ET3034TUx - 8.2 - Grid-connected PV systems

Welcome back.

In the previous block you learnt about the stand-alone PV system and its design.

Now, we will look at the characteristics of a grid-connected PV system.

So let's get started.

As the name suggests, the grid-connected PV system is connected to the electric grid.

There is a continuous exchange of power with the electric grid via the distribution panel.

As discussed before, the grid-connected PV system has these important PV system components.

The PV array is an interconnection of modules that supplies the required photogenerated power to the system.

The power rating of the array is determined based on the system design.

The grid-connected or grid-tied inverter is the backbone of the grid-connected PV system.

As discussed last week, it is the inverter that is responsible for not only supplying power to the grid as a current source, but also for tracking the grid voltage and frequency.

The grid and the load are usually connected through a distribution panel.

The interaction with the grid is two-way, while the interaction with the load is unidirectional.

A net meter is also usually found in this type of PV system.

A net meter is nothing but a two way power measuring instrument.

This meter takes into account not only the power consumed from the grid by the consumer, but also the power fed to the grid by the PV system.

Now let us look at the main features of such a PV system.

What happens when the PV array is producing more power than the load demand?

And what if the PV power is insufficient to power the load?

Let us understand this in the following animation.

On a normal day with the sun out, the PV modules on top of this rooftop are busy converting the incoming irradiance into photogenerated power.

The grid-connected solar inverters used in the system are also constantly converting the DC output of the solar modules into usable AC power.

The PV system is able to meet the load demand of the household.

On a different day, if it's a very sunny day, the PV system is providing much higher power than what the load needs.

Under such a condition, the net surplus power is fed to the grid.

In most countries, the consumer can offset his electric bills in this manner.

This facility is called net metering.

You can see that the net meter is reading a net production as the net power is being fed to the grid.

On the other hand, on a cloudy day, the PV system is providing less power than what the load is expecting.

Under such a condition, the load demand is fulfilled by taking the excess power from the grid.

Thus, the net meter registers a net consumption as well.

Now, we will look at the important concept of system efficiency.

We know that the PV modules could be as much as 20% efficient in converting the incoming irradiance into PV power.

We have also seen how the rest of the system components have less than 100% efficiencies.

So, what can be said about the overall system efficiency?

In this grid-connected PV system schematic, you see the various system components.

Let's walk through the system to see the efficiency loss at each stage.

I will suppose some efficiency values for each component so that we can get a rough estimate of how the system efficiency might look like.

Let's assume AM1.5 irradiance levels, and that the PV array is 20% efficient.

Therefore, the power density present at the output of the PV array is 200 W/m².

As the balance of system could be placed at a considerable distance from the PV array, due to the fact that inverters need to be well protected, it might be that the DC power loss in the cables is significant.

Depending on the length of the cables and the amount of current through them, this loss could be anywhere around 1-5%.

In this example, let's assume that we have a cable loss equal to 2% of the PV power production, or equivalently, the cables have a transmission efficiency of 98%.

Therefore, the DC power per area going to the inverters is 98% of 200 which is 196 W/m².

Now, let's go to the inverter.

With advancements in power electronics, it is rather common to have inverters that reach greater than 97% efficiencies.

However, usually, the efficiency of the inverter is dependent on the power at which it operates.

It is seen from practice that the inverters typically reach their rated efficiencies at around 50% of the rated operating power.

For the sake of simplicity, we shall assume an average efficiency of 95% for the inverter.

Thus, the AC power per area present in the system is 95% of 196, which is 186.2 W/m².

Assuming a lossless exchange at the distribution panel and negligible dissipation in the cables carrying AC power, we get an overall PV system output as 186.2 W/m².

This means, that the incoming irradiance at 1000 W/m² is processed by the PV system to give 186.2 W/m².

In other words, the overall system efficiency is 186.2 divided by 1000 W/m², which is 18.62%.

It can also be said that the overall system efficiency is calculated as the product of the various component efficiencies.

That is, eta_system equals eta_PV times eta_cable times eta_inverter.

Now let us move on to the design of a simple grid-connected PV system.

As a quick recap, let us look back at the flowchart of the stand-alone PV system design process.

You will remember that the system design process had several steps.

Given that the grid-connected PV system topology is significantly different than that of the stand-alone PV system, how does the flowchart of the grid-connected PV system differs from the stand-alone system design?

As expected, the grid-connected system design flowchart looks simpler, owing to the absence of the battery and the charge controller.

Although the load demand and the equivalent sun hours could shape the sizing of a grid connected PV system, it is not necessary to base the grid-connected system sizing on the load.

I will come back to this later.

However, for this example, to get a sense of comparison with the stand-alone PV system design, we shall consider the grid-connected system design process with a load demand.

In this design process, we shall first understand the load requirements from the system on a per day basis.

Then, we shall account for the system losses.

We will then take into account the equivalent sun hours.

Then we will size the PV array.

And finally, we will look at the inverter design.

So let's get started! Let us consider a similar load demand as shown in the stand-alone PV system design example of the previous block.

The required quantities of each kind of load, along with their duration of usage are mentioned.

Note that all the loads in this system are AC loads.

The total power and energy requirements have been tabulated here as well.

Another main difference here is that there is no concept of autonomous days, as there is no storage.

Instead, the electric grid acts as a limitless storage.

Let us first account for the losses in the system.

This would help us find the energy needed at the output of the PV array to successfully cover the daily load.

Here we assume the same component efficiencies as we saw in the earlier example.

That is, the cables have a transmission efficiency of 98% for the DC power, and the grid-tied inverter shows an efficiency of 95%.

We also see that the AC load at the inverter end demands a total of 600 Wh during the day.

Given the system component efficiencies, we can then calculate the equivalent energy required from the PV panels as shown.

This is basically nothing but the transposition of the energy before all these losses occur.

Therefore, the total energy requirement from the PV array is 644.5 Wh.

Next, we consider the irradiance.

Going by the same example as in the stand-alone system case, a location in India is considered with an average of 4.5 equivalent sun hours.

Let's look at the electrical specifications of an available PV module.

It is a 100 Wp rated module with the given voltage and current parameters.

Now, we need to find out how many of such modules are required to power the loads.

Assuming that the panel would be operated at its MPP, we can find out the required number of panels as follows.

We can first calculate the amount of minimum PV power required by dividing the total energy demand at the PV array output with the equivalent sun hours.

Thus the minimum PV power required is 143.2 W.

Also, the number of the panels could be calculated as shown.

In this case, the total number of required panels is 2.

Usually, panels are connected based on their compatibility with the DC ratings of the inverter.

Care should be taken that the worst case current and voltage from the PV array do not violate the input parameters of the inverter.

Now let us look at the possible PV configurations.

The maximum allowable current and voltage rating can be found by assuming these scenarios.

If the 2 panels are connected in parallel, then a maximum current of 2*Isc is possible, which in this case is 14 A.

On the other hand, if the 2 panels are connected in series, then a maximum voltage of 2*Voc is possible, which will equal 40 V.

Now I must clarify one thing about the grid-connected PV system.

Usually, the amount of PV panels or the rating of PV panels need not be exactly as per the load requirements, like it was in the stand-alone PV system.

This is because any excess or deficit of PV power can be compensated by the grid, that is present in the scenario anyway.

This was not true for the stand-alone system, as any surplus or deficit of power had to be met with a variation in the storage size, leading to considerable system costs.

Consequently, in grid-connected PV systems, it is usually seen that the inverter is sized based on the PV array sizes and not the load size, like in the stand-alone systems.

So the required PV power is 200 W.

The inverter should be able to at least handle this power.

Thus, we say that the minimal nominal rating of the inverter is 200 W.

Let us look at the operational parameters of an example inverter that fits the bill with respect to the required minimum power rating.

Note that this inverter has an MPPT feature, thereby making the panels work at maximum power point.

Looking at the I-V ratings of the DC side of the inverter, we see that the maximum DC input voltage for the inverter is greater than the maximum voltage.

On the other hand, the maximum DC input current for the inverter is less than Imax but greater than Isc.

Thus we can say that the ideal panel configuration could be in series.

Note that in practice, sizing of the system is not the only thing, one must take into account technical and regulatory policies before implementing a grid-connected PV system.

In this video, due to time constraints, we limit ourselves with the sizing of simple grid-connected PV systems only.

As a final note, I'd like to talk about oversizing the PV system sizing.

Now, should or can a user oversize the PV system, even if he can meet the load needs for much lesser power?

For instance, in the previous example, what if instead of 200 W, you had installed 500 W?

Well, in simple terms, it is possible.

Any excess you produce is sent to the grid.

Whether or not the grid operator pays you back for this excess depends on the net metering related policy of the electric utility you are connected to.

If your grid operator pays you back for every watt of PV power you pump into the grid, it might look beneficial to oversize your PV system.

But then the decision would depend on the system costs, and the expected system yields, which in turn depend on the irradiance of the place, module level effects, etc.

Thus, there could be quite some optimization that could be done purely at an economical level.

So you have now looked at the grid-connected PV system.

In the next block we shall look at some specific kinds of PV systems.

See you next block!