ECE 128B Power Grid Modernization

# Project Phase 1: Battery Charger with MPPT Algorithm

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# Introduction

The objective of this device is to take the unregulated DC voltage source of a solar panel and convert it into a regulated fixed DC source. Additionally, this device should maximize the power generated by the solar panel. The circuit uses the Buck-Boost topology. When the converter is in boost mode, the circuit acts like a step-up transformer. When the converter is in buck mode, the circuit acts like a step-down transformer. The solar panel has the following V-I characteristic.

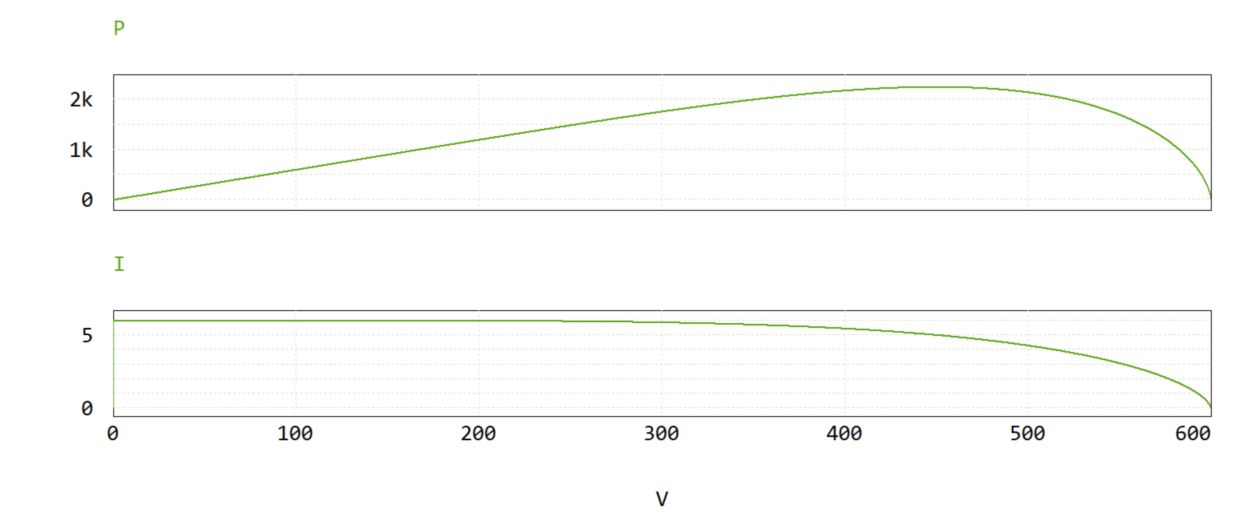


**Figure 0**: Solar Panel Characteristics

The maximum power of the ideal solar panel is 2250W at a voltage of 450 volts. However, temperature and irradiance changes affect both the maximum achievable power and the voltage where maximum power occurs. Therefore, this circuit must be able to dynamically adjust to these changes to maintain maximum power. This is accomplished by using a Perturb and Observe algorithm which is a hill-climbing technique. One common problem with this algorithm is that oscillations occur near the peak power; however, our algorithm mitigates this issue by ignoring changes in power less than some error term. The output of the maximum power point tracking (MPPT) is then used to control the voltage of the circuit. The tools used to develop this circuit is PSIM to model both the electrical simulation and the control signals.

# Problem Definition

The problem that this phase of the project is aiming to solve is how to extract as much energy as possible from the provided battery-charging photovoltaic system given the fact that there are varying outside conditions like irradiance and temperature. This is known as Maximum Power Point Tracking (MPPT). The algorithm implemented in the control system to solve this problem is called the Perturb and Observe method which is the most cost effective method as it only requires one voltage sensor. This algorithm involves perturbing the operating voltage and observing the power yield. The sign of the last voltage perturbation and the resulting change in power are compared when writing the logic behind this algorithm in PSIM. If the signs are the same, the perturbation should continue in the same way. If their signs are different, the perturbation should go the opposite way. With all of this applied, the operating voltage will oscillate around the Maximum Power Point. However, this algorithm is not the most efficient or accurate in all situations, specifically when extreme changes in radiation are considered where an incorrect MPP will be calculated.

Solution

The first step in designing the circuit is measuring the I-V characteristics of the functional solar panel model. The solar panel parameters are Voc = 600V, Vmp = 450V, Isc = 6A, Imp = 5A. Setting these parameters, the maximum power is measured as shown in figure 0 and 1.

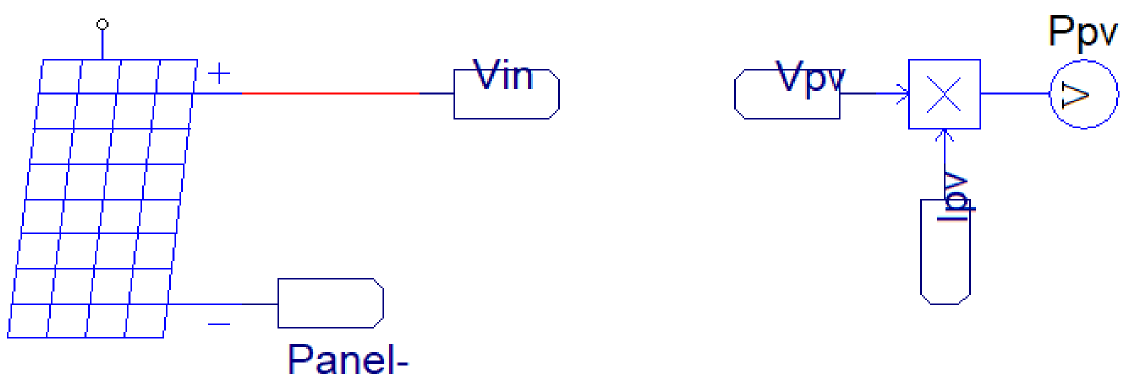


**Figure 1**: Solar panel and power measurements

Next, the circuit is designed using three current legs with a phase offset of 0, 120, and 240 degrees respectively. The purpose of this is to use the superposition of each current to cancel and minimize the peaks and valleys, leading to a more stable load current. The current is sensed for each leg which is used in each current controller. The input current of the panel uses a 2nd order low pass filter with a cutoff frequency of 5000 Hz and a damping ratio of .7 and then sampled and sent to the MPPT controller. The voltage across the solar panel uses a cutoff frequency of 1000 Hz and a damping ratio of .9. Experimentally, it was discovered that increasing the damping ratio on the voltage filter improved the MPPT tracking because of the reduced oscillations.

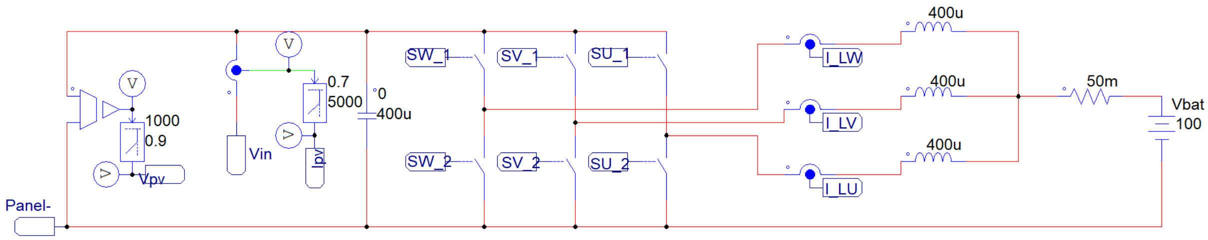


**Figure 2**: Buck-Boost converter

The filtered current and voltage are then sampled at 1000Hz and then inputted into the MPPT block using the simplified C block. The voltage step is .5V per iteration. Changes in power smaller than the ¼ the voltage step or .125W used the $V_{pv}$ as $V_{ref}$. Experimentally, the steady state voltage of $V_{pv}$ reaches 449.958V in .15 seconds. The lack of oscillations seen in figure 6 and 7 can be attributed to ignoring small changes in the power in the MPPT algorithm and the filtering of the voltage input.

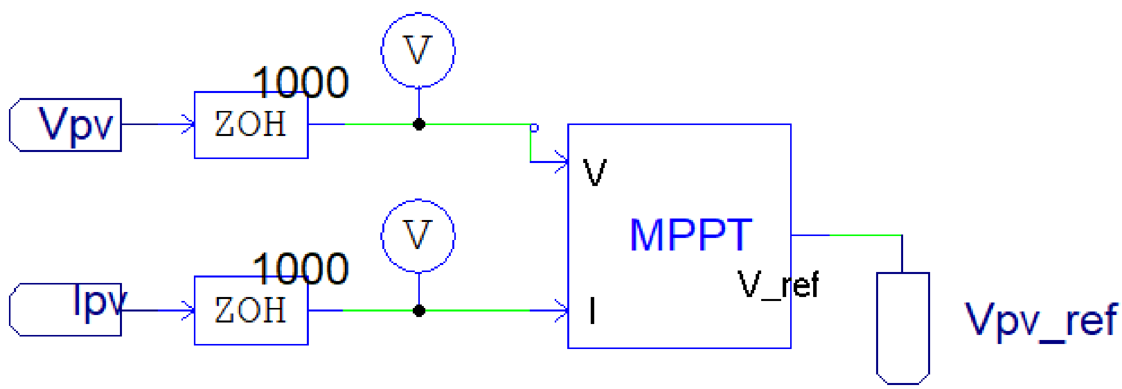


**Figure 3**: Maximum Power Point Tracking (MPPT) controller

The output of MPPT is then subtracted with the $V_{pv}$ and then sent to a PI controller. The gain is negative because the voltage is inversely proportional to current. The time constant is set to 10 times that of the current controller to allow for the current to reach steady state before making further adjustments to the voltage. The current is then limited to 50A and -50A and multiplied by ⅓ because the signal is sent to 3 current legs.

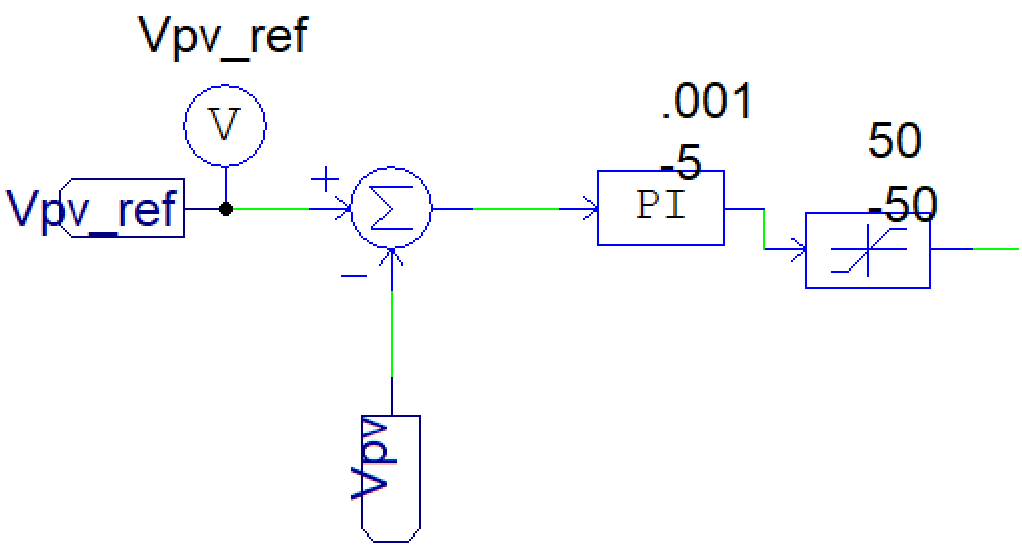


**Figure 4**: Voltage controller

The current determined by the voltage controller is then compared to load current through each individual inductor and then sent through a PI with a gain of .0001 and a time constant of .01. The output of the PI block is then limited between 0 and 1 and is the duty cycle for PWM. The phase offset for each leg is set using each PWM which controls the switching frequency of each pair of switches.

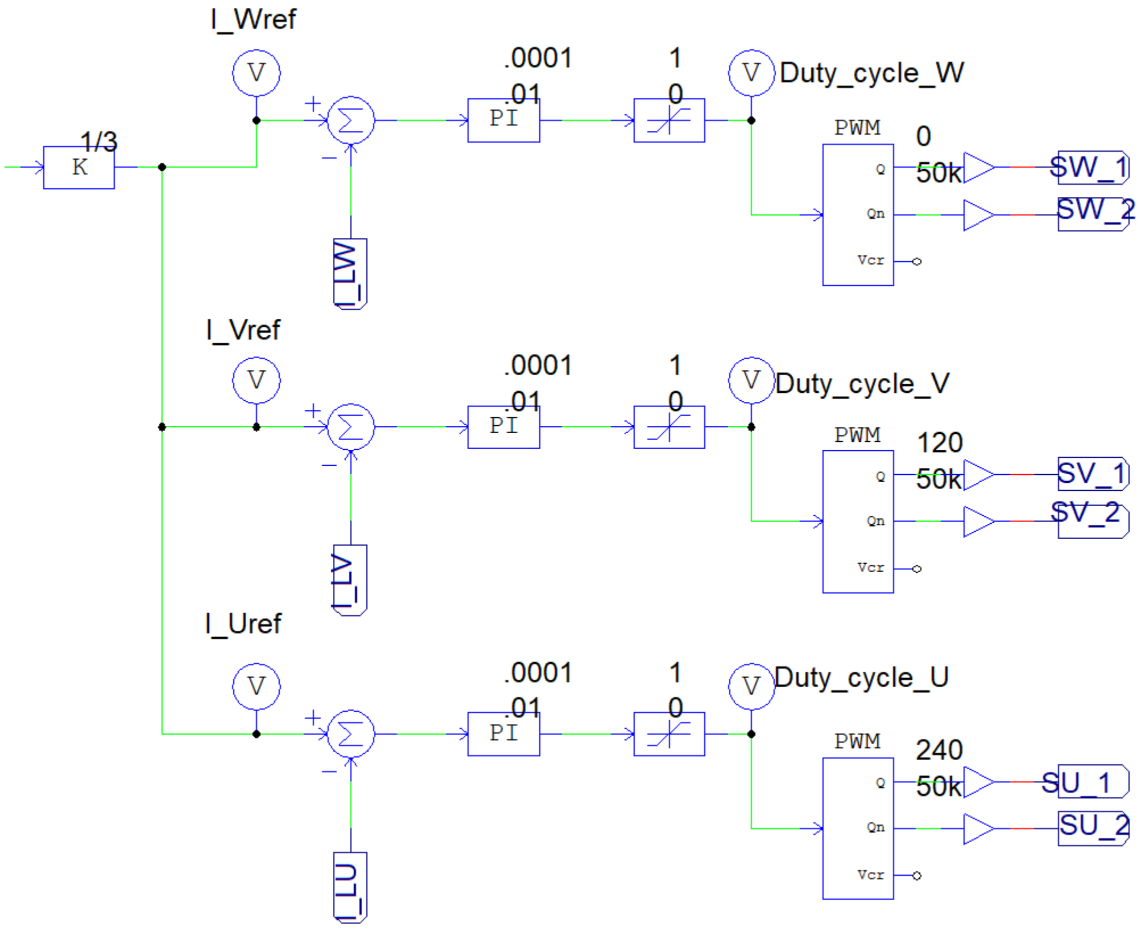


**Figure 5**: Current Controller (3-legs 120 degree offset)

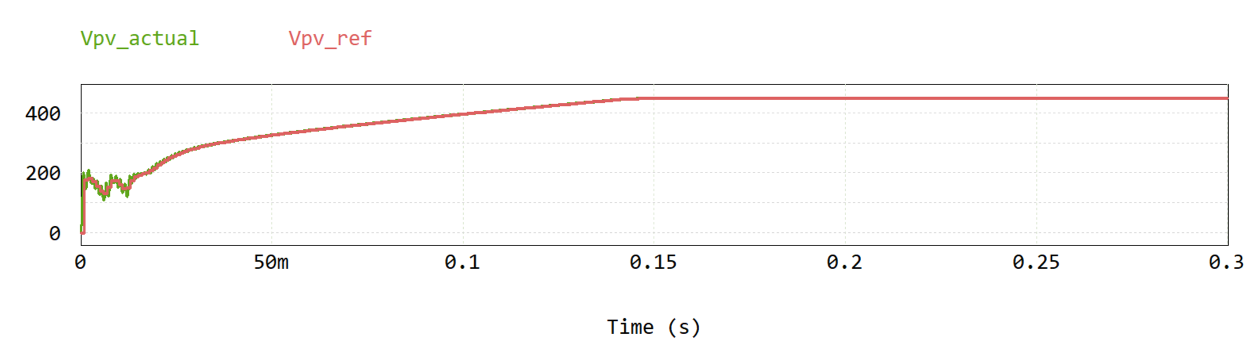


**Figure 6**: $V_{pv}$ and $V_{ref}$ over time. Initially starts at 0 volts until reaching steady state at 450 volts in .15 seconds

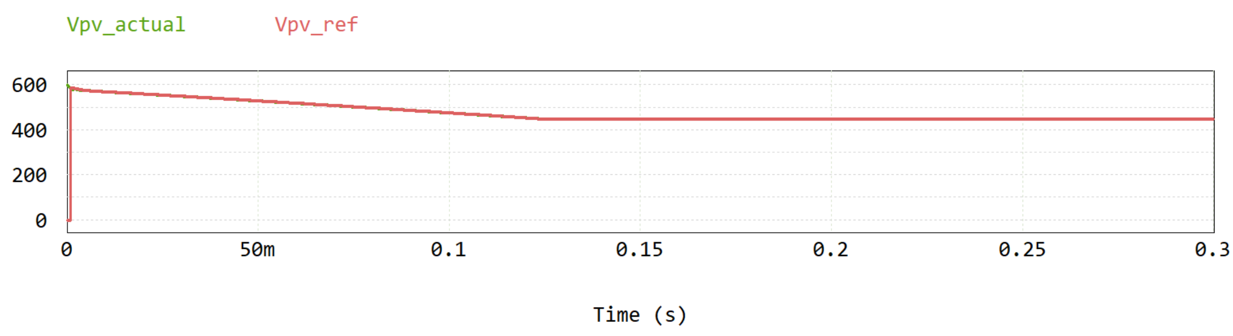


**Figure 7**: $V_{pv}$ and $V_{ref}$ over time. Initial capacitor voltage is 600V, properly reaches steady state at 450 volts

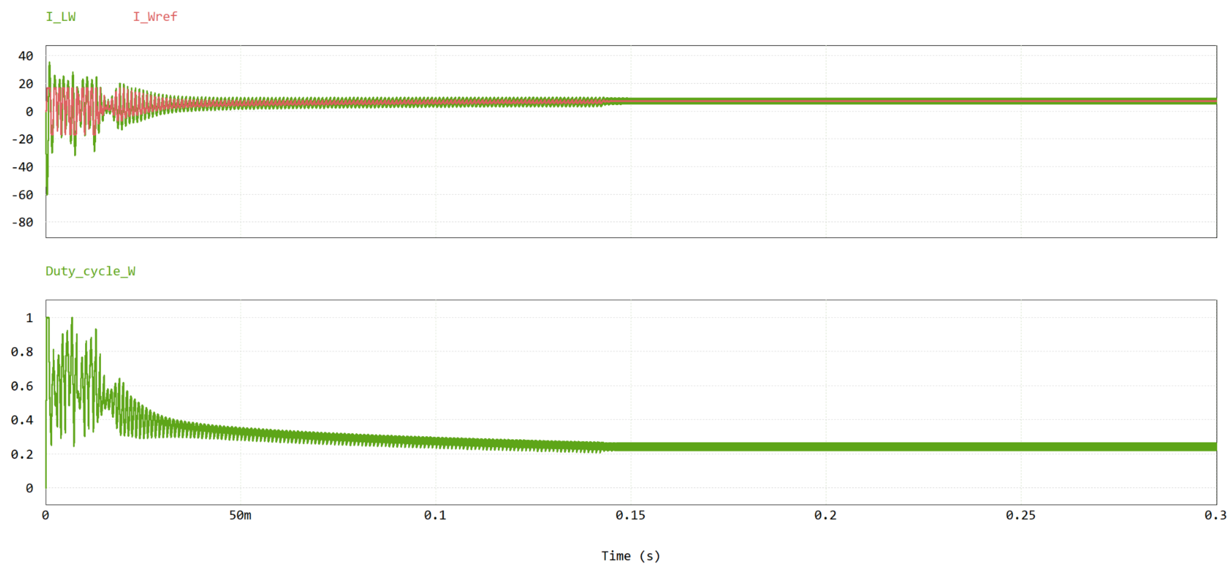


**Figure 8**: $I_{LW}$ and $I_{LW, ref}$ over time with corresponding PWM duty cycle. Initial capacitor voltage is 0V

# Conclusion

The Interleaved Buck-Boost converter built in PSIM (figure 1) has 3 single boost converters connected in parallel and uses Buck-Boost topology. As previously described, the Perturb and Observe method was applied in the control system in order to find the maximum power point. This can be seen in figures 6 & 7 where, after some oscillation, a steady voltage state is reached which can be interpreted as the MPPT. The settling time is reasonable as well at about 0.15 seconds. When looking at figure 8, we can see that $I_{LW}$ behaves as expected and tracks $I_{LWref}$. Once again, at about 0.15 seconds, the current and corresponding duty cycle level off after oscillating for a little time. Overall, the full system, with a solar power input, has a working voltage and current controller and is also successful in employing an algorithm that will find the MPPT.