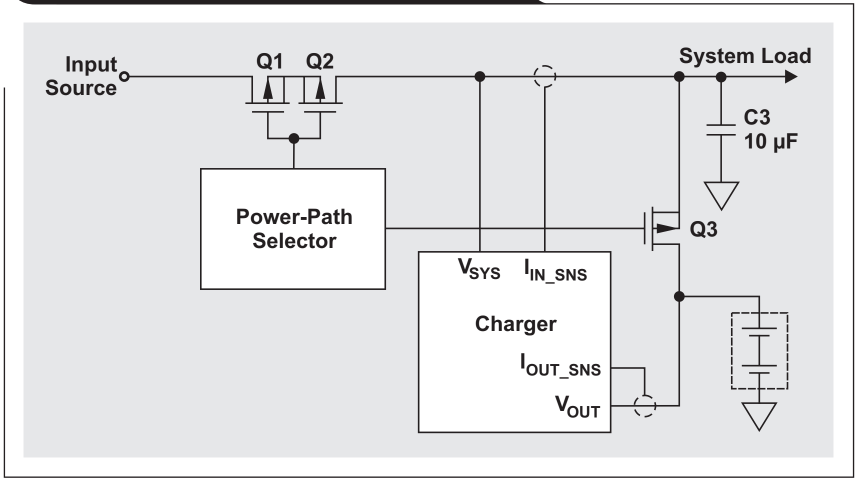
Conventional charger topology

Figure 1 shows a conventional charger topology used with high-power switching chargers. Notebook charging is a typical application for this topology. One drawback is the system's wide operating voltage range, which requires more expensive, less efficient power supplies to generate the power rails for the downstream circuitry.[1] The system voltage ranges from the highest AC adapter voltage (typically 22 V for a lightly loaded adapter) to the lowest battery voltage, which is 9 V for a 3S2P laptop battery pack. (3S2P is an abbreviation for three batteries in series with two of these series connections in parallel.) When the AC adapter is present, the power-path-selector MOSFETs (Q1 and Q2) turn on, and the battery MOSFET (Q3) turns off. The AC adapter voltage is applied to both the system voltage and the battery charger's input, delivering power to both circuits simultaneously. If the AC adapter voltage drops due to a brownout, an overcurrent condition, or unplugging the adapter, Q1 and Q2 turn off to prevent battery power from flowing backwards into the adapter. Q3 turns on and connects the battery-pack voltage directly to the system. In this way, the system is always supplied with power—either from the adapter or the battery.

Requirements of a solar-powered charger

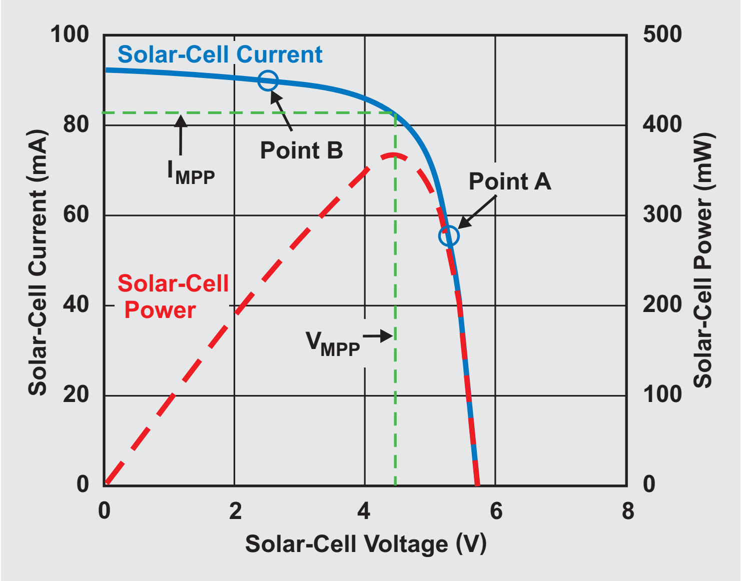
The battery-charger architecture in Figure 1 is acceptable for systems that use an AC adapter, but it is not ideal for solar charging applications because there is no way to limit the input current. To keep the solar cell always operating at its MPP, which will minimize battery charge time and the solar cell's size and cost, the charger needs a current-limiting mechanism. Unlike a conventional AC wall adapter,

Figure 1. Conventional charger topology



a solar cell should be operated with very tight control over its load current. Figure 2 shows the V-I characteristics of a typical solar cell under one light condition and helps explain this concept. The solid line represents the output current of the solar panel as its voltage varies, while the dashed line represents the output power. Because the panel's voltage drops as the current it delivers increases, an MPP is created at a specific voltage and current. A solar cell's MPP varies with different light conditions and temperatures. If very little charging and system current are required, the solar cell may operate at Point A in Figure 2, which is below its MPP. The solar cell delivers less than its maximum power, which is acceptable because the system is getting the power it needs. However, if the battery charge current or system power requirements increase, the charger pulls more current and the solar cell operates at Point B in Figure 2. At Point B, the solar cell's output current has increased, but the actual delivered power has gone down because of the drop in voltage. With reduced power from the solar cell, it takes longer to charge the battery. A well-designed solar-cell charger should contain circuitry that separates the solar cell from the system as well as circuitry that controls the solar cell's total current so the cell can be operated at its MPP. This combination of circuitry can fully utilize the solar cell's available power, resulting in a less expensive system because the designer does not have to oversize the solar cell to meet charging requirements.

Figure 2. Solar panel's V-I curve and output-power curve



Basics of maximum-power-point tracking

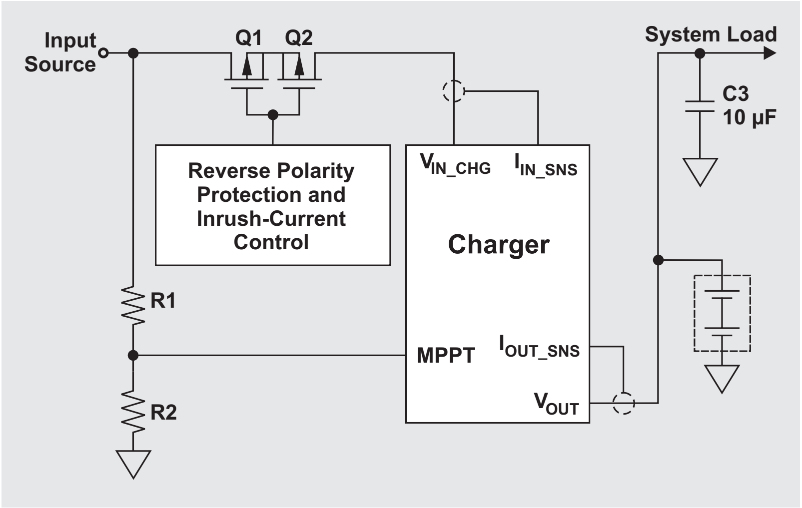
Solar-cell chargers include special circuitry called maximum-power-point tracking (MPPT) circuitry that prevents the charger from consuming more than the solar cell's maximum power. This is typically implemented by setting the minimum operating voltage that corresponds with the solar cell's MPP.

A design using the solar cell in Figure 2 allows the charger and system to draw any current from the solar cell as long as the solar cell's voltage remains above V_{MPP}. When the current increases to the point where the voltage drops to V_{MPP}, a special control loop in the charger takes over and regulates the total current from the solar cell to maintain the solar cell's voltage at V_{MPP}. At this operating point, the solar cell delivers its maximum power. Any power not required for the system load is used to charge the battery. This voltage-based MPPT circuitry is fairly accurate at providing maximum power, even with varying solar-cell illumination levels. Although reduced light lowers the solar cell's maximum power and current capability, the MPP is still achieved at approximately the same voltage.[2] Voltage-based MPPT circuitry typically consists of only two resistors external to the battery charger.[3] All other circuitry is integrated into the charger IC itself. A solar cell's V_{MPP} does vary significantly with temperature. If desired, additional circuitry can be added to track a solar cell's V_{MPP} change with temperature. Tracking MPP over temperature can reduce charging times by 40%.[4]

Adding NVDC charging architecture

Figure 3 shows how a narrow-voltage DC/DC (NVDC) charging architecture can separate the solar cell from the system. Rather than being connected to the solar cell via

Figure 3. NVDC architecture with MPPT circuitry



the power-path-selector FETs, the system is connected directly to the battery. The system voltage is now equal to the battery voltage, regardless of the input voltage of the adapter or solar cell. The narrow operating voltage allows the designer to optimize the system power supplies for size, cost, and efficiency.[1] It also eliminates the need for the battery FET. The NVDC architecture is useful for solar charging because it routes all current through the charger. This allows the MPPT circuitry to effectively control the total current from the solar cell and maintain operation at the maximum rated power.

Connecting the system directly to the battery as in Figure 3 has significant advantages, but it also has disadvantages under certain operating conditions that should be considered. These conditions are as follows:

1. When the battery voltage is lower than the battery's precharge voltage, the battery current must be limited to the precharge current, which may not be sufficient to operate the system.
2. When the battery temperature is outside the allowable range for charging, the charger must disable charging, which also disables the system's power.
3. When the battery is fully charged, it should be disconnected from the charging source to extend battery life, but the system should remain on.

All of these conditions can be addressed with the addition of FETs Q4 and Q5 to the NVDC architecture (see Figure 4). A gas gauge or a host controller monitors voltages, current, and battery temperature and uses these inputs to control the FETs, which connect or disconnect the battery to or from the charger depending on the operating conditions. The host can be as complicated as a microprocessor with analog-to-digital converters that continuously monitors operating conditions and adjusts charger performance based on the system's needs, or it can be simple, discrete circuitry that monitors only battery voltage and temperature.

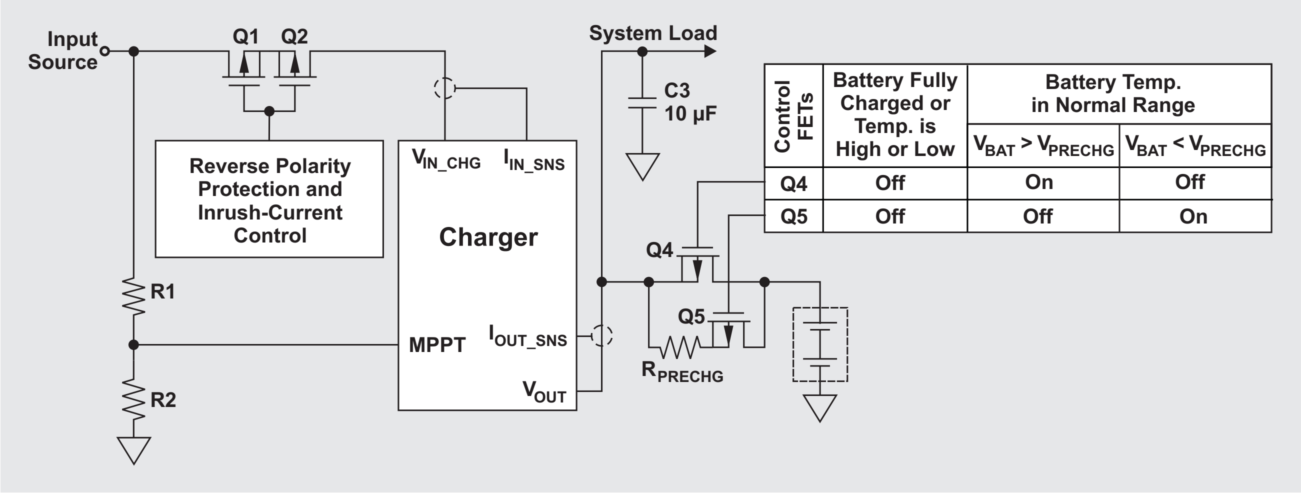
A deeply discharged battery requires preconditioning prior to being charged. Typical Lithium-Ion (Li-Ion) batteries require the charger to apply a precharge current that is 1/10 of the fast-charge current until the battery voltage rises above a specific voltage, typically 3 V/cell. When the host detects a battery voltage that is less than the specified precharge voltage ($V_{BAT} < V_{PRECHG}$), it turns Q5 on and provides a precharge current through R_{PRECHG}. The value of R_{PRECHG} is chosen to provide the maximum allowable precharge current when the battery voltage is fully discharged. In this operating mode, the system is effectively isolated from the battery voltage, which allows the charger to maintain the NVDC regulation voltage even with a discharged battery. When the battery voltage increases above the precharge voltage, the host turns Q5 off and Q4 on, effectively shorting the battery and the system together. The battery's charge current increases to the charger's maximum output current minus the current into the system. If the system current exceeds the charger's fast-charge current, the battery enters supplement mode where current flows out of the battery to the system.

If the host detects an over- or undertemperature fault condition, it turns off both Q4 and Q5. This stops the battery charging while still allowing the charger to power the system. The host can also turn Q4 and Q5 off when the battery reaches its full-charge voltage to increase battery life. Detailed information on the battery-disconnect circuitry can be found in Reference 5.

Conclusion

The NVDC charger architecture coupled with MPPT and the battery-disconnect circuitry provides several advantages over standard charging architectures. It intelligently connects and disconnects the battery from the system

Figure 4. NVDC architecture with battery-disconnect circuitry



Control FETs	Battery Fully Charged or Temp. is High or Low	Battery Temp. in Normal Range	
		$V_{BAT} > V_{PRECHG}$	$V_{BAT} < V_{PRECHG}$
Q4	Off	On	Off
Q5	Off	Off	On

under the appropriate operating conditions, allowing the designer to optimize the solar panel's output power for the system's needs. The charger also provides a narrow system operating voltage, which optimizes efficiency and extends battery life.

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