ET3034TUx - 4.5 - From solar cells to solar modules

We now know what a solar cell is.

But how do we make a module out of solar cells?

What is the performance of a solar module?

These are the questions I will answer in this final block.

A wafer based device is usually referred to as solar cell.

A solar module is a larger device in which many solar cells are connected.

If you look at the level of a PV system, we can have several modules connected, and this is what we call an array.

Now we look at how we make a solar module out of an ensemble of solar cells.

We can connect the solar cells in different ways.

First we have the series connection as shown in this figure.

In a series connection the voltages add up.

It means that if the open-circuit voltage of one cell is equal to 0.6 V, the string of the three cells deliver an open-circuit voltage of 1.8 V.

If we look at the classic front metal grid, it means that the bus bars at the front side have to be connected with the back contact of the neighboring cell.

In this slide you see a cross-sectional view of a few solar cells connected in series.

Every solar cell has its back contact connected with the front contact of its neighboring cell.

For series connected cells, the current does not add up.

The current flowing through the solar cell is determined by the photocurrent in each solar cell.

It means that the total current in the string of solar cells is equal to the current generated by one single solar cell.

Let's look at the J-V curve of solar cells connected in series.

If we connect two solar cells in series, it means that we can add up the voltages.

However, the current remains the same in series connection.

The resulting open-circuit voltage is two times that of the single cell.

If we connect three solar cells in series, the open-circuit voltage becomes three times as large, whereas the current is that of one single solar cell.

A second way of connecting the solar cell is in parallel.

Here you see three solar cells connected in parallel.

The I-V curve shown is that of a single solar cell.

Parallel connection means that the voltage is the same over all solar cells, however the currents of the solar cells add up.

If we have two solar cells connected in parallel, the current increases two times, whereas the voltage remains the same.

If we have three cells in parallel, the current becomes three times as large, while the voltage is the same as for a single cell.

This means that if we consider a module, you can partly tune the voltage and the current output by the arrangements of the connections of the solar cells.

Here we see a typical solar panel that contains 36 solar cells connected in series.

If a single junction solar cell would have a short-circuit current of 5 A, and an open circuit voltage of 0.6 V, it means that the current output of the module is equal to that of a single solar cell, which is 5 A.

The open-circuit voltage would be 36 times that of a single junction cell, which equals to 21.6 V.

If we would rearrange the connection of this module, we can get a different current and voltage output.

If we connect 2 strings of 18 series connected solar cells in parallel, we would get a short circuit current of 2 times that of a single solar cell, which is 10 A.

The open-circuit voltage would be 18 times that of a single solar cell, which is 10.8 V.

Another aspect of modules is that some bypass diodes are integrated into the modules.

Why do we need bypass diodes?

For that we have to look at a solar module in real life.

In real life, the solar module can be partly shaded.

This can be the shade of an object nearby, like a tree, a chimney or a neighboring building.

The shading can be caused by a simple leaf that has fallen from the tree.

This can have significant consequences for the output of the solar module.

Let's consider the situation in which one solar cell in the module is for a large part shaded.

For simplicity we assume that all 6 cells, part of this small module, are connected in series.

This means that the current generated in the shaded cell is significantly reduced.

In a series connection the current is limited by the cell producing the lowest current.

This cell dictates the maximum current flowing through the module.

In this J-V curve we show the theoretical J-V curve of the 5 non-shaded solar cells and the 1 shaded solar cell.

If we have a constant load, like the resistance R in the previous picture, it means that the voltage over the module is dropping due to the lower current generated.

However, since the 5 non-shaded solar cells are forced to produce high voltages, they act like a reverse bias source on the shaded solar cell.

The dashed line represents the reverse bias load put on the shaded cell.

It is the J-V curve of the 5 cells, mirrored into the vertical axis, equal to 0 V.

This means that the shaded solar cell does not generate energy, but starts to dissipate energy.

It means the solar cell is getting warmer and warmer.

The temperature can increase to such a critical level, that the encapsulation material cracks, or other materials wear out.

In general, high temperature conditions lead to decrease of the PV output as well.

This can be prevented by including bypass diodes in the module.

In this figure you can see bypass diodes included in the electric circuit.

A diode, as discussed in week 2 and 3, blocks the current in a direction when it's under negative voltage, but conducts a current when it's under positive voltage.

If no cell is shaded, no current is flowing through the bypass diodes.

In the case that 1 cell is shaded, due to the biasing of the other cells, the bypass diode starts to pass current through.

As a result the current can go around the shaded cell and the module can still produce the current equal to that of a non-shaded single solar cell.

As you can see, going from a solar cell up to module level gives rise to a whole new set of technical considerations.

In week 7 we will discuss the operation of modules and the design considerations in the PV system in greater detail.

So this week we have discussed crystalline silicon wafer based PV technology.

I hope it was a helpful introduction into this technology.

You have to realize that in view of time limits, we only covered the most rudimentary concepts.

In the next week we will discuss different PV technologies: technologies which are based on thin-film materials, such as amorphous and nanocrystalline silicon, cadmium telluride, CIGS, dye-sensitized and organic materials and the III-V semiconductor materials.

You will discover that every technology will have its own specific design rules and challenges.

See you next week!