ET3034TUx - 7.3 - Maximum power point tracking

In this block, I will discuss the concept of maximum power point tracking, or as is commonly called - MPPT.

This concept is very unique to the field of PV systems, and this also brings about a very special application of power electronics in the field of photovoltaics.

The concepts discussed in this block are equally valid for cells, modules, and arrays, although Maximum power point tracking (MPPT) concepts are usually employed at PV module/array level in practice.

For reasons discussed before, the solar cell has an I-V curve as shown in the figure (graph).

As a quick recap, you might remember how the I-V curve of a PV module is similar to that of a single solar cell, as the PV module is merely an interconnection of several solar cells.

A series or parallel interconnection of cells increases the voltage or current respectively, but the overall nature of the I-V curve remains the same.

In a similar manner, it can be said that the interconnection of the PV modules to form a PV array would yield comparable I-V curves, albeit at different I-V levels.

Thus, it is reasonable to consider the I-V curve of a solar module or array similar in nature to that of a solar cell.

So let's head to the simple I-V curve of a solar module.

Now, the I-V curve is nothing but the current-voltage curve.

This I-V curve of a PV module is defined for a unique set of temperature and irradiance conditions.

For instance, if the irradiance (or illumination) were to increase, the I-V curve would also change to a higher level.

In general, a higher irradiance gives a better I-V curve, but a higher temperature gives a worse I-V curve and vice versa.

Now let's try to understand the concept of the operating point.

At any given point in time, the solar module operates at a particular voltage and current.

The point on the I-V curve where the solar module operates is called the operating point.

For a given irradiance and temperature, an operating point on the I-V curve corresponds to a unique (I,V) value.

We know that power = V*I.

If we draw the power-voltage curve, or the P-V curve, it takes a form as shown.

Of course, an operating point on the I-V curve will also correspond to a unique operating point on the P-V curve.

Now what is the significance of the P on the P-V curve of a solar module?

Well, this is the power that is produced and delivered to the rest of the PV system, and eventually the load.

Therefore, it is clearly advantageous that the solar module operates at maximum power as seen in the figure as the peak of the P-V curve.

Now, without any external electrical manipulation, the PV module's operating point is largely dictated by the electrical load seen by the PV module at its output.

To get maximum power delivered by the PV module, it is therefore imperative to force the module to operate at the operating point corresponding to the maximum power, or as it's generally called, the maximum power point (MPP).

This point corresponds to the peak of the P-V curve or the "knee" of the I-V curve.

The simplest way to do this, is to force the voltage of the PV module to be that at the MPP (called Vmpp) or regulate the current to the right amount as that at MPP (called Impp), using converters.

But what if, after forcing the PV module to operate at MPP, the ambient conditions, like irradiance or temperature change and in turn cause the I-V/P-V curve to change as well?

This would mean that the old MPP is no longer valid under these conditions.

Thus, to be continuously at the MPP at all times, we would need to track any such changes in the I-V curve, and find out the new MPP.

This process is called maximum power point tracking or MPPT, and the devices that perform this process are called MPP trackers.

So how do these MPPT devices work?

An MPPT device is nothing but a hardware implementation of an MPPT algorithm or algorithms.

There are several algorithms to track the MPP effectively.

These are also called MPPT techniques.

Some of the modern literature talks about two broad categories of MPPT techniques: • Indirect MPP tracking, like fractional open-circuit voltage method, or • Direct MPP tracking, like the Perturb and Observe method or the Incremental Conductance Method Each of these techniques have their own advantages and disadvantages.

Let's talk about the indirect MPP tracking first.

In this kind of tracking, simple assumptions and periodic estimations of the MPP are made with easy measurements.

An example from practice is the fixed voltage method.

This technique is based on adjusting the operating voltage of the solar module only on a seasonal basis.

This is under the assumption that the higher MPP voltages are expected during winter, and lower MPP voltages are expected in the summer, for the same level of irradiance.

Of course, this method is not very accurate and accuracy is increased if such an idea is implemented in a place with minimal irradiance fluctuations on a particular day.

One of the most common MPPT techniques in indirect tracking category is the fractional open-circuit voltage method.

This method exploits the fact that a good approximation of Vmpp is given by constant k multiplied by Voc.

This constant k, for crystalline silicon is usually found to be around 0.7-0.8 in practice.

In general, constant k is based on the PV technology and the kind of solar cells in use.

How is this technique rationalized?

Let's discuss that for a moment.

We know that every illumination level and therefore irradiance level corresponds to a particular I-V curve and therefore a specific level of Voc.

It is found from practice that for a range of I-V curves, the ratio of Vmpp to Voc shows little variation.

Thus, for changes in irradiance, if the Voc can be measured quickly, the Vmpp can be easily estimated as a fraction of the Voc.

This technique is easier to implement compared to some of the more complicated techniques.

What then, are the drawbacks of such technique?

Well, first, as the concept of k is just an approximation, this method does not always point us to the true MPP, but only in the region around MPP or as it's commonly called, the MPP region.

Secondly, every time the system needs to respond to a change in illumination conditions, the MPPT algorithm needs to measure the Voc.

How does the MPPT device measure the Voc of a solar module under operation?

This is done by disconnecting the PV module from the load momentarily, or in other words, the PV current is zero so as to measure the Voc.

Although temporarily, this results in a loss in production of the PV power.

This handicap only worsens if this measurement of Voc has to be made more frequently.

A slight modification to this method can help in overcoming this apparent drawback.

This involves the inclusion of a pilot PV cell that is highly matched with the rest of the PV cells that constitute the PV module.

The idea here is that the lone pilot PV cell receives the same illumination as the rest of the PV module, and a measurement of the pilot PV cell also gives an accurate representation of the PV module under consideration.

Thus, while the PV cell provides for a good estimate of the module's Voc, the Vmpp can be calculated as Vmpp = k*Voc and the PV voltage can be adjusted accordingly, without having to disconnect the PV module.

Note that the inclusion of PV cell merely avoids the losses due to module disconnection.

This method would still suffer from the problem of depending on the k value for estimating the Vmpp.

Now let's look at the more involved kind of MPPT - the direct MPP tracking.

This kind of MPPT involves direct measurements of current, voltage or power and a more accurate/faster response than the indirect method.

Due to time constraints, we shall look at a couple of the most popular kind of algorithms, which are sometimes also classified as "hill climbing" algorithms.

We start first with the Perturb and Observe, or P&O algorithm.

In this algorithm, a perturbation is provided to the PV module or array voltage.

This would translate to an increase or decrease in power.

If an increase in voltage leads to an increase in power, this means that the operating point is to the left of the MPP, and hence further voltage perturbation is required towards the right to reach the MPP.

Conversely, if the increase in voltage leads to a decrease in power, this means that the current operating point is to the right of the MPP, and hence further voltage perturbation is required towards the left to reach the MPP.

In this way the algorithm converges towards the MPP over several perturbations.

You would have noticed that this algorithm takes advantage of the fact that the P-V curve has an increasing nature to the left of the MPP and a decreasing nature to the right of the MPP.

The problem with this algorithm is that the operating point is never steady at the MPP.

It is always hovering around, in the MPP region, although this could be minimized using very small perturbation steps around the MPP.

This algorithm also struggles under rapidly changing illuminations.

For example, if the illumination (and therefore irradiance) changes in between two sampling instants in the process of convergence, then the algorithm essentially fails in its convergence efforts.

This situation is illustrated in the figure as well.

In the latest perturbation, the algorithm has determined that the MPP lies to the right of point A, and hence the next step is a perturbation to converge towards the MPP accordingly.

However, as the illumination changes rapidly before the next perturbation, the next perturbation shifts the operating point to B, while the new MPP actually moves to the left of B.

This can be severely erroneous because the algorithm has now reached a point B such that PB > PA.

But the MPP still lies to the left of point B, which makes the algorithm think that the MPP is to the right of point B.

This is detrimental to the speed of convergence of the P&O algorithm, which is one of the critical figures of merit in the field of the MPPT techniques.

Thus, drastic changes in weather conditions severely affect the algorithm's efficacy.

Next, we look at another kind of direct MPPT algorithm, called the Incremental Conductance Method.

To better understand the algorithm, we shall first arrive at a relation between conductance and incremental conductance.

Conductance of an electrical component is nothing but a ratio of current to voltage, or in other words, reciprocal of resistance.

We know, at the MPP, the slope of the P-V curve is zero, i.e.

$dP/dV = 0$.

Now dP/dV could be written as $d(I*V)/dV$.

Using basic differentiation, we get $dP/dV = I + V.dI/dV$.

If the sampling steps are small enough , then dI/dV could be approximated to $\Delta I/\Delta V$.

Thus, at MPP, $\Delta I/\Delta V = - I/V$.

To the left of the MPP on the P-V curve, $\Delta I/\Delta V > - I/V$ and to the right of the MPP on the P-V curve, $\Delta I/\Delta V < - I/V$.

The algorithm exploits these basic facts about the I-V and P-V curve of a solar module.

In general, the algorithm imposes a voltage on the PV module at every iteration, measures the incremental change in conductance, compares it with the instantaneous conductance, and decides if the operating point is to the left or to the right of MPP.

I will explain this in a brief conceptual flowchart.

Note that this flowchart is not exhaustive.

In this example, we see an MPPT algorithm based on Incremental Conductance Method.

The instantaneous voltage and current are the observable parameters, while the instantaneous voltage is also the controllable parameter.

V_ref is the voltage value forced on the PV module by the MPPT device.

It is the latest approximation of the Vmpp.

For any change in the operating point, the algorithm compares the instantaneous and incremental conductance values.

If incremental conductance is more than the negative of the instantaneous conductance, this means the current operating point is to the left of the MPP; consequently, V_ref is incremented.

Conversely, if the incremental conductance is lower than the negative of the instantaneous conduction, the current operating point is to the left of the MPP and is decremented.

This process iterates until the incremental conductance is the same as the negative of the instantaneous conductance, in which case the chosen reference voltage is equal to the Vmpp.

This MPPT algorithm can be more efficient at the MPP as it doesn't hover in the MPP region under steady state like the P&O algorithm.

Also, low sampling intervals make it less susceptible to the changing illumination conditions.

However, under very highly varying conditions and partial shading, the incremental conductance method might also be rendered less efficient.

The main drawback of this algorithm is the complexity of its hardware implementation.

It needs to not only measure the currents and voltages but also calculate instantaneous and incremental conductance values.

I will not go into the details of the hardware implementation of the MPPT techniques, it is beyond the scope of this course.

Usually, a DC-DC converter is used for implementing the current or voltage regulation at the PV output.

A typical example from power electronics is the buck-boost DC-DC converter, like the one shown here.

The algorithm needed to decide what voltage and current to force the PV output to, could be any of the ones discussed here or several others from literature.

The choice of the algorithm would dictate the complexity of the implementation.

In modern PV systems, the function of the MPPT is often implemented within other system components like solar inverters and charge controllers, like shown here.

Please note that the list of techniques and typical implementation are definitely not exhaustive.

In fact, several algorithms and implementation techniques exist in practice as well as in literature.

There are scores of scientific papers, patents, and proprietary technologies existing in this rapidly growing space.

In view of time we have covered only the most common MPPT techniques.

In summary, maximum power is delivered from the PV cell, module or array, if the operating point is the same as that of the "knee" of the I-V curve.

An ideal MPPT device is not only able to track that knee under varying conditions, but also maintain the voltage and current accordingly.

In doing so, the device is expected to use as low an energy amount as possible, so as to not undo the additional energy gains the MPPT process provides.

The MPPT device is also expected to respond swiftly and accurately to the changes in the ambient conditions that impact the PV output.

In the next blocks this week, we shall look at the other components of the PV system that make the harnessed, intermittent solar energy usable for various applications.

See you in the next block.