

# Max Peak Power Trackers increase efficiency of Solar Panels in Street Lights

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## Executive Summary

Street lighting in many municipalities accounts for nearly half of the electrical expenditure. In addition to the energy bills, replacement and maintenance of low pressure sodium or metal halide lamps pose additional costs and disruption of traffic. High Brightness LED (HBLED) based solar powered street lights do not depend on the grid for electric power and have the potential of saving billions of dollars in electricity and maintenance costs.

Despite their possibilities, solar street lights are not commonplace because of their price compared to conventional alternatives. Nevertheless, as the world looks for cleaner and greener alternatives, solar powered street lights continue to benefit from advancements in the field of semiconductors, both in photovoltaics and integrated microcontrollers, to produce more cost-effective implementations.

While the sun radiates up to 1000 Watts per square meter, a typical panel can convert only 30% of irradiant energy to electricity. In most street lights, the energy harvested by day has to be stored in a battery and using conventional charge controllers can lead to further conversion losses. As solar panels are p-n junctions, they do not operate as ideal power sources. Instead, they have an operating point at which the power produced is at its maximum and any movement away from this point will progressively decrease the efficiency of the panel. In order to extract all the energy that a solar panel is capable of delivering, a fully electronic system called the Max Peak Power Tracker (MPPT) is required. The MPPT is a DC-to-DC converter that poses as an optimum load allowing the panel to operate at its peak power state. Since the Max Peak Power Point (MPP) is dependent on the amount of radiant sunlight and temperature of the panel, the MPPT must constantly adapt to maximize the energy conversion.

To further understand the significance of the MPPT, an example of a system with and without the converter can be examined. Consider a system that uses a SunPower 225 Solar Panel with operating voltage of 41V to charge a battery pack with nominal voltage of 24V. Figure 1 shows the measured relationship of the panel's current and power to its forward voltage.

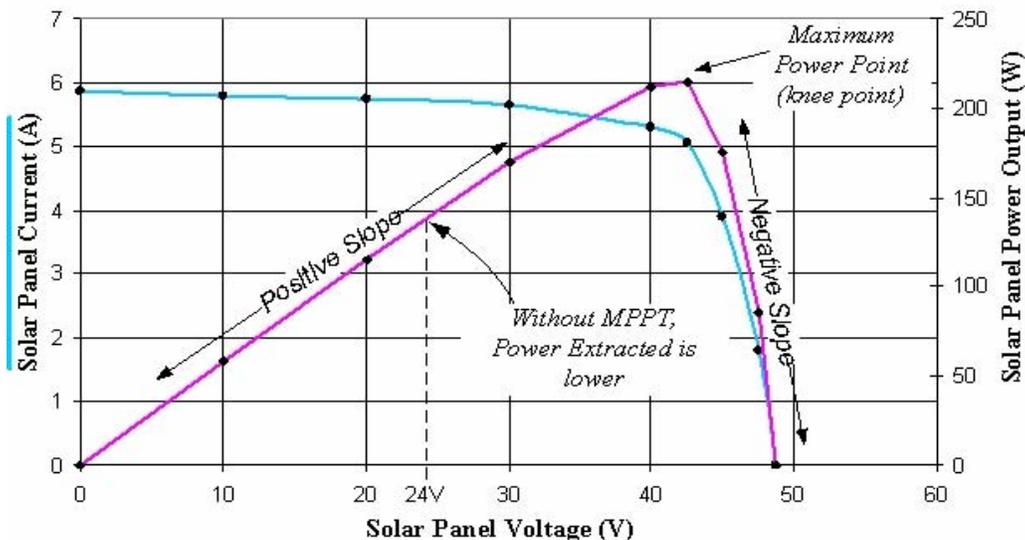


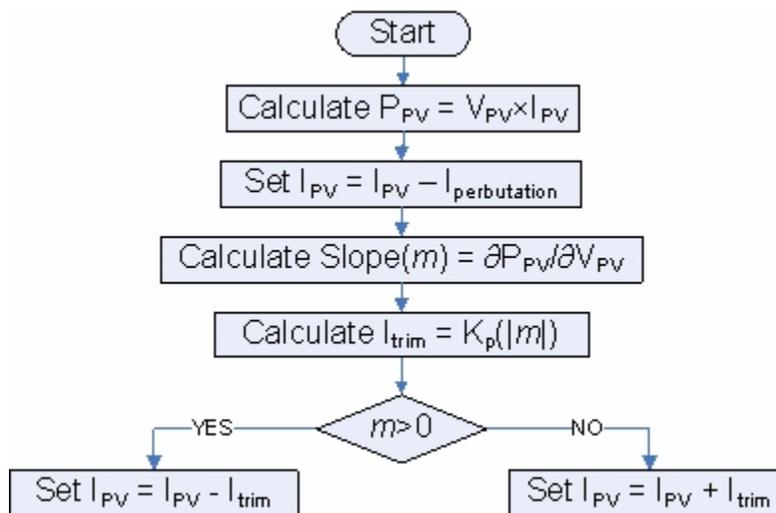
Figure 1: Relationship of this panel's current and power to its forward voltage

Due to the characteristics of the panel, the current delivered remains steady before falling dramatically once the operating voltage has been passed. The power produced by the panel (Voltage  $\times$  Current) is highest at a specific point on the curve called the *knee point*. When a conventional controller without an MPPT is used to charge the 24V battery pack, the operation voltage of this PV panel is forced to the battery voltage and as a result the power produced by this particular setup is around 140W.

An MPPT system on the other hand, will allow the panel to operate at the *knee point* allowing the power to be equivalent to 215W. In this particular example, the use of a MPPT system increases the total power harvested by 50%. Neglecting the losses in the wiring and electronics of the charge controllers and fuses, the current charging the battery in the above scenario is 8.5A  $((V_{PV \text{ Panel}} \times I_{PV \text{ Panel}})/V_{\text{Battery}} = (41V \times 5A)/24V)$  while the current from the solar panel is 5A.

The location of the solar panel's *knee point* changes continuously based on factors such as the amount of irradiant sunlight available, ambient temperature, and partial shading. Therefore, a reliable MPPT must constantly update itself to operate at the varying ideal point. An MPPT capable of actively sensing the voltage and current can measure the power and, through an iterative and corrective process, arrive at the max power point.

Figure 2 shows a simplified algorithm that can be used by an MPPT. In each perturbation, the system calculates its location on the slope by changing the current by a small measurable quantity -  $I_{\text{perturbation}}$ . If the change leads to a positive or negative slope in power output, the next perturbation decreases or increases the extracted current until the slope becomes zero.



**Figure 2: Simplified version algorithm that can be used by an MPPT**

The zero slope point on the curve always translates to the highest power extractable from the PV panel. The value of  $I_{\text{trim}}$  is varied proportional to the magnitude of the slope to allow the system to quickly approach this point. Such an algorithm enables the MPPT to successfully 'hunt' for the optimum operating point while being agnostic to any panel and environmental characteristics.

The DC-DC conversion topology used by the MPPT depends on the difference in operating voltage between PV panel and battery. Under normal charging conditions, if the panel voltage is greater than the battery, a buck topology is used. Conversely, if the panel voltage is lesser, a boost topology increases the charging voltage with a reduced current. In either case, the goal of the MPPT is to maintain the current extracted from the PV panel at the peak point. This relationship is given as  $MPP = V_{PV(\text{knee point})} \times I_{PV(\text{knee point})} = V_{\text{battery}} \times I_{\text{battery}} + \text{Conversion Losses}$ . The charging current or  $I_{\text{battery}}$  depends on the duty cycle of the DC-DC convertor which is set by the controller based on the MPPT algorithm.

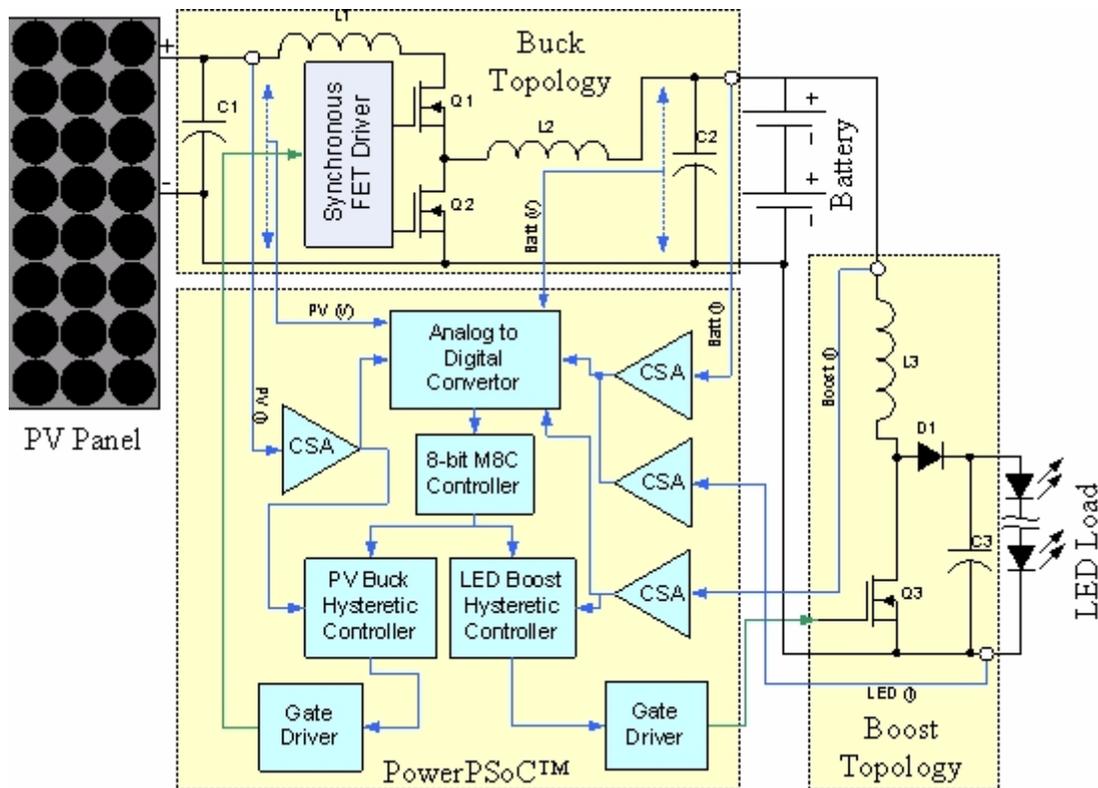
The charge controller must also consider the type of battery being used. Street lighting applications typically use either Lead Acid or Alkaline batteries because of their high energy density to cost ratio and ability to function over a wide range of temperatures. The voltage of these batteries has to be constantly monitored during the charging process to prevent over charging that may lead to damage in the form of leaks or explosions. Likewise, undercharging of a battery over extended periods of time can dramatically reduce the overall capacity of the battery. To prevent any product degradation, the system may disconnect all loads until the charge content reaches a predetermined threshold. Properly implemented charging routines are the key to the longevity of a battery. The inherent ability of the system to accurately control the current to the battery throughout the course of the day enables advanced charging routines and diagnostic functions.

When the amount of irradiance reduces at dusk, the MPP of the PV panel will reduce until energy cannot be effectively collected from the panel. This condition corresponding to diminished ambient light can be detected by the system eliminating the need for an ambient light sensor. Once the MPPT operation is suspended, the system can automatically switch to driving the light source.

HBLEDs are today's popular light sources for street-lighting applications. Their increased efficiency, low maintenance costs, and ability to reproduce a variety of color temperatures are some reasons behind their rapid adoption. Frequent replacement of bulbs is very costly and improved life span of HBLED light engines is an impetus behind their use.

Streetlights typically produce more than 3000 lumens and need large numbers of individual HBLEDs. Since the diodes are connected in series to reduce current drift between individual strings, the net forward voltage of the LED string is usually greater than the battery voltage. In such cases, a boost topology can be employed to create a step-up converter. A switching step-up DC-DC converter works under similar principles as the charge controller with the relationship  $V_{LED\ String} \times I_{LED\ String} = V_{battery} \times I_{battery} - Conversion\ Losses$ .

Because MPPT and LED driving require DC-DC converters, similar constant current hysteretic controllers can be used for both designs. An adjustable hysteretic controller with quick response time can be used to create a buck or boost topology. Figure 3 is a block diagram of a system that includes topologies for charging and discharging the battery.



**Figure 3: System and topologies for charging and discharging the battery**



At the heart of the design is a programmable System on a Chip (SoC), which uses onboard analog resources to constantly measure VI characteristics of PV panel, battery and LED load. SoC devices like the PowerPSoC contain built in hysteretic controllers and gate drivers allowing for further integration of the control loops.

In figure 3, the 'PV Buck Hysteretic Controller' switches the FET driver to keep current through L1 steady with a tight ripple. A true hysteretic controller will compare the rising and falling edges of the current to programmable thresholds. The resolution of the current control is only limited by the speed of the hysteresis channel and the resolution of the Digital to Analog Convertors (DACs) that are generating the thresholds. A synchronous FET driver is used in the buck circuit to increase the efficiency of the system. As a further cost to efficiency trade-off, the driver, MOSFET, and inductor L2 can be replaced with a flyback Schottky diode.

The 'LED Boost Hysteretic Controller' receives feedback from a similar high side current sense amplifier to control current through Boost inductor L3. An ultrafast diode D3 blocks the higher voltage at C3, which is used to drive the LED load. A proportional integral loop running on the microcontroller of the SoC device will enable accurate regulation of LED current. This driver implementation with properly chosen components can conveniently yield higher than 95% efficiency.

Just the MPPT functionality on a PV panel charge controller can significantly improve the energy harvesting capability. Costs involved in moving away from conventional charge controllers are immediately relieved by savings in reduction of PV panel size. In addition, the high degree of analog control allows for better lifespan from the battery reducing associated maintenance costs. Integration of different fundamental blocks into programmable SoC devices allows for significant reductions in costs and time to market. As the world ushers in a green revolution, efficient and grid-independent street lights will illuminate the roads of tomorrow.

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