BUILDING ENERGY SYSTEMS AND AUDITING

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Lecture 37

Lecture 37: Solar Energy-II

Welcome to the NPTEL lecture on Building Energy Systems and Auditing. We are in module number 8. This is the second lecture in module number 8. We started with solar energy; part 1 was discussed in lecture number 36. In this 37th lecture, we will discuss the second part of solar energy.

In this lecture, we will cover the PV module and its rating system, and we will also discuss energy generation and the estimation of solar energy. Again, we see that the components of the solar PV systems have various types, as discussed in the earlier lecture. Out of all, I have marked some systems in red color: the PV module, the charge controller, battery, and inverter. These four components are very important for a particular PV system to determine the capacity and how much energy is harvested. This is called the balance of system (BOS) of the particular system. So, you can create some kind of balance. If you have a very large area of PV modules, you need to have a very large storage capacity for the battery and a high rating for the inverter. The rating of the inverter or so.

Based on that, there must be a balance system, and this balance system depends on these four components. Now, we see there are three such components out of these four balance systems: one is the PV module, which is definitely there, and the other three—charge controller, battery, and inverter—will be placed one after another. So, first is the charge controller, then the battery, and then the inverter, because we cannot shift their positions. Why? The charge controllers

First, you have to place it and control the charge so that it should not be overcharged or sometimes the battery should not be discharged. That is why the charge controller has to be placed first. Then you need to put the battery, and this particular battery is also one of the very essential components. What should be the capacity of the battery? The battery is also very costly from the point of view of investment.

So, you need to decide what should be the optimum capacity of the battery. Now, when we decide upon the optimum capacity of the battery, we need to know the actual storage capacity of the battery that I am going to purchase. And when this particular decision has to be taken—what should be the storage capacity of the battery—I need to have a critical application period or so. That means how many days of extra additional storage capacity I want to keep, because I know that in the nighttime every day, I do not have any kind of electricity generation through solar. So, definitely, each and every day, I have to provide a battery bank or something. But suppose there are two or three continuous cloudy days,

even in a very sunny month like February or March or something, there must sometimes be two or three very cloudy days because of some kind of weather change or so. So then, on those two days, there may not be that much generation. So how many extra days of storage do I need to account for? So mostly, it fluctuates between 2 to 6 days.

If you have a high number of days, your battery capacity also has to be high, and that is also going to impact or affect your investment, the capital cost, or so. So that you have to check. So next one is the inverter. Inverter, I have discussed that it has to be changed to transform the battery current, which is a DC current, to an AC current. So, it depends upon how much total AC load is there in your room or in your building, and based on that, what is the running time and all those factors. From that point of view, you need to decide what the inverter capacity should be.

Now, in the second method, if you remember from the last lecture, we discussed the first method where we talked about the tilt angle and all those. So there is a second method also. We can actually, without considering the tilt angle and all, find out the area of the solar panel required for your harvesting or the generation of the electricity needed and all. And this is almost, I can say, an approximate kind of formula, but it can work very well. If you know the tilt angle and something like the sides that give you the maximum amount of peak radiation or so, then you can directly go for this particular second method. This method tells me that there are some components. This E is the energy

which is in kW, A is the total area of the solar panel in m^2, SPY—yes, this SPY is the solar panel yield of each module. So, this is actually the efficiency percentage of the module, expressed as a fraction. And we will discuss SPY a little more elaborately in the next one or two slides. What is R? R is the annual daily average solar radiation and all. So how much kW/m² and all.

So that data already we have discussed. I have written down this depend upon the orientation for the specific tilt orientation as smooth and all those even it depend upon the if there is a character some elements is there near to the site which can cast shadow on all trees and all those kind of things also going to be give you some kind of the effect on that are the last one is pier the performance ratio this performance ratio is taken as in between 0.5 to 0.9 is the it depends upon lot of things it depends upon the shading that I told you this is it depend upon the your this does this this all the components the downside components and their efficiency is the charge controller battery and the inverter and all it depends upon the maintenance point of view the uh the solar panels is of course will be placed outside open to sky and it will almost going to i mean every possibilities are there it will be actually accumulate dust and dirt and all those and we may not clean very frequently and that will definitely going to decrease the harvesting capacities also.

So, all together it is the total performance of the system. So, the system performance we can keep 0.5 to 0.9. Usually we can default value we can take as 0.75, but please remember we have to check each and every downside the equipment ah the for ah the better production of the electricity we have to see the ah the cleaning of this particular the pv panel arrays very frequently very regularly with water and it has to be washed properly so that the surface the top surface the glass surface is very clean and get almost whatever radiation comes and that actually use for the this photoelectric conversations or so now let us discuss about this rating the solar pv i think this has to be not pn it is the pv

PV are rated in peak watt or peak power capacity. And this peak power capacity is called as KWP. KW you all know that is a kW and P stands for peak. How much peak kilowatt can be generated under a STC? STC is a standard test condition.

So, in laboratory we will do that. Each and every panel will be now exposed to 100 W/m² of the standard radiation and at a temperature cell temperature of 25° temperature and the wind speed of 1 m/s the in the laboratory environment we will see that what is the generation how much is the generation of the kilowatt how much kilowatt is generated is it point is it 300 W then it is 0.3 is the generation capacity like that we have to check and then we have to say that yeah this particular panel is having uh this much kilowatt peak or sometimes we may say also the this much watt peak So, the solar panel yield SPY is defined by the ratio of the electrical power in kilowatt peak of one solar panel divided by the area of the panel.

So, if suppose there is the PV panel of area $1.6m^2$. So, suppose there is a $1.6m^2$ of the area. So, this area is your $1.6m^2$ and this is generated the 250 W peak. That means under the given condition, given condition I have again written here, that is under this given condition 1000 or whatever and this temperature and watt perm^2, this is actually generating 250 W peak.

at that particular temperature. Then we will see this SPY is kilowatt peak divided by the module area into 100 percentage. So, this is your kilowatt peak which comes from here. It is actually not kilowatt peak. This 250 divided by 1000 is your kW peak.

So, this is your KWP. And 1.6 is your area and by 1 into 100 that means, it is 15.06 percentage that is the efficiency and this efficiency will lie between 10 to 20% not more than that. So, we are going to find out for that the find out the output of the PV cell systems of area $250m^2$ performance ratios 60% The daily average solar radiation is 400 W/m^2.

The PV shell of 2.4 meters and smaller PV cell produced 320 W peak. So, if I go back here you need this area of this 250 SPY you have to find out R is given PR is given. So, here you see we have to see this first we have to find out the SPY. So, from the SPY this is your W peak is your 230. So, I have to put it as a kilowatt peak this and this is your sorry this is the module area.

So that means it is 13.3 is your SPY and next I can find out the E as A into SPY into R into PR or whatever. The A is your you see I have drawn the arrows 250 is them^2 is the total TV system area. And 0.133 is your SPY, 13.3%. And the radiation is almost about 400 W, that means 400 by 1000 kW. 0.6 is the performance ratio PR.

So, it will generate 6.98 kW. And if it is this particular 400 W/m^2 is carried for 3 hours, 4 hours, whatever time, I can multiply with this kilowatt hour into the hour. and that much kilowatt hour will be the generation. So, we will solve a small problem in a rooftop of an apartment. The building has proposed the solar panel.

Suppose we are proposing some solar panel for an apartment building. The solar electricity will be used to run some of the basic appliances and the features of the residence. It is found that the solar panel can be installed in the south and the west direction only. So, these two are the most favorable direction for yielding electricity. the south direction can hold up to 70% of the solar panel so that means the south facing rooftop areas are more so it can hold almost 70% and the rest 30% can be placed in the west facade west the facing the solar panels right so and the size of each panel what i can purchase is of 151.5m by 0.6m

That means 5 feet x 2 feet gives almost about 320 W peak. So, from these two data I can find out the SPY. performance ratio is 65% solar radiation data is given that means average solar radiation in the south and the west are 450 and the 350 watt perm^2 respectively and the average solar hour in the south is six hours almost six hours you will get in the south So radiation average radiation is 450 sometimes it is high sometimes it is low but average is 450 for 6 hours whereas in the west it is average for 3 hours and average is 350 watt perm^2. And also, I have given the what are the things I want to run by electricity.

The solar electricity is that there are 9 units in the apartment. All the 9 units will have some balcony, 2 balcony light of 8 watt. and that will operate for two hours so is all the wattage of balcony light toilet there are three toilet light there are one kitchen light there are four ceiling fans and there is one 32 watt storage light is i want to operate through this electricity the number of fixtures are there how much it will operate that is also there the kitchen light will be going to operate for four hours in the night or maybe any time in another day The ceiling fan will operate for 12 hours in a day like that. And those are the first table.

The first top part of the table is for the 9 such apartments. You have to calculate the total load and multiply with 9 for the total apartment. And the common area which is staircase area and the parking area is also having some number of lights and wattage and the operation hours are given. So, what I have to find out that how much solar panel I have to install in the south facing and how much will be the west facing. I only know that I have an area almost 75% I can go for the south and 30% is for the north.

So, I will let us go step by step. so first of all i found out the spy which is 35.55% but this value is these values i have taken some value it is not the i may say it is the proper value from the from some manufacturer you won't get 35.5% yield you have to be very careful in that it has to be definitely less than 20% or so but anyway for my our calculations or for our understanding it is fine So, this is 33.55%. So, I have used kilowatt peak as 32 W divided by 1000 and 0.9 is you know it is the area of each panel. So, that is your actually this is your 1.5 meter by 0.6 meter which is equal to 0.9m^2 which is placed over here.

Next is I know the solar hours. So let us, I have assumed that let us A will be the area for the south. Sorry, sorry. The A will be the total area.

So, 0.7 A will be the total area of the south and 0.3 A will be the total area of the north. Now you see I have calculated the energy generation from the panel from the south and the west is that first the south okay for the south that is 0.7 a so what is the formula the energy e equal to the a into spy into your r into your performance ratio so this is your a 0.7 this is your spy 35.55 450 is your Solar radiation in the south, so this is your 450. 0.6 is the PR and 6 hours.

Similarly, 0.3A is your west area. 35.5 SPY, SPY, 350 is your this. Solar radiation in the west average, 0.6 is the performance ratio and 3 hours is that. So that means this is the total summations or whatever and then I may say that this 471.33 A watt hour because these are all in watt and this is in hour and this is in watt. So that means 0.47133 A kilowatt hour is your I can generate.

That much generation is possible. If There is an amount of a square meter of the area, keeping 70% in the south, 30% in the west. And with those given data, I can generate 0.47133 kilowatt hours. And I have to match this with my demand in the next slide.

So, the demand has been calculated. The balcony light, 18 watts multiplied by 2, 36 multiplied by 2, 72 Wh. Second one is the toilet light, 18 into 3 numbers into 3 into 0.5, that means 9 through the 27. 27 Wh is for the toilet. Like that, the total apartment requires 4115 kilowatt hours of electricity to run, and the common area requires 1592 Wh to run.

Now if I Find out there are 9 such apartments. So, 9 multiplied by 4115 plus 1592, that is the common area. So, my total need or the demand is 38.68 kilowatts per day. So, this is my 38.63 kilowatts per day need to run those electric bulbs and whatever in the 9 apartments at night or whatever may be the day, and this is the common area.

And how much I can generate? I can generate this much. So, if I equate, I can find out the value of A, right? I have to equate this. I can find the value of A as 82 m^2.

A has to be 82 such a way that I can actually balance this need and the necessity and what I am providing. Now, this 82 can be subdivided into 82. 0.7 and 0.3 70% and for 30% for east and sorry for south and the west and module size is 0.9m^2 because it is 1.5 by 0.6 so i can find out the number of panels as 64 panels towards the south and a 28 panels towards the west so this is the way we can broadly uh came to know that how much panel and whatever is required for to generate The next one is to discuss about some of the basic principles of the battery because battery is also going to be a very essential part of the system. I need to know that how much battery is required to hold this particular system, this particular electricity.

Now, there is a demand also, there is the harvesting capacity also in between there is a battery situated. Now, there are two equations we have to understand. One is the battery life equation and one is the battery capacity equation. The battery life is defined as the battery capacity divided by the circuit current. Battery capacity is defined as milliampere hour or ampere hour.

Okay, how much ampere hour or milliampere, so for the small batteries like our mobile batteries and all, our camera batteries, they are actually designated as the milliampere hour. If you see the power bank charger and all or the, sorry, the mobile batteries and all. Mobile batteries may come around 5000, 3500, 5000 milliampere hour. The power bank comes around 15000, 20000 milliampere hour. so like that it can actually charge three battery three mobiles or so something like that

And the charge that divided by the current. So, if it is milliampere hour by milliampere or ampere hour by ampere. So, how much is the hours of life that I can calculate. So, if I say simple this is hours. So, if I say something like that.

There is a battery which is having operated in 6 volt battery small 6 volt battery. Which is having designated as 3000 milliampere. And if it is connected to a load of 300 ohm. something like that so my battery voltage is 6 volt and the load is 300 so from the load and the battery voltage i can find out the how much electricity ampere is flowing so v equal to if you know this v voltage equal to i into r so the ampere i the electricity will be voltage by the resistance so i can find out the current is your v divided by i6 divided by 300 which is 0.02 ampere which is nothing but 20 milliampere so the is the circuit current is your 20 milliampere and if you know that this is 20 milliampere and your battery is 300 milliampere

So, you can see this the battery life is 150 hours. So, this battery will actually run 150 hours which is for a load of 300 the ohm or so maybe what may be the load it may be you may be your small camera or something like that whatever may be the load that can be. So, that can actually last for 150 hours or so right. Now, the second equation is this battery capacity equation. So, battery capacity equation is the total battery bank capacity.

How much total battery bank I require? How much capacity of the battery bank I require? So, that is device by or that can be defined as the equipment power multiplied by the running time, the watt hour. The equipment power and the running time. multiplied by the backup days, how much backup day I want to have, total load per day.

So, suppose that whatever we have discussed, 5000 something watt hour is the total load per day. If my batteries want to store more electricity, more charge for 2 days or 3 days extra because of the overcast scenarios or so, how many extra days? Or the backup days is one just for today I am going to generate and today I will the battery will empty after the today in the early morning or so. And tomorrow again it will be generating the electricity through the sun and again it is discharged by the end of the day. So that is then the backup time is one day.

But if I charge fully and can run for two subsequent days, maybe tomorrow will be a cloudy day. So then, even the day after tomorrow, I will not have any issues. So then, this is one day of backup. So, how many backup days do you require? So, you have to multiply.

So, that much amount of total load per day into the number of backup days. So, that is the total amount of load your battery can hold, divided by the battery voltage. Various types of batteries, like 12-volt, 24-volt, or 48-volt, are very popular. Battery efficiencies depend upon the age of the battery, as you know. It depends upon the chemical type—acid batteries, lithium-ion batteries, or whatever—which have different efficiencies and running times. For example, a new battery starts with very high efficiency. Sir, today I brought it. It started with very high efficiency, but down the line, due to chemical reactions or temperature changes in the battery, the efficiency may decrease.

The efficiency may decrease a bit, maybe by 2-3%, reducing the generation capacity. So, there are some complex scenarios here. So, we will assume an efficiency of around 90% for our calculations. So, by virtue of that, I can find out the milliampere-hour or ampere-hour capacity of the battery bank. Because at the top, it is Wh, and then the voltage gives me the ampere-hour or milliampere-hour.

So, now there are battery can be connected in series, battery can be connected in parallel. So, if it is supposing 24 volt and 200 ampere hour 3 batteries are in series, then the volts are will be added. So, there will be much higher volts. So, this is 72 volt because 23 sorry 24 3's are 74, but the capacity of the battery 200 ampere hour will remain same. In the other way, if you connect it in a parallel 3 such 24 volt and 200 ampere hour battery, then your voltage remains same, 24 ampere hour remains same, but your total capacity will be now increased to 3 times 200 ampere hour.

So, it will be 600 Ah. So, what we learn from here is that if I connect in a series, my voltage will multiply. And if I connect in parallel, my battery capacity will multiply, voltage remains same. Now I am again going back to the problem that we have discussed little earlier. So, this is an amount of, let us assess the battery bank capacity for the single apartment.

I am talking about the single apartment. I have nine such apartments, but this is for the single apartment data. So, I am going to use 24 volt 200 ampere hour battery for this thing and I have to want to have three days of the backup. So, what I did is that first I have calculated that calculation already have discussed. So, per apartment is 4115 Wh is my requirement load.

So, I am this 4115 Wh is the per day per apartment load my battery voltage will be 24 volt i have to have three days of three days of backup again there is a typological error this is days three days of the backup and i will assume a 90% of the efficiency of the battery so i will directly put in this equation So total load per day per apartment is 4115 Wh. Please remember this is in watt hour not in kilowatt hour watt hour. And the backup days is 3 battery voltage.

Suppose the load given you in kilowatt hour you have to actually change it to the watt hour. Because the watt hour because the watt is equal to volt into ampere. Okay. So that is why you have to change it to the watt. So, the 4115 is the total load per day per apartment.

Three days I want to keep for the backup day. The total load is almost about 4115 multiplied by three. That much watt hour has to keep through my battery having voltage 24 volt. So that gives me some ampere hour and the efficiency is 0.9. So, I calculate I am getting 571 ampere hour battery.

But if you see, I have to go to the market. I am going to purchase a 24-volt, 200-ampere hour battery. I require 400, and how much? 400? I am sorry, 571. So, I have to do some permutation and combination with this battery. So, what I can do is that I can actually use three in parallel. So, in parallel, what happens?

The voltage remains at 24. But your ampere-hour capacity is multiplied. So, if I purchase three such batteries of 24-volt and 200-ampere hour, the final output or capacity will be

24-volt and 600-ampere hour, which satisfies my demand of 24-volt and 571 kAh. So, 571 is my requirement. I have 600. Or suppose I am not getting a 24-volt battery, but a 12-volt battery. A 200-ampere hour, 12-volt battery. So, what can I do? I have to make it 24-volt. So, I will use two in series. As I use two of them in series, the voltage will multiply from 12 to 24, while the 200-ampere hour remains the same. Then, three such sets—meaning six such batteries—will give me

three permutation combinations of 24-volt and 200Ah, and that will give me 24-volt and 600-ampere hour. So, either of these two ways I can go: I can purchase directly three 24-volt, 200-ampere hour batteries and make a series-parallel connection, or I can go for six 12-volt, 200-ampere hour batteries and use two such batteries in series and three series in parallel to get 24-volt and 600-ampere hour. So, that is all for this lecture. What we understand from here is the solar PV modules and the kilowatt-peak rating. We also discussed the solar energy generation estimation requirement from the geometric data of the building locations and all. And also, we understand the battery operations or the battery capacity equations and all.

Thank you very much.