Lab 7: Solar Panel Characterization

1 Task

Solar panels can be found everywhere around us in our daily life, for example, beside bus stop, on the roof of the boat or in the garden to provide power from sun. In this lab, you will learn more about the inner structure and the output characteristics of a solar panel.

This lab consists of two parts. In the first part, you will study the electrical model of solar panels in LTSpice and verify the effect of series resistor and parallel resistor to the output power.

After a better understanding of the solar panel, you will get a hands-on experience with a real panel and figure out how the environment parameters change the solar panel output characteristics.

2 Pre-Lab:

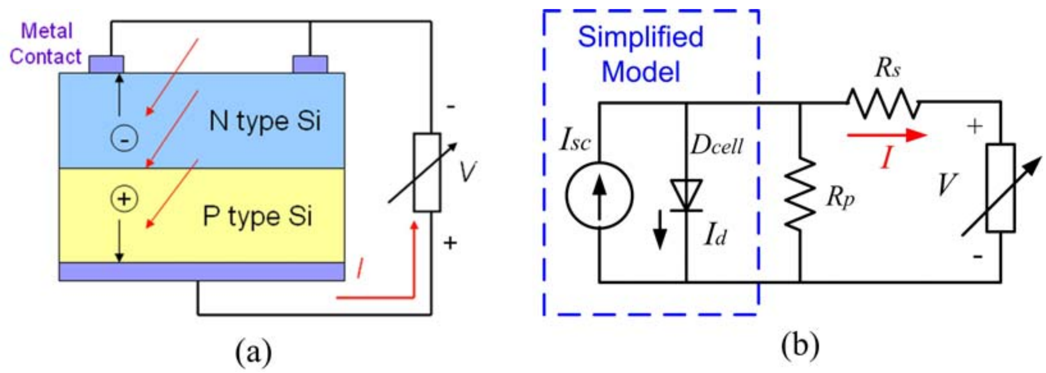

Figure 1: (a) A PV cell structure and (b) its electrical model

Figure 1 illustrates the structure and equivalent circuit model of a PV cell, which we have studied in detail in class.

As shown in Fig.1 (b), the PV cell is essentially composed of a light generated current source I_{sc} and a diode D_{cell} in parallel, along with other cell parasitic resistances. Therefore, ignoring the effects of the parasitic resistances (i.e. R_S=0 and R_p=∞) in the model, the net current from the cell is ideally given by

$$I = I_{sc} - I_d = I_{sc} - I_o(e^{V/V_T} - 1),$$

where I_{sc} is the cell short circuit current, I_o is the reverse saturation current of the diode (also known as the dark saturation current of the cell) and V_T is the 'thermal voltage' given by $V_T = nkT/q$.

Figure 2 illustrates the I-V curve and power output of a PV cell. Here, I_{SC} and V_{OC} are the short circuit current and open circuit voltage of the cell. The maximum power point (MPP) is the operating point at which the peak value of P-V curve is reached or is the knee point of the I-V curve that defines the largest possible rectangle area (=$V_{mp} \times I_{mp}$) under it. Fill factor (FF), which is desired to be as large as possible, is defined as

$$FF = \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}} = \frac{P_{mp}}{V_{oc} \times I_{sc}}$$

The parasitic parallel and series resistors R_p and R_s result in additional internal power loss in the cell and subsequent degradation in performance. They are important cell design parameters.

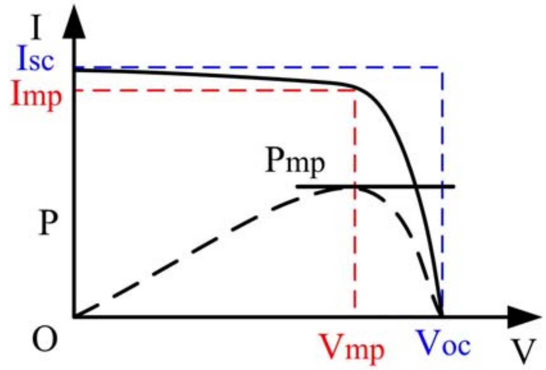

Figure 2: Current-Voltage and Power–Voltage curve for PV cell

In a typical photovoltaic module, several cells will be connected in series. Hence the V_{OC} value of the module will be equal to that of the cell multiplied by the number of cells. Assuming identical cells, the short circuit current will remain the same.

The performance of the PV module will be influenced by different weather conditions, by the module's orientation and by any shading that may be present. Some of these effects will be studied in this experiment.

Light intensity sensors:

Light intensity sensors are commonly used to measure the irradiation level of the sun. In our lab, a low cost monolithic photodiode with on-chip trans-impedance amplifier is used for this purpose.

As shown in Figure 3, the photodiode translates the light intensity to a current, which is then amplified into a voltage by the internal feedback resistor (1M) when the pin 4 is connected to pin 5. Alternatively, a lower value resistor can be connected between pin 2 and pin 5.

The sensed voltage is therefore,

$$V_{irr} = k_{iv} \cdot Light\ intensity = A_{si} \cdot I_{res} \cdot R_{fb} \cdot Light\ intensity$$

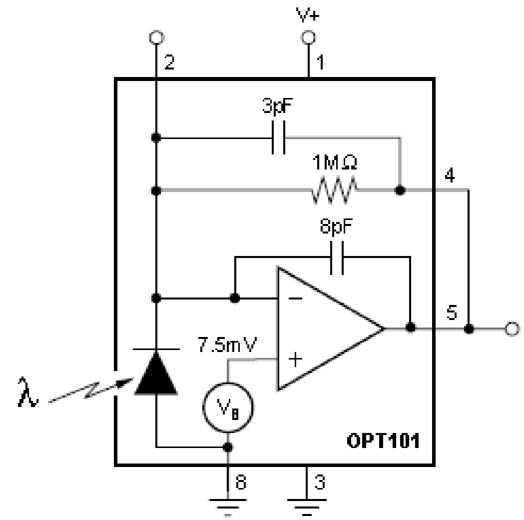

Figure 3: Circuit diagram of a monolithic light sensor and amplifier

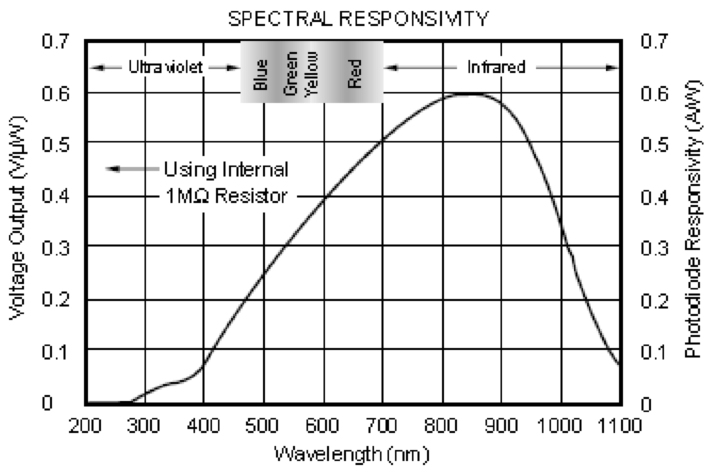

Figure 4: Spectral Responsivity of the light sensor

As shown in Figure 4, the spectral responsivity covers 200nm~1100nm, which is the same with silicon panel.

Attention: Temperature range for this sensor is 0~70^{o}C. Therefore it is better to use it to measure the light intensity at lower irradiation level. In our lab, we limit the maximum exposed irradiation level for this sensor below 500W/m^2.

3 Equipments:

- Computer with LTspice
- Solar light simulation system
- Solar panel: (a. 110mm*94mm; b. 90mm*50mm)
- Light sensor with amplifier OPT101
- Precision centigrade temperature sensor LM35
- Laboratory power supply

- current meter
- Oscilloscope

4 Lab Procedure:

4.1. Electrical Model Simulation:

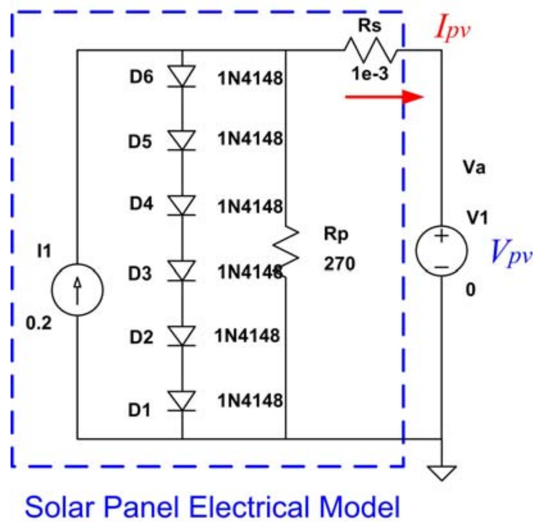

Figure 5: Simulation circuit in LTspice

1. Simulate the circuit of Figure 5 in LTspice. Set up the current source (i.e. the light generated current) to be 0.2A. Use 1N4148 as the diode model (six solar cells). Set up the load to be a voltage source V1.

2. Perform the following steps with various resistors combinations shown below. Do a DC sweep analysis on V1. Plot $I_{pv} - V_{pv}$ curve (i.e. the current through R_s versus V1). Plot $P_{pv} - V_{pv}$ curve, i.e. the power (current through R_s multiplied by V1) versus V1. **Please attach the print out from the simulation.**
   - $R_p = 100k\Omega$, $R_s = 1m\Omega$;
   - $R_p = 100k\Omega$, $R_s = 1\Omega$;
   - $R_p = 270\Omega$, $R_s = 1m\Omega$.

4.2. Light and temperature sensors

1. Familiarize with the temperature sensor on the sensor board. Find out the conversion ratio $k_{tv}\left[V/{}^{o}C\right]$ between temperature and sensed voltage from datasheet.

Figure 6: Bottom View of LM35 (temperature sensor)

2. Read the datasheet about the light sensor. Note down the specified photodiode area, $A_{si}\ (mm^2)$, current responsivity at 650nm, $I_{res}(A/W)$. Measure the resistance $R_{fb}(\Omega)$ between Pin2 and Pin 5. Calculate the conversion ratio k_{iv} from light intensity at 650nm to output voltage. **<u>(Attention: Please keep in mind that both room light and the solar simulation light consist of light within a wide spectrum. However, this conversion ratio is only applicable to the light with wavelength of 650 nm.)</u>** In our lab, we use this conversion ratio to indicate the variations of irradiation. The calculated irradiation corresponds to 650nm wavelength only.

3. Apply a power supply of 5V~15V to the sensor board. (Do not put it in the solar simulation system at this step). Measure the output voltage from the temperature sensor and irradiation sensor in the lab. (hint: when the power supply changes, the output reading should be stable)

- Put your hand on or blow wind to the surface of the sensor IC, verify whether the change of the reading follows change of the temperature.

- Put the light sensor under normal light in room. Change the irradiation level by putting it closer to light source or blocking the light by semi-transparent paper, verify whether the change of the reading follows the change of irradiation.

4.3. Solar panel characterization

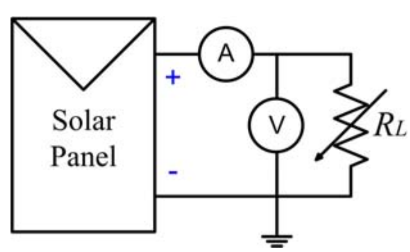

Figure 7: Measurement of current-voltage characteristics of solar panel ($R_L = 0 \sim 10k\Omega$)

4. Put the solar panel, temperature sensor and light sensor boards in the solar lamp simulation

system (the location). Set the dimmer to the lowest irradiation level.

5. Turn on the solar lamp simulation system for 20 min. to make sure the light intensity is stable. After that, read the voltage of temperature sensor and light intensity sensor.

6. Connect the solar panel and a variable resistance with power rating of 3W as shown in Figure 7. Change the value of R_L and plot the I-V and P-V curve of the solar panel.

7. Change the position or use dimmer to change the light intensity. Repeat step 4 to 6.

8. Turn off the fan. Repeat step 4 to 6.