ET3034TUx - 7.2.1 - PV Modules 1 - Module parameters, orientation and tilt

Welcome back.

In this block, we shall focus on the central character of the PV system - the PV modules.

Before I start, I want to touch upon briefly on the subtle difference between the terms solar modules and solar panels.

You must have observed that a lot of people use these terms interchangeably, but what is exact the difference?

A module is an interconnection of solar cells, as you had seen before.

It is the generic name given to any kind of packaging for an interconnection of solar cells.

That is, irrespective of technology or packaging, an interconnection of solar cells will be called a module.

However, the term solar panel is a bit more exclusive for the rectangular, rigid packaging with typical encapsulations.

For example, most standard crystalline modules are called solar panels.

All solar panels are solar modules but the converse is not true.

For instance, a thin-film silicon solar cell that is packaged as a flexible laminate is a solar module.

But it is not entirely accurate to call it a panel.

Note that in most cases, the commercial modules being used are panels, and therefore modules are synonymously called as panels in common usage.

Henceforth, I might use the terms solar panels and modules interchangeably as well.

But I hope you understand the exact difference between the two.

So let us move onto the module level concepts.

First of all, I would like to introduce a new term - the I-V curve.

So far we have been discussing the J-V curve at the solar cell level, J being the current density, current per unit area.

But at the module level, the total current that the module can generate is of more interest.

Hence, we look at an I-V curve, or the current-voltage curve.

As the area is a constant, the I-V and J-V curve of the solar cell or solar module will have identical nature.

As a quick recap, you might remember how a solar module exhibits similar output characteristics to a solar cell, as a module is nothing but an interconnection of solar cells.

In a nutshell, it can be said that just like for the solar cells, a set of parameters can be similarly defined for the solar modules, like module efficiency, module fill factor, Voc and Isc, can be defined.

You will remember that the voltage and current characteristics for a module with m identical cells in series and n identical cells in parallel will look like this.

The current multiplies by a factor n due to parallel connection, and the voltage multiplies by factor m due to a series connection.

But what about the other parameters like efficiency and fill factor for a solar module?

Do they increase, decrease or stay the same?

Think about this for a moment.

In an ideal world with perfectly matched solar cells and no losses, one would expect that the efficiency and fill factor at both the module and cell levels to be the same.

But this is not the case in practice.

We know that cells are connected together using interconnects.

Although a very small amount, resistive losses occur in these interconnects.

Also, there might be small mismatches in the cells that are interconnected.

For instance, of the m x n cells interconnected, the cell with the lowest current in the m cells in series dictates the module current.

Similarly, the cell with the lowest voltage in the n cells in parallel dictates the module voltage.

This can be attributed to the non-homogeneity of the cells in mass production.

Therefore, the module in practice performs a little subpar compared to the expected performance of the ideally matched and interconnected solar cells.

This translates to a lower fill factor and efficiency at the module level.

In fact, if the module is undergoing variable illumination or non-uniform heating, the module performance is bound to get even worse.

Even module manufacturers mention in their datasheets the difference between module and cell level efficiency.

For example, the datasheet of Sanyo HIT-N240SE10 module speaks of a cell efficiency of 21.6%, but a module level efficiency of 19%.

Perhaps this gives you an idea of how different the cell and module level parameters can be.

Even though so many technological advancements are being made at the cell level to improve efficiency (as discussed in the previous weeks), there is still a lot to be done at the PV system level to ensure a healthy PV yield.

Getting a good module (in terms of efficiency and output sensitivity) is winning only half the battle, what matters ultimately is the yield of the PV system.

So the question is: What else can you do to increase the yield of your PV system at the system level?

Of course, MPP tracking is a valuable tool to ensure that the PV module always operates at the MPP on an I-V curve, under a given set of irradiance and temperature.

This will be discussed in great detail in block 7.3 dedicated to MPPT.

But how do we improve the amount of light falling on the PV module, at the system level?

The simplest way of doing that is by playing with the orientation and tilt of the module.

What do we mean by orientation and tilt?

Tilt is the degree of freedom that defines the elevation or the pitch of the solar module with respect to the horizontal.

Orientation is the degree of freedom that defines the azimuth or the yaw of the module with respect to a position, which, in this case, is the geographic South.

Note that different places and people have different practices of defining the azimuth.

The most common reference points are the geographic North and South.

So how does playing with the orientation and tilt of the PV module alter the amount of light falling on it?

For this let's take a look at this animation.

As seen in this video, there is a solar panel tracking the sun by varying the tilt and orientation continuously.

Of course, this stems from the basic fact that in order to get maximum energy from the sun at any instant, the plane of the solar panel (or the plane of array, as sometimes called) should be perpendicular to the direct rays of the sun at that instant.

The amount of solar energy falling on the Earth is dependent on astronomical factors like the tilt of the Earth's axis and the near-spherical shape of the Earth.

These factors combined with celestial mechanics give rise to the complex path vector between the sun and a point on the surface of the Earth.

As a result, we see the need for having to track the sun by changing the tilt and orientation of the solar modules.

Let's try to study this a little more.

Why do we need to change the orientation of the solar panels to always face the sun?

This is because of the Earth's rotation.

Here you see how the Earth is rotating on its own axis, which is inclined 23.5° to the perpendicular to the plane of the Earth's orbit.

As the Earth rotates, different places on the surface of the Earth are illuminated differently at various points of time during the day.

Thus, the need for solar panel's orientations arises.

In this animation it is seen clearly how the solar panel is changing its orientation during the day.

Simple orientation need not be a result of complex calculations though.

Common sense dictates that a place in the Northern hemisphere will have the solar panels facing in the general direction of South, while a place in the Southern hemisphere will have the solar panels facing in the general direction of North.

Now, why do we need to change the tilt as well?

This is because the Earth is revolving around the sun in an elliptical orbit as shown.

While the 23.5 degree inclination of the Earth remains the same with respect to the Earth's orbital plane, the Earth's axis is continuously changing position relative to the sun's rays.

Now this complicates the relative path between the sun and the Earth even more.

The existence of the various seasons is also because of this very reason.

Its effect is that in June and December the sun is closer to the Northern and Southern hemisphere's mid latitudes respectively, while in March and September, it's closer to the equator.

Thus we see a need to vary the tilt of the solar panel.

This is exactly what is shown in the video, that the tilt of the solar panel is changing as the year progresses.

Now most solar panels or systems don't have the luxury of employing a dual axis solar tracker.

Not only are they very expensive, they are also difficult to implement if the panels are to be mounted on the rooftop.

Hence the need arises for the concept of an optimized orientation and tilt.

What do I mean by this?

As the majority of PV systems have fixed mounting of the panels, designers have to live with a single orientation and tilt throughout the year.

So, what should these fixed angles be?

The answer would change depending on the geographical location.

Here we see various places marked along with their latitudes on the globe.

Depending on the latitude of the place, a panel tracking the sun will have to go through a range of tilt angles throughout the year.

Let's see how a sun tracking PV panel is working in different places around the Earth.

We will first go to London.

London has a latitude of around 51°.

Consequently, the range of tilt angles throughout the year for a panel tracking the sun varies from 28° to 76°.

The panel in this case is oriented towards the South.

The optimized angle of tilt will be 35-40°, facing South.

Moving closer to the equator, we have Cairo at around 30° latitude.

We notice that the range of tilt angles has diminished to around 6° to 54°.

The optimized angle of tilt in such a case would be around 20-25°, facing South.

Now let's go to the Southern hemisphere with a solar panel mounted in Sydney.

Sydney has a latitude of around 34° S.

Note that being in the Southern hemisphere, the panel is oriented towards the North.

We see that the range of tilts experienced by the PV panel is from 10° to 58°.

The optimized angle of tilt in such a case would be around 30°, facing North.

It has been seen in practice that optimized angles can give up to 70 to 80% of the maximum PV yield.

As long as the solar panels are facing in the right direction in general, that is, facing South for a panel in the Northern hemisphere and North for a panel in the Southern hemisphere, it is usually observed that the variation in the optimal orientation angle doesn't vary the PV yield much.

Consequently, the optimal tilt of the panels help in saving more energy than the optimal orientation.

It is also interesting to note that the optimized tilt could also be based on the seasons.

That is, we could either use an angle that maximizes the PV yield in summer or in winter.

This could be interesting for application-specific PV systems.

Thus, we have seen the importance of the orientation and tilt for the PV module.

Now we have one more important effect to discuss at the module level, and that is the temperature effect.

I will discuss that in the next video.