Experiment #6

Maximum Power Point Tracking

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The objectives of this experiment are:

- To design and implement a maximum power point tracking system that charges your battery with the maximum power available from your battery
- To model and optimize your MPPT algorithm using MATLAB/Simulink
- To implement sensing circuits as needed
- To compare the power you achieve via MPPT vs. direct energy transfer

In this experiment, you will design, construct, test, and demonstrate maximum power point tracking, to charge the battery at a faster rate than would be attained with direct energy transfer. Figure 1 is a high-level depiction of the power circuitry, in which your SEPIC interfaces your solar panel to your battery, and in which the PV panel voltage/current operating point can be controlled by selection of the SEPIC duty cycle. Your microcontroller will implement a maximum power point tracking (MPPT) algorithm that maximizes the current charging the battery.

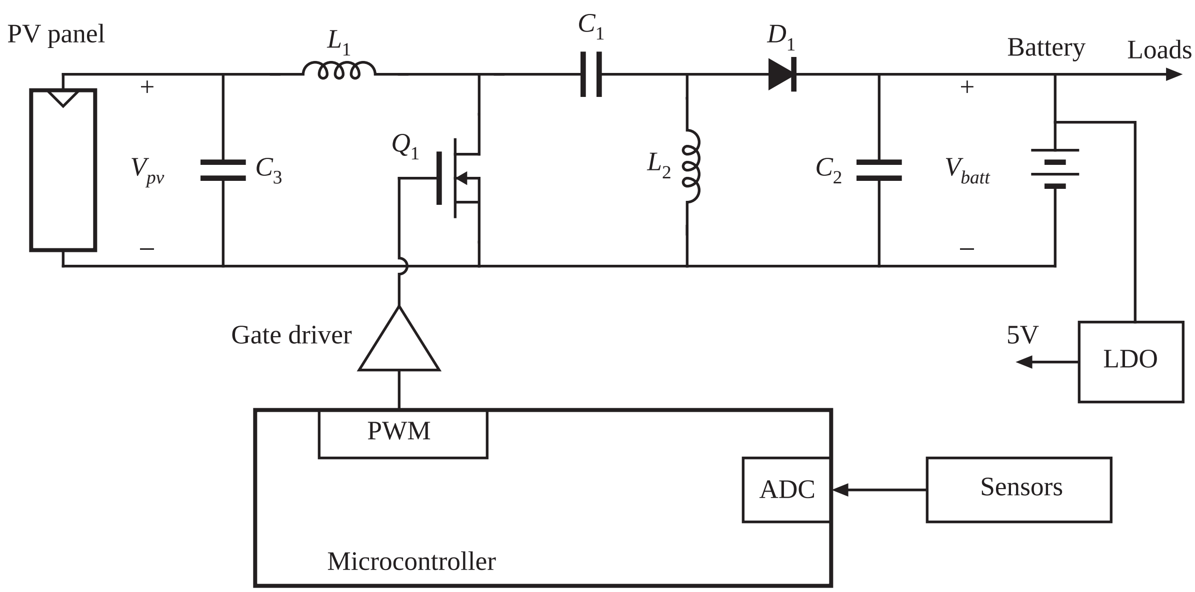

Figure 1 SEPIC MPPT system.

1. Battery current and voltage sensing

Design circuitry to sense the battery voltage and current. Include a complete schematic of this circuitry in your report. To sense the converter output current, employ the average current sensor circuit illustrated in Fig. 2, which provides a dc output voltage that is proportional to the average diode current of the SEPIC.

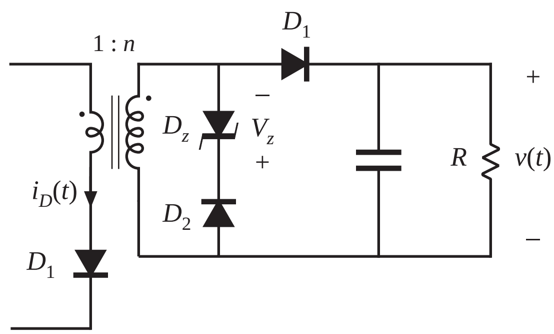

Figure 2 Sensing the average diode current.

This circuit is similar to the MOSFET current sensing circuit employed in the earlier courses of this specialization. The transformer primary is connected in series with the SEPIC diode D_1 to sense its pulsating current. The secondary circuit includes resistor R that converts the reflected diode current to a sensed voltage $v(t)$. Diodes D_z and D_2 reset the transformer volt-seconds while diode D_1 is off. An additional capacitor connected in parallel with R smooths the pulsating waveform, so that the voltage $v(t)$ is proportional to the average diode current $\langle i_D(t) \rangle$.

Design the transformer, and select the element values. Construct your current sense circuit and implement in your SEPIC that drives a resistive load. Connect your sensor circuit output voltage to a Launchpad ADC input, and acquire this voltage in an interrupt service routine. Measure the load current with a multimeter, and compare with the output voltage of your current sensor circuit and with the ADC output count. Vary the load current over at least five data points, and plot load current vs. ADC count. What is the gain of your circuit? Is the dc output current vs. ADC count characteristic linear? How well does your sensor circuit work at low output currents?

For your report, document the design of your current sensor circuit. Include a plot of your measurement data, and specify the sensor gain: (ADC count)/(converter dc output current).

You will also need to measure the dc battery voltage, and capture its value in your microcontroller code. You may be able to reuse your output voltage feedback circuitry from the previous experiment for this purpose; if not, it will be necessary to construct circuitry to do this. Note that two ADC inputs are needed, one for battery voltage and the other for current. In your report, document your voltage sensing circuitry and provide your interrupt service routine code that captures both dc current and voltage.

2. MATLAB/Simulink model

Follow the instructions on the course Coursera site to download, install, and activate MATLAB using your University of Colorado Boulder Identikey. Download the PV system Simulink model from the course Coursera site, and open it on your local computer.

Adjust the following parameters and element values in the Simulink model as appropriate to represent your hardware design: (a) PV panel model (from Experiment 1), (b) element values of your SEPIC converter, and (c) capacitance you connected across the PV panel.

Design an MPPT algorithm that adjusts the SEPIC duty cycle to maximize the average current flowing out of the SEPIC, in the PV system Simulink model. Implement this algorithm in the controller code of the Simulink model, and capture a simulation showing that the algorithm correctly finds the maximum power point. Your simulation should start at zero duty cycle and at a PV panel voltage near its open circuit value, and you should employ a solar irradiance of 1000W/m^2.

For your report:

- Include a listing of your controller code
- Include your simulation scope waveform showing the system finding and maintaining the maximum power point
- Document that values of (i) the sampling period, (ii) the number of sampling periods employed for settling, (iii) the time required to reach the maximum power point.

3. Hardware maximum power point tracking

The goal of this section is to demonstrate maximum power tracking and battery charging with the PV panel outside. The tasks required to achieve this goal include: verifying operation with the battery as the load; acquiring the battery voltage and SEPIC average output current through the processor ADC; developing, testing and de-bugging Launchpad code to implement your maximum power tracking algorithm; and evaluating system operation with the PV panel.

Carefully monitor the battery voltage: *do not overcharge your battery!*. If necessary, connect power resistors in parallel with your battery to maintain the battery state of charge below 100% and above 0% while you perform this part of the experiment.

For your report: when operating successfully around the maximum power point, capture oscilloscope waveforms of the PV panel voltage and the current sensor output voltage, showing the purturb-and-observe or other MPPT algorithm behavior around the maximum power point. Alternatively, capture a short video showing this operation. Also compare the average charging battery current your circuit achieves, vs. the battery current achieved with direct energy transfer.

Grading Rubric

1. Battery current and voltage sensing

(30 points total)

- Document complete schematics of the voltage and current sensing circuits that you implemented.
- Document the details of your current sense transformer design, including turns, wire gauge, and maximum flux density

- Include the plot of measured current sensor characteristic and the gain as defined in part 1 above
- Document the interrupt service routine code that measures battery current and voltage

2. MATLAB/Simulink model

(30 points total)

- Document the code that implements the maximum power point tracking routine of your Simulink model
- Include your simulation scope waveforms of duty cycle and SEPIC output current, showing the system finding and maintaining the maximum power point, as described in part 2 above
- Document the values of (i) the sampling period, (ii) the number of sampling periods employed for settling, (iii) the time required to reach the maximum power point.

3. Implementation of MPPT

(40 points total)

- Document the C code that implements your hardware maximum power point tracking algorithm
- Document your oscilloscope waveforms of the PV panel voltage and current sensor output voltage, showing the perturb-and-observe or other MPPT algorithm behavior around the maximum power point.
- Compare the average charging battery current that your MPPT system achieves, vs. the battery current achieved with direct energy transfer.