

ET3034TUx - 3.2.2 - Series and shunt resistance

We are going to measure the efficiency of a solar panel.

We do this by measuring the J-V curve and its external parameters as discussed in the previous block.

How does such experimental setup look like?

It consists of several components.

The first component is a solar simulator, which is a light source that simulates both the shape of the AM1.5 solar spectrum and an irradiance of 1000 W/m^2 .

Secondly, the setup has a voltage source which applies a varying voltage over the solar cell or solar panel.

An ampere meter measures the current generated by the solar device at every voltage.

Finally, a temperature controlled substrate guarantees that the solar cell is at the required standard temperature of 25 degrees Celsius.

Let's see how such measurement in reality works.

For that we will go to the Delft Solar Lab.

Here you see the voltage supply and the ampere meter.

Typical panel areas are in the range of 1.5 square meters.

This means that you need a light source with a spectrum shape and irradiance which is homogeneously distributed over large areas.

In the solar lab, we use a large AAA solar simulator from Eternal Sun.

AAA indicates that the spectral match, the uniformity and the stability is of A class quality.

The c-Si solar panel needs to be connected to the voltage supply and the ampere meter.

In addition a thermocouple is connected to the panel to monitor the temperature of the panel during the J-V measurements.

Without additional temperature control, the solar panel will heat up in time.

Here we demonstrate that the panel is at the required 25 degrees Celsius using a Fluke infrared thermometer, before the panel is moved under the solar simulator.

A software program controls the J-V measurements.

The voltage over the panel is varied, while the current is measured.

On the screen the resulting J-V curve and power density is plotted from 0 volts up to the open-circuit voltage.

As the setup measures the total current of the panel, the active area of the panel is an input parameter for the software.

Using the given active area, the software calculates the current density of the panel.

In this example, the maximum power density is 17.4 milliwatts per square centimeters, which corresponds to a panel conversion efficiency of 17.4%.

The J-V curve measured does not perfectly match the J-V curve of an ideal solar cell.

In reality a solar cell can have additional electrical losses.

These losses can be represented as parasitic resistances in the electrical circuit in addition to a non-ideal solar cell.

Here we will discuss two important resistances: the series and the shunt resistance.

The first resistance is called series resistance.

Several effects can be the origin of a series resistance in a solar cell.

Let's consider a standard c-Si solar cell which we will discuss in great detail next week.

First, the current moving through the semiconductor materials of the p-n junction can experience a resistance.

Secondly the interface between the semiconductor material and the metal contacts can act as a resistor as well.

Thirdly, the metal contacts will have a resistance as well.

How does the series resistance appear in an electric circuit?

Here we will use a zig-zag line as a symbol for the resistor.

Note, that sometimes a rectangle is used as a symbol for the resistor as well.

As discussed earlier, the ideal solar cell is a parallel connection of a current source and a p-n diode.

The series resistance is, as the name already reveals, connected in series with these two elements.

If the solar cell generates current, the solar cell will lose voltage over the series resistance.

The second resistance is the so-called parallel resistance, or also referred to as the shunt resistance.

A shunt is a macroscopic defect in the solar cell, which provides an alternative path for the generated photocurrent.

Examples of a shunt are a crack through the semiconductor layers or a current path at the edge of the solar cell.

In the electrical circuit the shunt resistance appears as a resistor connected in parallel with the current source and the diode.

A low shunt resistance means that a large fraction of the photocurrent prefers to travel through the shunt.

While a high shunt resistance means that less or no photocurrent is lost through the shunt.

Important to remind is that you would like to have the series resistance as small as possible and the shunt resistance as large as possible to come close to an ideal illuminated p-n junction.

The series and shunt resistance result in a more complicated expression for the J-V curve.

The voltage at the terminal is the voltage of an ideal solar cell minus the voltage lost over the series resistance.

The total current density is the photo current density minus the dark current density of the diode and the current density leaking through the shunt resistance.

The shunt current is given by the voltage of an ideal solar cell divided by the shunt resistance.

This results in the complex expression shown here.

The current density J appears on the left hand side of the equation as well as on the right hand side.

Note, that this expression can not be solved analytically.

How do the series and shunt resistance affect the J-V curve and the FF?

Let's start with the J-V curve of an ideal p-n junction as shown in this figure.

Now we are going to increase the series resistance.

As you see the slope around the open-circuit voltage point starts to become less steep.

The larger the series resistance, the less steep the slope will be.

Furthermore, the maximum power point is affected as well by increasing the series resistance.

The larger the series resistance, the smaller the maximum power point will be.

This also implies that the larger the series resistance will be, the smaller the FF.

In conclusion the series resistance can affect the FF and has to be as small as possible for high FF's.

Note, that the series resistance does not affect the position of the open-circuit voltage.

As at the open-circuit voltage the current density is equal to zero, the voltage drop over the series resistance is zero as well.

Let's start again with the J-V curve of an ideal p-n junction.

This means that the shunt resistance is infinite large.

Now we are going to decrease the shunt resistance.

As you can see the slope at the short-circuit current density point starts to become more positive.

The maximum power point and FF is affected as well.

The smaller the shunt resistance, the smaller the FF will be.

Let's look in more detail to the slopes in a J-V curve.

The slope is current density divided by voltage which is equal to one over the resistance.

In this week's homework we have included an exercise in which you have to prove that the slope at the open-circuit voltage point, is equal to 1 divided by the series resistance.

The smaller the series resistance, the larger the slope and the FF will be.

The slope at the point corresponding to the short-circuit current density in a J-V curve is 1 divided by the shunt resistance.

The larger the shunt resistance the closer the slope will be to zero and the larger the FF will be.

In summary the real solar cells and panels have series and shunt resistance and in solar cell design and manufacturing it is important to minimize the series resistance and to make the shunt resistance as large as possible.

The J-V curve of a solar cell has a power density which is varying with voltage.

What will determine at which J-V point the solar cell will be operating?

This is determined by the load, which is connected to the solar cell.

If the load has a low impedance the current density will be high and the voltage will be low.

It means that the solar cell is not operating in its maximum power point.

Whereas, if the load has a high impedance the voltage will be high and the current will be low.

Again, the solar cell is not operating in its maximum power point.

This means that we need to tune the impedance of the load to have the solar cell working in its maximum power point.

If we discuss PV systems later in this course, we will talk about maximum power point trackers.

These are electronic devices which varies the load in time such that the solar panel is always working in its maximum power point, such that the maximum amount of electrical power can be generated by the solar panel.

So far, we have discussed the external parameters of an ideal and non-ideal solar cell this week.

The remainder of this week, we will discuss how these external parameters are affected by the design of the solar cell.

I will introduce you general design rules for solar cells.

These design rules will help you to understand the performance of the different PV technologies which will be discussed in the coming three weeks.