Operation and Planning of Power Distribution Systems

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Lecture - 32
Wind and solar energy conversion systems

In this lecture I will talk about two mostly used renewable energy systems, one is called wind turbine or wind energy system, wind energy conversion system, another is solar energy ok. And solar energy is of two types, one is called photovoltaic energy, another is called solar concentration power. So, I will talk about ok and in my last lecture, I gave you a brief overview on what is called wind energy conversion system.

So, in this lecture, we will continue that and we will show you how we will get or how much power we will get from a typical wind turbine, how to determine the efficiency of the wind turbine and how do we generally extract power from this wind turbine ok. So, as in the last lecture I mentioned that wind power is a source of intermittent power and it usually depends upon the speed of the wind, and the speed of the wind throughout a day is used to be variable or used to be varying in nature ok.

And that is why, whatever power that we will get from a typical wind energy conversion system that is also varying in nature, time varying in nature. So, we will discuss on what exactly characteristics of a wind turbine has ok.

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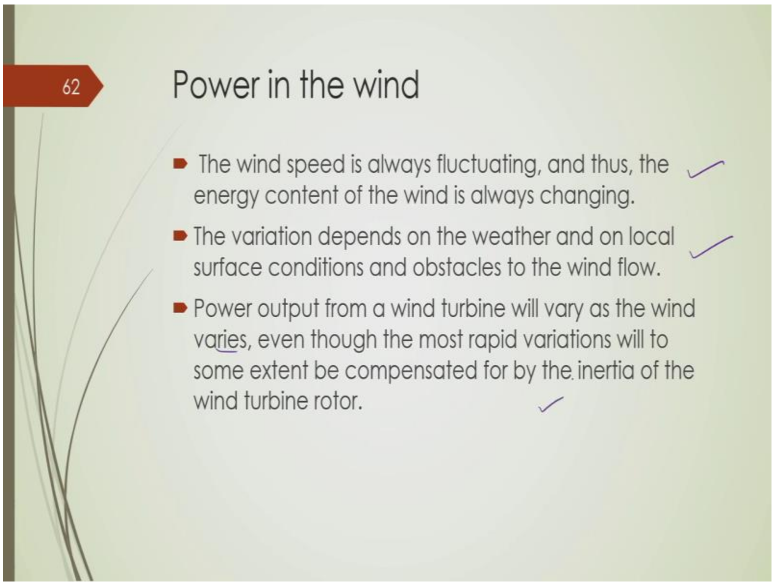

So, wind turbine is of intermittent nature and it depends upon weather; and power output of a wind turbine will vary as the wind varies ok, even though most of the rapid variation will be some extent compensated by the energy of the wind turbine rotor.

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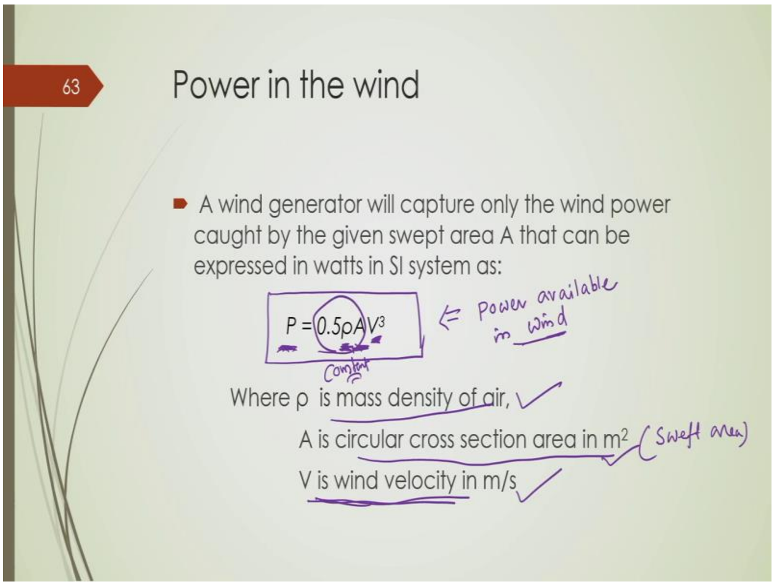

Now, this is the expression for power available to a wind, but this is not the expression for how much power we are getting from the wind turbine, this is the expression for power available in wind. Now what is actually this for? So, if you consider that power available in wind is P, in watt or kilowatt so this depends upon a variable rho, where rho is the mass density of air. So, it is proportional to rho. It is also proportional to A, A is the circular cross section area that is called swept area, we already discussed about what is called swept area.

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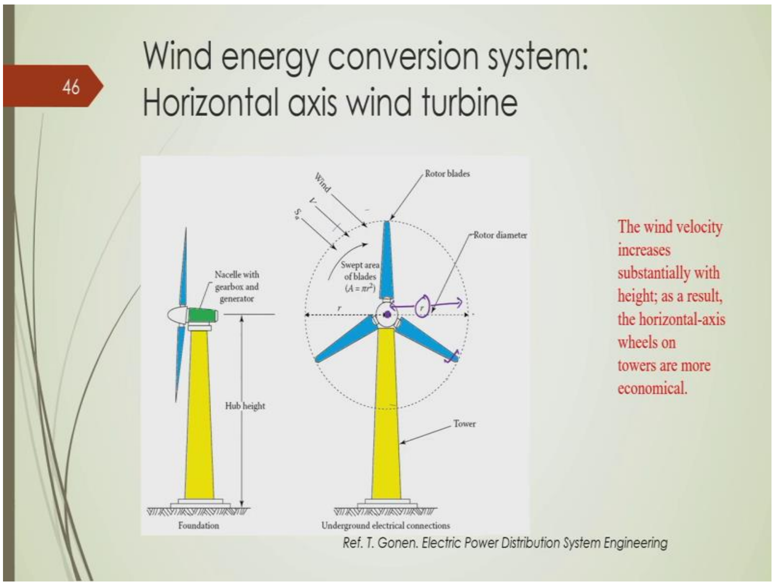

So, it is the, I can show you I can go back and show you. It is the area under this circle, suppose this typical 3 blade wind turbine, say, this is the center of the turbine or the swept of the turbine and suppose this is the radius ok r, which is almost equal to the length of the blade ok, length of a typical blade. So, if this is r, this is radius which is r and it forms a circular area then this area is called swept area, we discussed in the last lecture ok.

So, typically this power availability in wind depends upon this swept area and also it is proportional to the cube of the wind velocity, it is proportional to the cube of the wind velocity. So, power available in wind depends upon or it is proportional to the mass density of the air, the swept area and it is also proportional to the cube of the wind velocity ok. That does not mean that much of power we will get actually from this wind turbine. We have several other factors that I will come to that.

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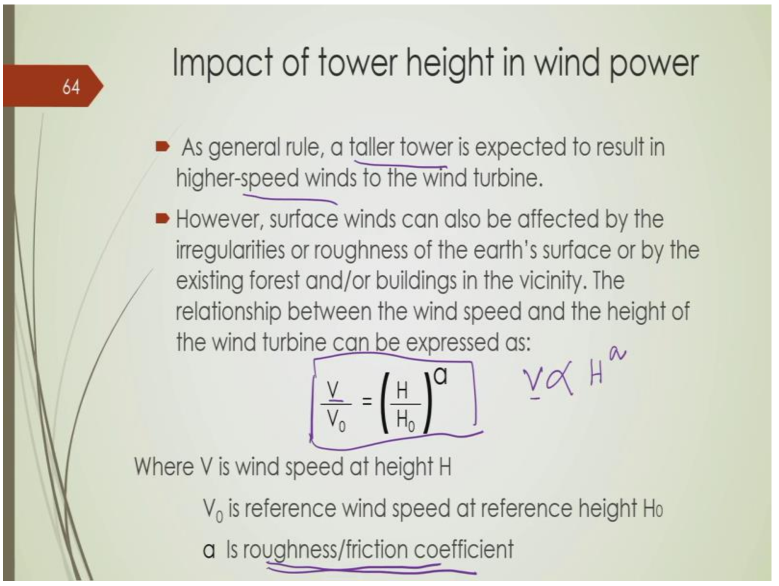

Now, before I go to wind detail, the wind turbine characteristics one thing one needs to know that wind speed. So, you can see the most dominant factor here is the wind speed; basically, rho used to be fixed in a particular area and a it is also constant because for a particular turbine we cannot increase the swept area, it is design parameter and it for a particular wind turbine it used to be constant. So, this part is on, this part is constant ok.

So, only part only V is variable which is wind velocity. So, basically power available in wind is varying with the cube of the wind speed, that one should know. So, if wind speed increases power available to the wind increases cube of that ok.

So, of course, we need to know that what is the value of wind velocity in order to find out how much power can be available or how much power is available corresponding to a typical wind speed. So, wind speed also varies with the height of the tower. So, taller tower is expected to result in higher speed, wind speed ok.

So, relationship with this tower height and this wind velocity is given over here. So, you can see it is proportional to H to the power some constant, that is called roughness or friction coefficient. So, wind speed is typically varying proportional to this H to the power a, where a is roughness or friction coefficient. So, if you make a taller tower, you will expect you will; obviously, get a higher wind speed ok. So, therefore, you will be having more power available at that particular wind speed ok.

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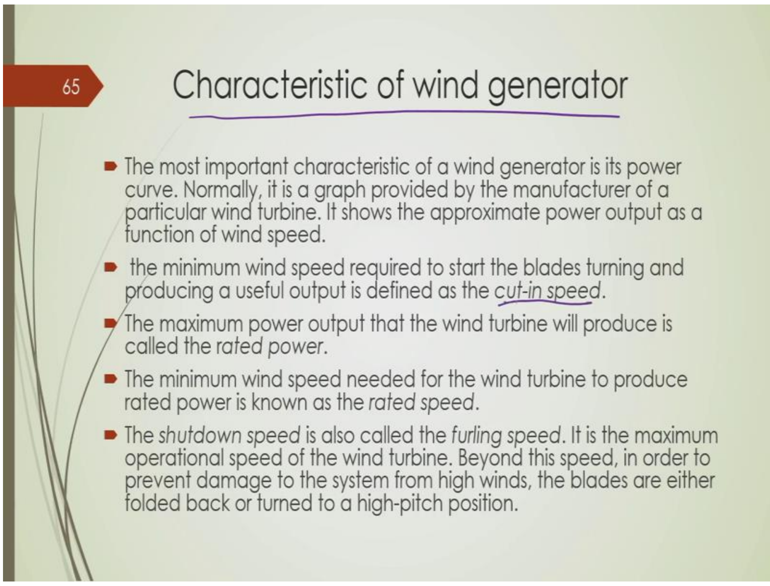

Now, this is the most important thing that I was talking about, the characteristics of a wind turbine, and for us, for a distribution system engineers or power system engineers we need to understand, how this power available in the wind varies with this velocity of the wind. And we cannot expect that we can run a wind turbine at any velocity at any wind velocity, because as you know like other electrical appliances or like other electrical generators the wind turbine generator set, we will have some rating.

So, it cannot produce energy beyond its rating. So, we need to know that how can or how much power we can get from a typical wind turbine.

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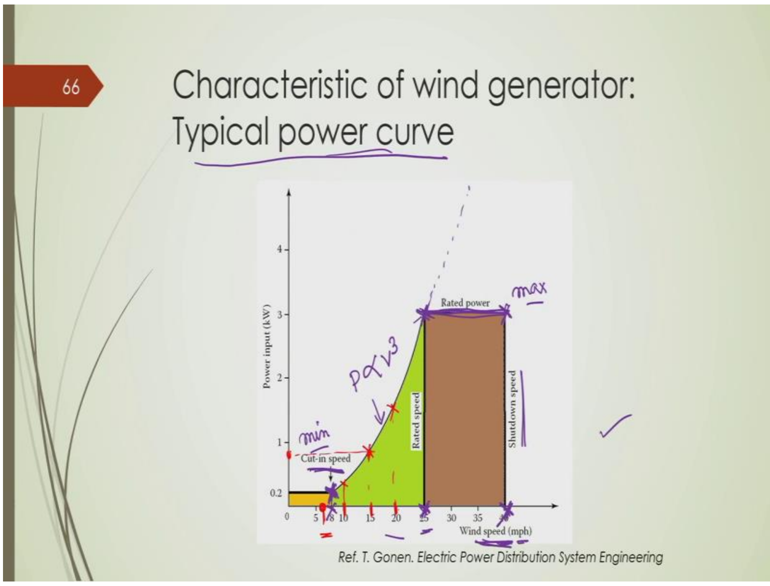

So, let me show you this typical power curve, this is called power curve which means that power out input versus this wind speed, power input versus this wind speed. Now, this gives you that there are some, there are some operating points, one is this operating point which is called cutting speed ok. So, this is the minimum speed at which this wind turbine would operate. So, below this cutting speed we cannot operate a wind turbine ok.

So, cutting speed is the minimum wind speed to operate a wind turbine ok and there is another operating point that corresponds to the rated wind speed, which gives you the rated power of this wind turbine. So, this is another operating point and from this cutting spin to the rated speed this production of power in a typical wind turbine will vary according to this cube of this wind velocity. Because here this characteristic is similar to P varying cube of the wind speed ok.

And there is another operating point that is called shutdown speed or falling speed, this is the maximum wind speed at which we can operate a typical wind turbine. So, there is a minimum speed, so cut in speed is minimum speed, minimum speed and cut off shutdown speed or falling speed is the maximum speed ok.

So, these speeds are marked over this horizontal axis, that is x axis. So, here for this particular curve, you can see 8 mile per hour is the cutting speed for this wind turbine; that means, that below that particular speed we cannot operate the wind turbine ok.

And 40 mile per hour is basically the wind speed that is the shutdown speed. So, if with wind speed becomes higher than this shutdown speed we also cannot operate. So, below this cutting speed and above this shutdown speed we cannot operate this wind turbine ok, because of its design construction, because of this characteristic.

And here, 25 miles per hour is the rated speed for this wind turbine. So, from this rated speed to shutdown speed, even if that power available of the wind will be higher than that, but we will operate this wind turbine at this rated power and that is a flat top characteristic.

So, beyond this, you know, rated speed up to this shutdown speed, we will operate this wind turbine at its rated power because it cannot provide you any amount of power, even if whatever amount of power is available in the wind ok. So, beyond this rated speed even if the power availability in the wind is higher. So, this wind turbine is capable of providing you its rated power ok.

So, whatever I mentioned over is mentioned here, so cut-in speed is basically the minimum allowable wind speed at which this wind turbine will operate and rated speed is, rated power wind power is as per the rating of the turbine which is designed and also rated speed corresponds to the rated power of this wind turbine.

That means, at what wind speed this turbine is generating or wind turbine is generating the rated power that is called rated speed, and the shutdown speed is the maximum allowable speed at which we can operate the turbine.

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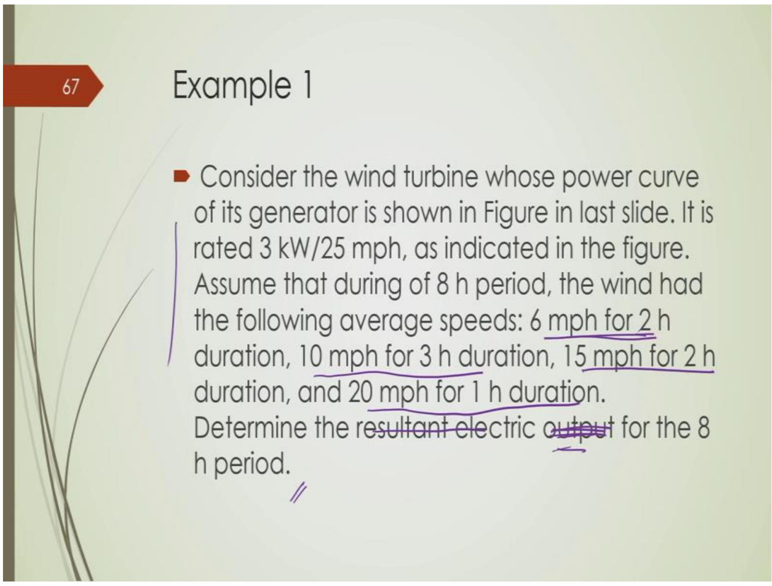

Now, we have an example; so this example is very simple and it is based upon this figure shown over this slide, that we have different wind speeds in different duration of a day ok. So, for 2 hours the wind speed is 6 mile per hour, for 3 hours wind speed is 10 mile per hour and for 2 hours wind speed is 15 mile per hour and for 1 hour the wind speed is 20 mile per hour.

Now, you have to determine that how much energy that is not extractable, but that is available in the wind ok, that is not that is cannot be resultant electrical output this is not this electrical output, but this is basically that much of wind speed is available, that much of power is available in the wind.

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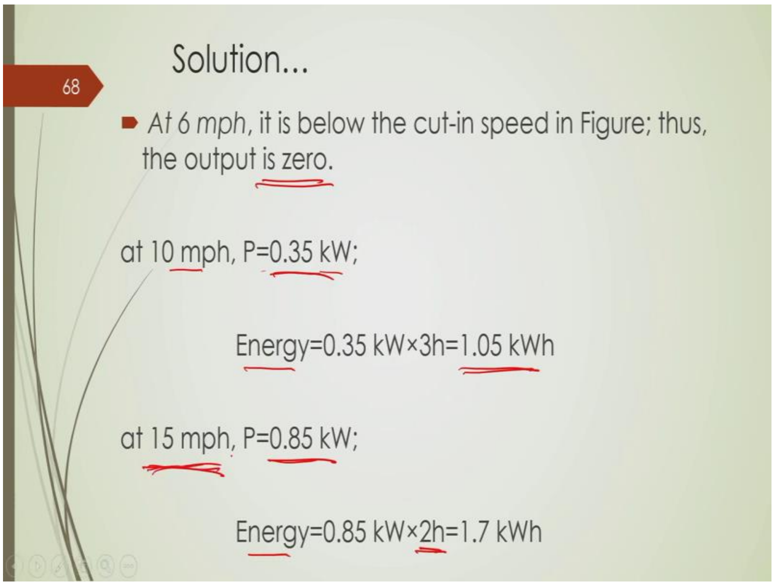

So, you can find out in different operating condition, one is 6 mile per hour, 15 mile per hour, 10 mile per hour and 20 mile per hour. So, corresponding to these values you can find out. So, this is 6 mile per hour and then next is 10 mile per hour, then next is 15 mile per hour and another is 20 mile per hour. So, corresponding to this, you can find out that how much power is available in the wind ok.

At 6 mile per hour since it is less than the cut in speed that is 8 mile per hour we cannot generate any power, but corresponding to 10, 15 and 20 mile per hour we can generate power corresponding to these values of power ok. Now, so we find out that at 6 mile per hour this generation would be 0, at 10 mile per hour it is 0.35 kilowatt.

So, since the duration or for this particular wind speed of 3 hour, total energy that is available in the wind is that much. Similarly, at 15 mile per hour that much; that means, corresponding to 15 mile per hour, you can get this much of power available in the wind, and accordingly you can find out that how much energy is available by multiplying the duration of the day on which you have that much of wind velocity.

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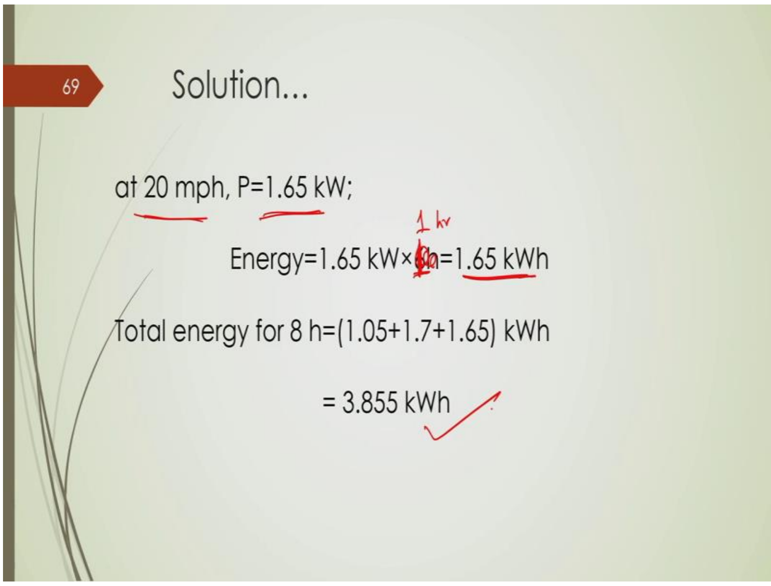

And similar to that, at 20 mile per hour, when power availability is that much and duration is of 1 hour, so this gives is that much. So, this is what the total energy for this 8 hour.

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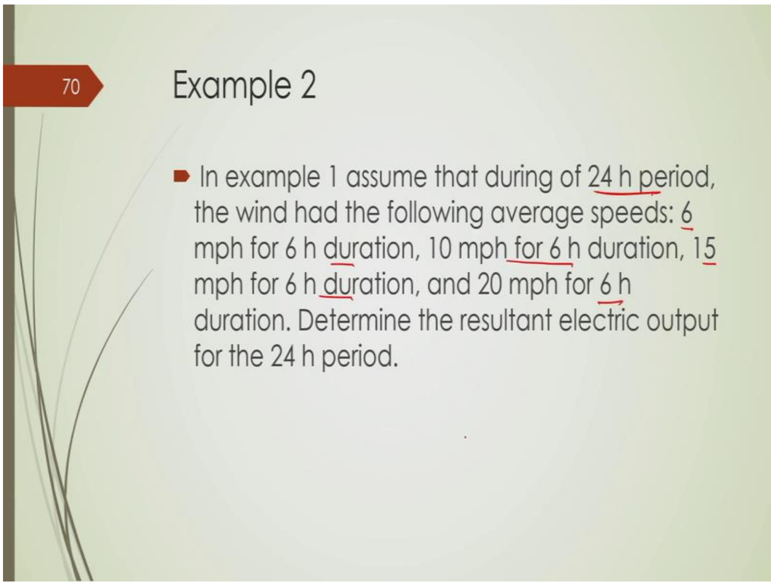

Now, similar problem is there, where this duration is 24 hours and this wind speeds are given in different duration; 6 mile per hour per 6-hour, 10 mile per hour for 6-hour, 15 mile per hour per 6-hour, and 20 mile per hour per 6-hour. We are supposed to determine the total energy available in the wind.

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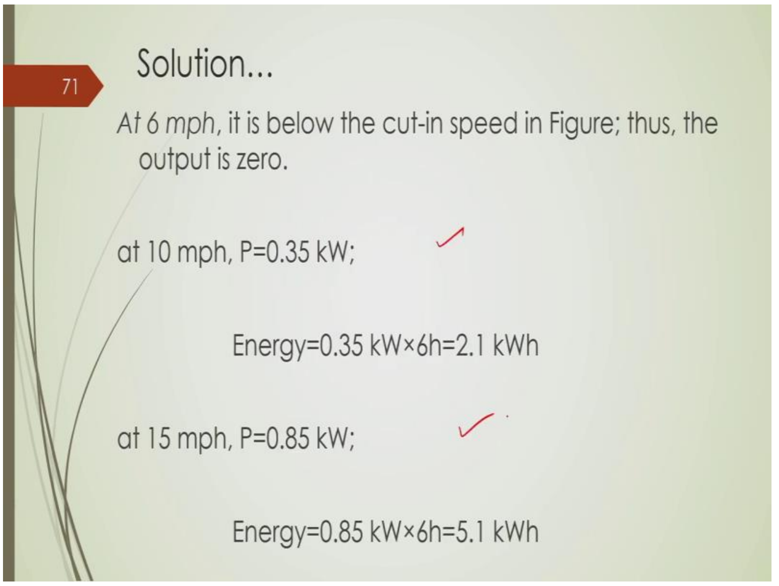

So, that is eventually can be done by similar way ok.

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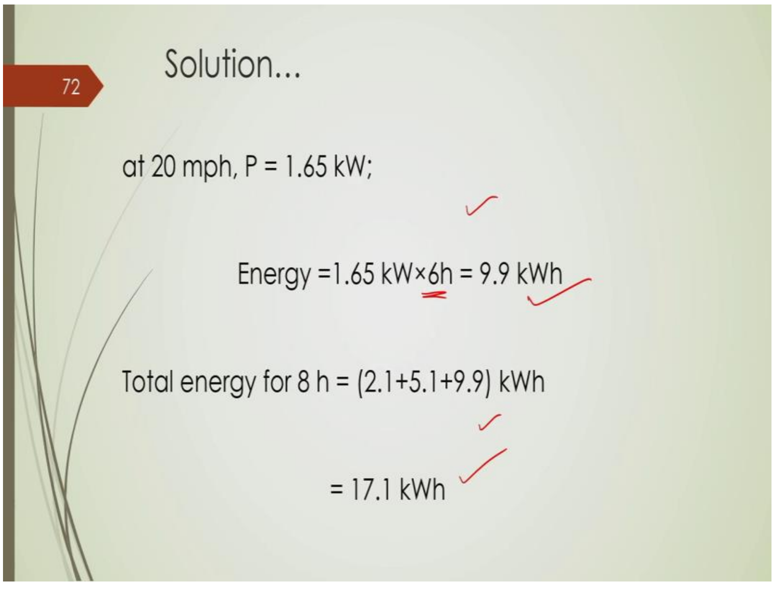

So, only duration is changing, so accordingly you multiply it with 6.

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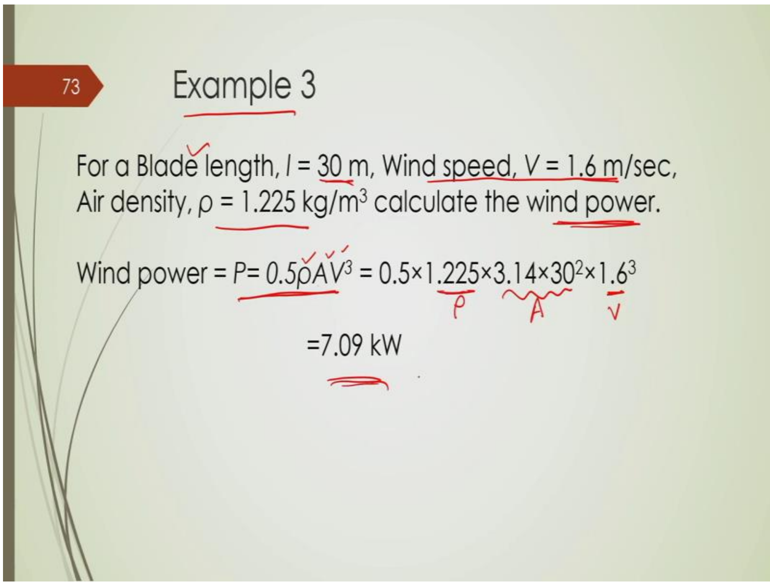

And you will get, if you sum up this, all this energy, you will get total energy available in the wind in a particular day ok. Now, there is another example where the parameters are given. One is blade length, that is 30 meters, that is wind turbine blade length; another is wind speed that is given as 1.6 meter per second, then air density is also given. You are supposed to calculate the wind power or power available in the wind ok.

So, you simply apply this expression where values of rho, A and V are given to you. So, rho is, you can directly put this value, A is the swept area that is pi A multiplied by r square, r is the equal to almost blade length. So, which is, this is our A or swept area, this is rho and this is the velocity ok. So, if you put this will come to some value, that is 7.09 kilowatt. So, (Refer Time 16:17) this is very very easy and straight forward problem ok.

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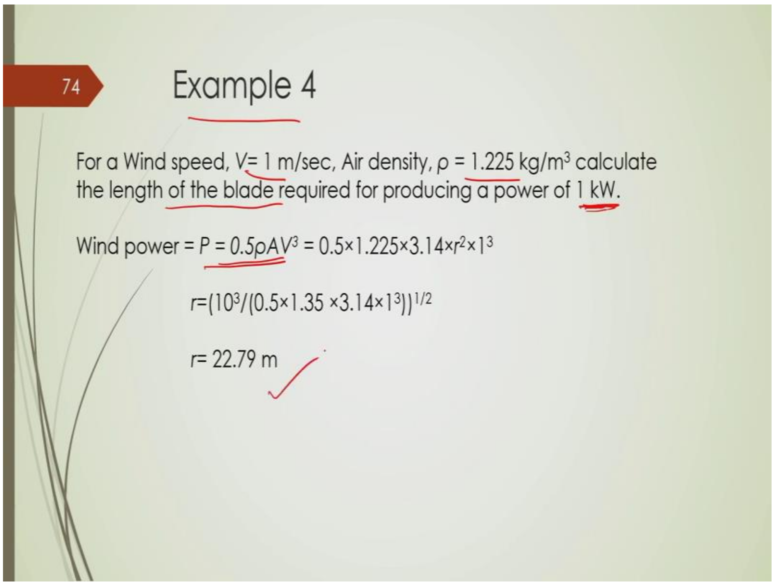

So, similar to that we have this example 4, where this velocity of the wind turbine is given, air density is also given, then you have been asked to determine that what should be the length of the blade so that you can produce one kilowatt of power. Again, you apply this expression here, you know P is known to as 1 kilowatt, rho and V are known to us. So, you can find out what should be the A and accordingly what should be r, that is coming out to be some value.

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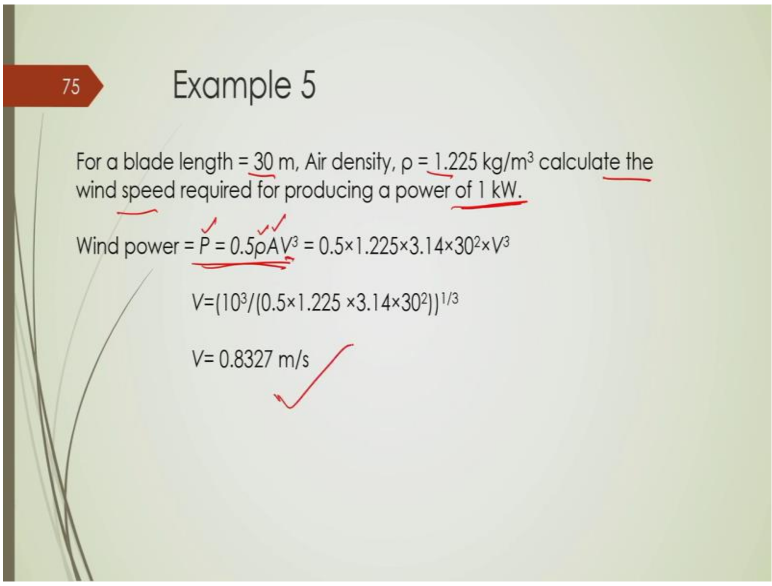

Similarly, here this blade length is given, air density is given we have to find out that how what should be the wind speed so that we can get 1 kilowatt of power or so that this 1 kilowatt of power is available in the wind. So, you can do in the similar way. I can, you can apply this expression, where P is known to us, rho is known to us, and A is known to us, we are supposed to determine V that is wind speed. So, you can get some value.

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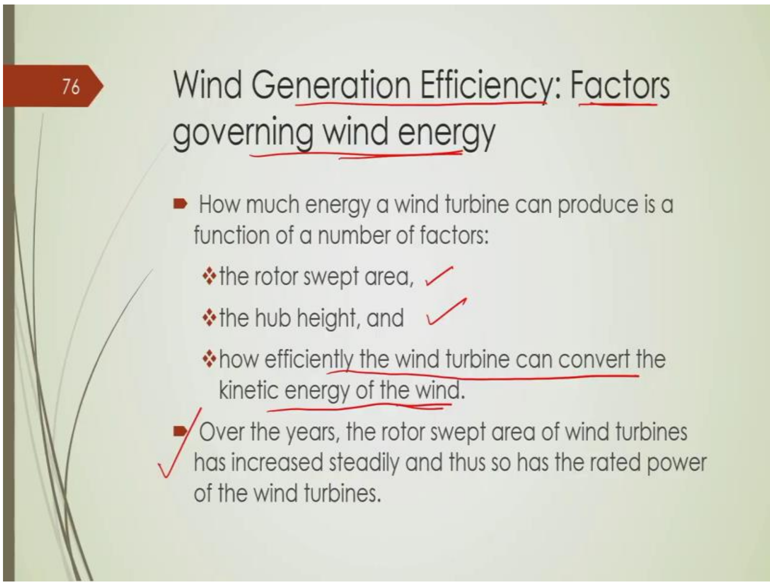

Now, that is the most important point that I am trying to make that, this wind power is not the power output of a wind turbine. That is basically power available in the wind and we have some factors to be multiplied in order to find out the output of the wind turbine. So, whatever this expression you have seen, that P is equal to half rho a V cube, that expression gives you the power availability in the wind, but that does not give you the power output of the interval ok.

So, this power available in the wind cannot be 100 percent extractable. So, we cannot get 100 percent extraction of the power availability in the wind. So, we have to multiply it with, multiply this with some factors in order to find out the power output of the wind turbine. Now, here we should know that how you, what are the factors that govern in wind energy generation, and also, what are the factors on which this efficiency of the wind energy conversion system depends ok.

Or of course, you have seen that all the parameters, rotor swept area a, height of the tower on which this velocity will depend, that is an important factor. And also, the A P how efficiently the wind turbine can convert this power, kinetic energy of the wind or power available in the wind to the electrical power, that is also an important factor ok. And you know, that over the years this designer, who designs this wind energy conversion system, they design a very tall wind turbine. So, having a very longer wind blade which gives you higher swept area and from which higher amount of power can be extractable ok.

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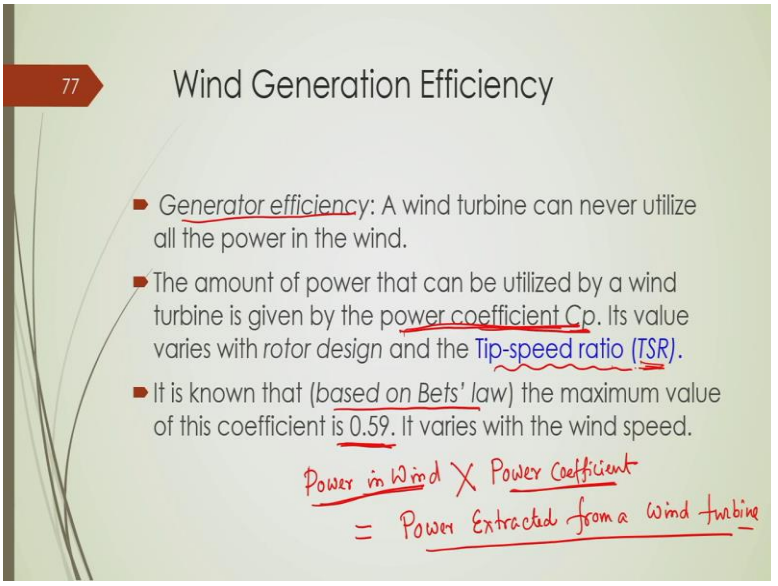

So, those things are there, but apart from that we have one another different parameter, one is called efficiency of the generator and also efficiency of all stakeholder, who are there in this wind energy conversion system. One is called efficiency of the gear box, which is used to change this rotation, rotational speed of the wind turbine to the speed of the rotational speed of this wind turbine blade to the speed of the generator, at which we would like to generate.

So, we have a gear box, so its efficiency also needs to be multiplied and this generator efficiency needs to be multiplied and wind turbine efficiency needs to be multiplied in order to get the power output that from this wind energy conversion system. But apart from that, there is another factor, that is called power coefficient ok. So, that power coefficient also plays an important role.

Now, what do you mean by this power coefficient? This power coefficient I think is discussed over here; this is usually power coefficient that is discussed over here. So, this power coefficient means how much power can be make, how much power available in the wind can be convertible to the mechanical power ok.

So, if you multiply power in wind with this power coefficient that is Cp, power coefficient then whatever you will get that will be power extracted from a wind turbine ok. So, power available in the wind needs to be multiplied with this power coefficient Cp, in order to get that how much power we can extract from a typical wind turbine ok. And this power coefficient, it varies with several other factors, one is called tip to speed ratio, tip speed ratio, I will come to that what is tip-speed ratio.

Another is of course, the pitch of that particular blade and these two control actions should be there, in order to maximize the power extraction, one is called pitch control, another is called TSR control ok.

So, this pitch control is basically controlling the pitch of the blade so that you can make this orientation of the blade to an optimal angle of attack to the wind ok and people are working on this pitch control. And also, TSR control I will come to that, I will show you a characteristic where this Cp is, how the Cp is varying with this TSR ok.

So, depending upon that, we can also have an optimum value of TSR, corresponding to a maximum value of Cp ok and this maximum value of this power coefficient is determined from this bets law and it is near 2.59 so; that means, in an ideal case only 59 percent power can be extracted, at max 59 percent power can be extracted from a typical wind turbine ok.

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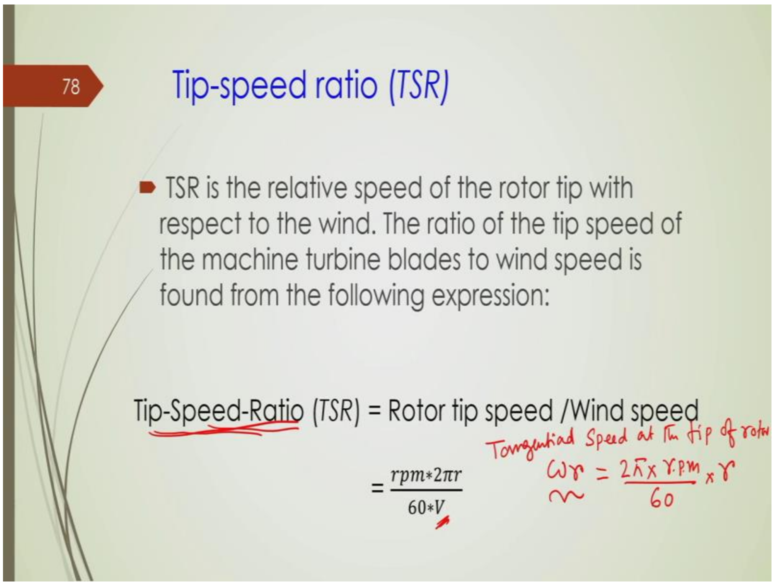

So, this is what, this tip speed, definition of tip speed ratio, it is the ratio of the tangential speed of this blade of the rotor, of wind turbine to this wind speed. So, what is; it is the ratio of tangential speed of the blade of the rotor to the wind speed. So, tangential speed of this tip of the rotor is nothing but omega multiplied by r as you know. So, omega can be replaced by this 2 pi multiplied by this speed in rpm divided by 60 and multiplied by r. So, this gives you the tangential speed, tangential speed at the tip of the rotor ok.

So, this if you divide by, with this actual speed of the wind then whatever you will get that is tip to speed ratio ok, this is an important factor on which the efficiency on which the power coefficient will vary.

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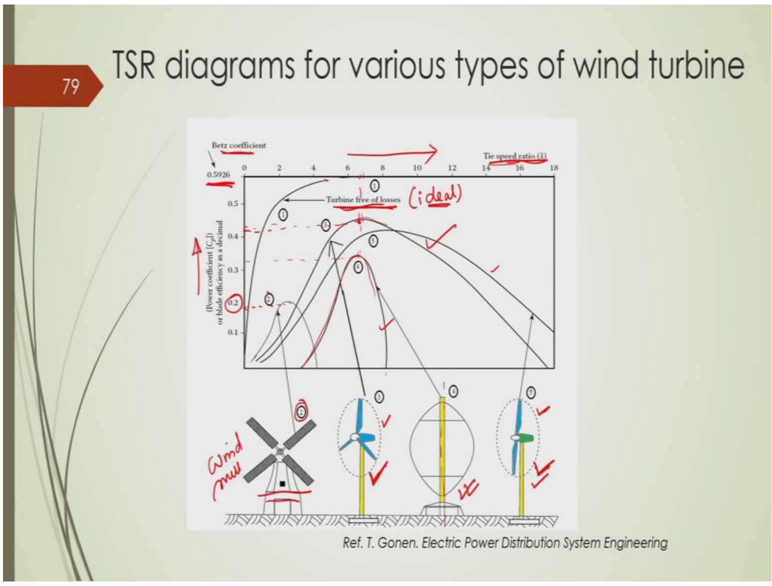

Now, how this power coefficient will vary with this tip speed ratio, which is represented often by lambda, that is lambda. So, here you can see this is how tip speed ratio is varying and this is how power coefficient is varying ok. And there are 5 different cases mentioned; one is turbine free of losses that is ideal case, that is ideal case; so that is a hypothetical case does not exist in practical form.

So, in that case this, you know, if you increase this tip speed ratio, power coefficient will increase, but up to a certain point it will stop. That is as per this bets coefficient that value is 0.5926, that is maximum amount of power or maximum fractional power extractable from this wind turbine ok.

So, this is hypothetical case, but this case 2, it is a typically you know older form of this wind turbine, which is used in wind mill, wind mill long time ago. So, this wind mill, this tip speed ratio versus this power coefficient characteristic is something like that and which gives you maximum value of power coefficient close to 0.2; that means, only 20 percent of power can be extracted from this wind mill ok.

This is basically, these two are basically, two horizontal axis wind turbine; two horizontal axis wind turbine, one is having three blades, another is having two blades. And these are the types which are used in the present day, one is called horizontal axis three blade wind turbine, another is called horizontal axis two blade wind turbine. So, they are typical Cp versus lambda characteristic, that is power coefficient versus tip speed characteristics is shown over here.

So, one is this number three characteristics and another is number 5 characteristics, both are close to each other where you can get maximum value of power coefficient correspond to a given value of tip speed and that is something similar closer to 6 to 8. And you know maximum value of Cp is around 0.4, that is 40 percent of power at max can be extractable ok.

And this number 4, this is a typical vertical axis wind turbine ok, this is a vertical axis wind turbine characteristic is given over here, where your maximum value of Cp is bit less, it is around 0.3, that is 30 percent of wind power can be extractable. And according to that tip speed max the value corresponding to this tip speed is also in between 6 and 8.

So, these characteristics will give you some idea that how can we control the operation of the wind turbine. And accordingly, we need to design a proper control approach so that we can extract this maximum power from the wind so that we can operate the wind turbine corresponding to the maximum value of power coefficient ok.

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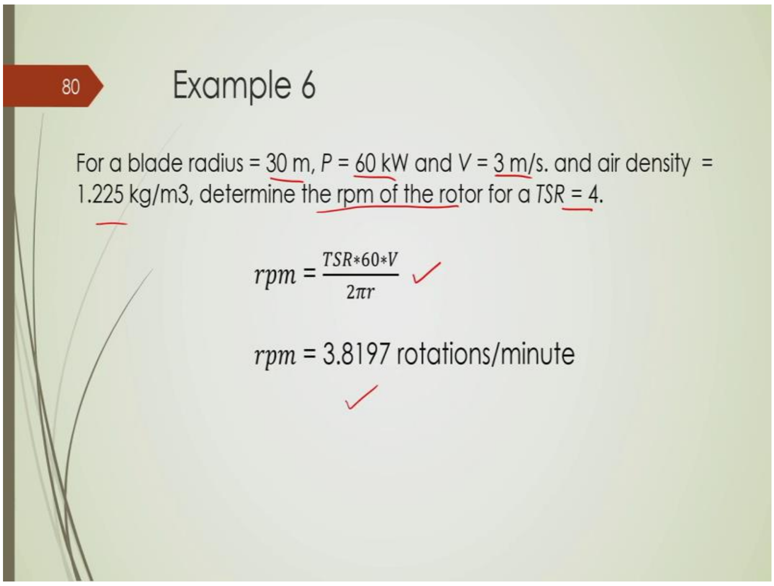

So, these are some examples where you can see that blade radius is given, power output is given, velocity is given, air density is given, TSR is given. So, you have to (Refer Time: 28:47) determine the rpm of the rotor. And similar way, this tip speed ratio expression that you have seen, it is also, you can find out with this TSR is nothing but tangential speed which is omega r divided by this wind speed. So, you can find out.

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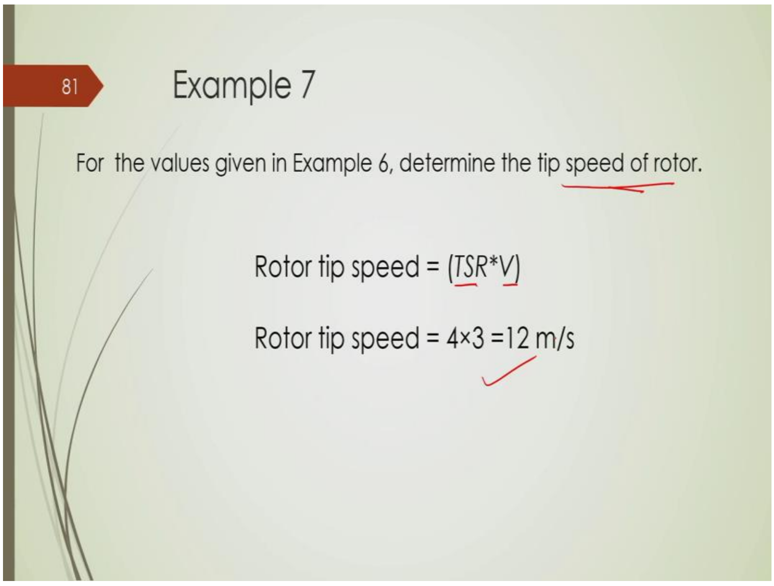

Similarly, here also you are supposed to determine that tip speed of the rotor, where TSR is given, wind velocity is given so you can easily determine.

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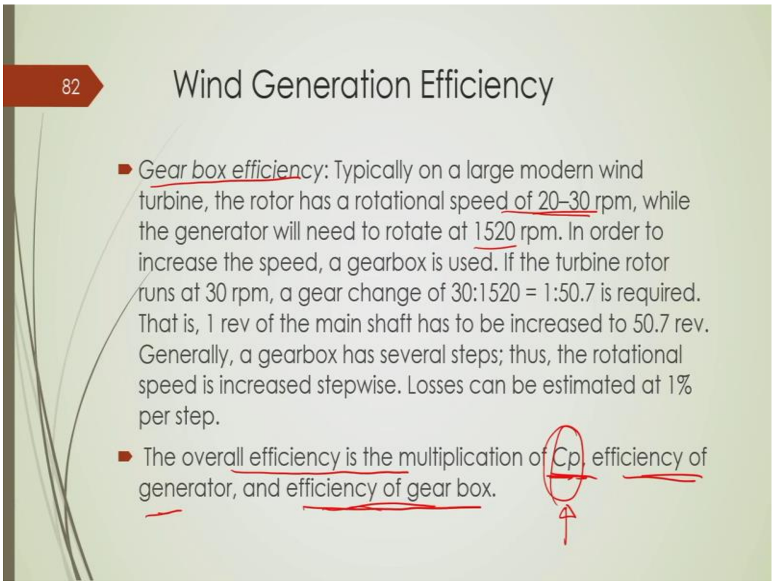

So, apart from this Cp, that is, power coefficient as I said, there are some factors which dominates the efficiency of the wind turbine or wind energy conversion system, one is called gearbox efficiency. And as I mentioned that why we require gearbox because you know rotor of the wind turbine typically rotates at a not a very high speed, only 20 to 30 rpm and the generator needs the rotation of somewhat closer to 1500 rpm. So, you have to change the speed 30 rpm to 15, close to 1500 rpm and that speed change is possible by using gearbox.

So, we have to have a gearbox in a typical wind turbine and the overall efficiency of power, wind turbine also depends upon the gearbox efficiency ok. So, overall efficiency of the wind energy conversion system is typically multiplication of power coefficient, efficiency of the generator and efficiency of the gear box ok, roughly on these three parameters. So, overall efficiency of the wind energy conversion system is C multiplication of Cp, multiplication of generator, multiplication of gear box ok.

Where we can control this Cp by varying or by orienting this wind turbine correspond to different values of pitch angle and different values of TSR ok. And there are some, you know, research going on, how can we control this wind turbine operation corresponding to a maximum value of power coefficient ok, so that we can maximize the power extraction.

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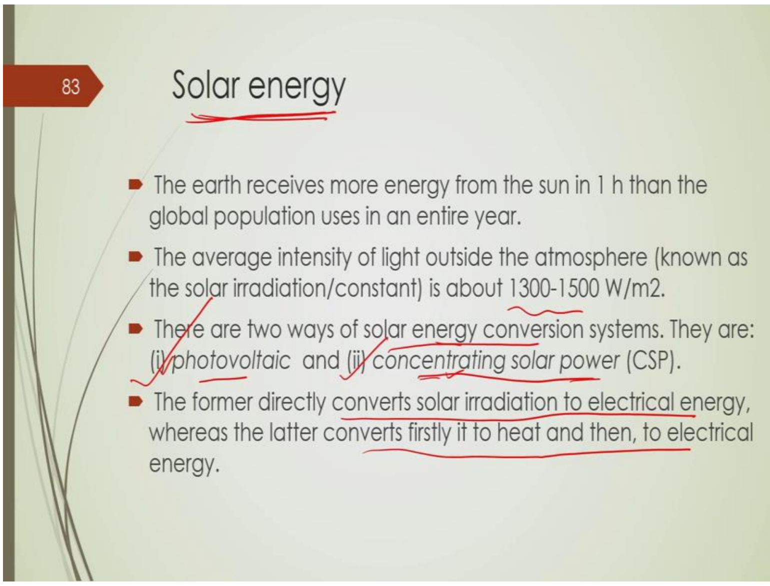

Now, next another important renewable energy generation systems, I will talk about that is called solar energy ok and as you know it is a top form of renewable energy, which will not be depleted with time and we have typically average intensity of the light around 1300 to 1500 watt per meter square. And we have two forms of solar energy conversion system, that is photovoltaic and concentrating solar plant. So, photovoltaic use the intensity of the light and concentrating solar power utilize the heat of the solar irradiation ok.

So, the former directly converts the solar irradiation to electrical energy whereas, these concentrating solar plants, CSP converts to heat and then electrical energy ok. Mostly we know that photovoltaic type of solar energy conversion system is used in power generation and it is extremely extensively used in power generation nowadays ok.

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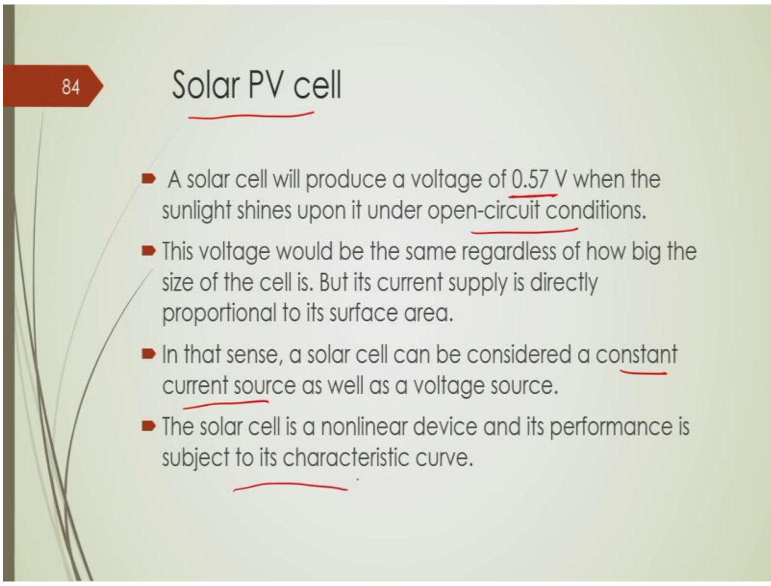

So, in a in a typical photovoltaic solar cell, it produces only a DC voltage of 0.57 ok, and it is open circuit voltage, I will show you the typical voltage and current characteristics for a typical solar cell. In a typical solar cell, it can be considered as a constant current source ok. And it is a non-linear device, its performance depends upon the characteristic curve.

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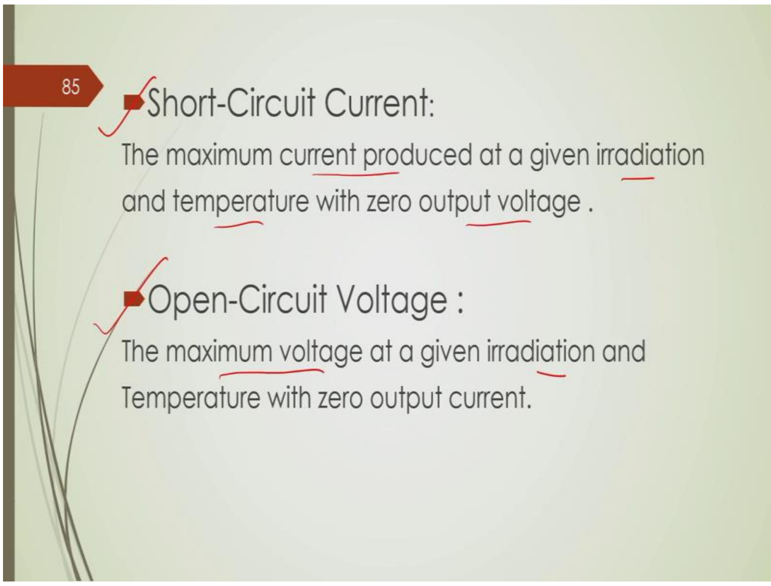

So, before I show you this characteristics curve, we have different definitions that one needs to know. One is called short circuit current: the short circuit current is maximum current produced at a given irradiation and temperature with 0 output voltage. Short circuit means output voltage is 0 and it gives you maximum current. And open circuit voltage means: it is maximum voltage corresponding to 0 current corresponds to a given value of irradiation and temperature.

In fact, similar to this wind energy conversion system, where this power available in the wind typically varies with the wind speed, here also in photovoltaic system the generation of solar cell depends upon the temperature and solar irradiation of a particular instant of time.

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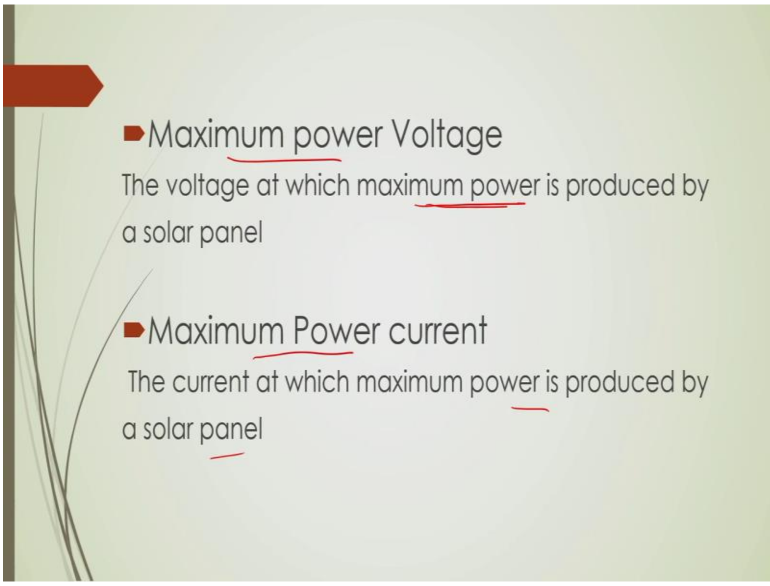

Now, there is another definition called maximum power voltage, which corresponds to the maximum power produced by a solar panel. So, voltage and current corresponding to maximum power, it is a matter of interest and maximum power current at which maximum power is produced by a current at which maximum power is produced by a solar panel. So, maximum power voltage, maximum power current corresponds to the maximum power produced by a solar panel.

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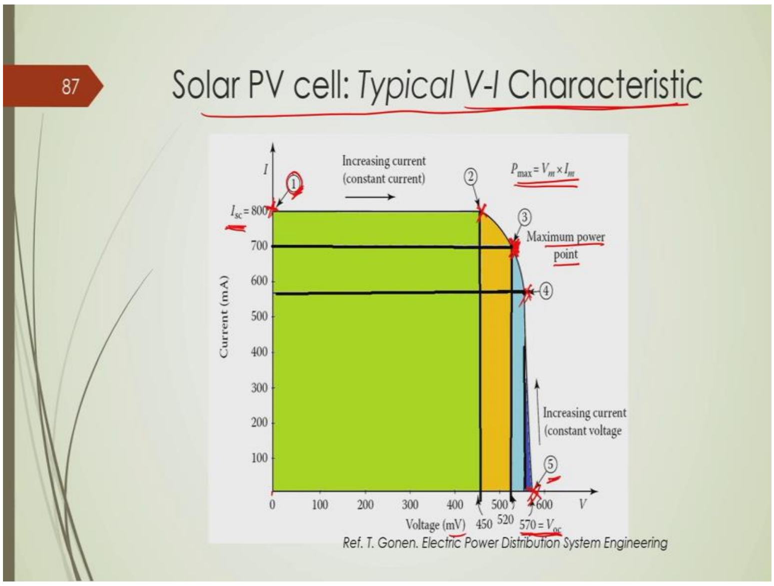

And this is a typical volt ampere characteristics V-I characteristics of a typical solar cell. As you can see, there are different operating points one is marked with 1, one is marked with 2, one is marked with 3, another is 4, another is 5, ok. So, operating point 1 correspond to maximum current ok at 0 voltage, so it is of course short circuit current, I sc ok. And operating point 5 corresponds to maximum voltage with 0 current which is open circuit voltage or V oc that is given as here 570 milli volt ok.

And operating point 2, 3, 4; at 3 typical operating points in which you can see at operating point 3, corresponds to maximum power which means that if you multiply this voltage and current it gives the maximum value of power ok. And that is also a point of interest to the researcher and also to the people who devised the control of a solar cell or solar panel ok. And we wish to operate the solar set corresponding to this maximum power point and this process is called maximum power point tracking ok.

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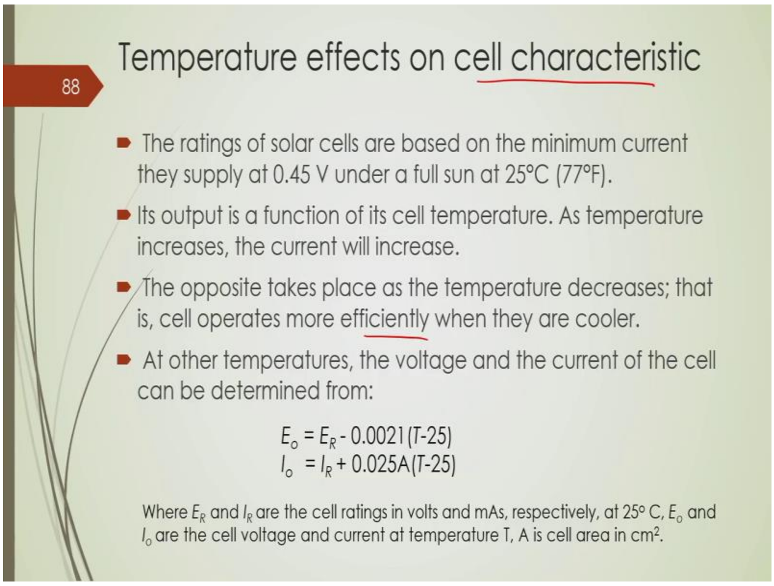

So, as I said, a typical voltage in a solar cell depends upon the temperature as well as solar irradiation. So, in fact, solar cell generation will vary with these different seasons, in winter and in summer there will be different ambient temperature, accordingly the solar generation would also vary and also it depends upon the solar irradiation ok.

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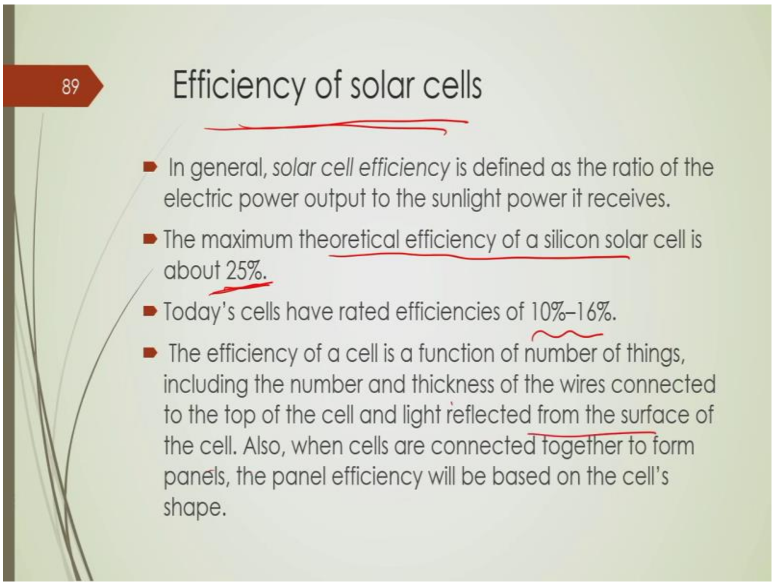

Now, the efficiency of the solar cell is again the matter of interest to us, but we know that maximum theoretical efficiency of a solar cell is only around 20 to 25 percent ok. So, this power density of this solar cell is very poor ok, and this is the maximum theoretical value, but actual efficiency is only 10 to 15 percent ok.

And the efficiency of a solar cell is typically a function of few things, one is this particular material is used to build that, another is thickness of the wire connected to the top of the cell, light reflected from the surface to the cell etcetera ok.

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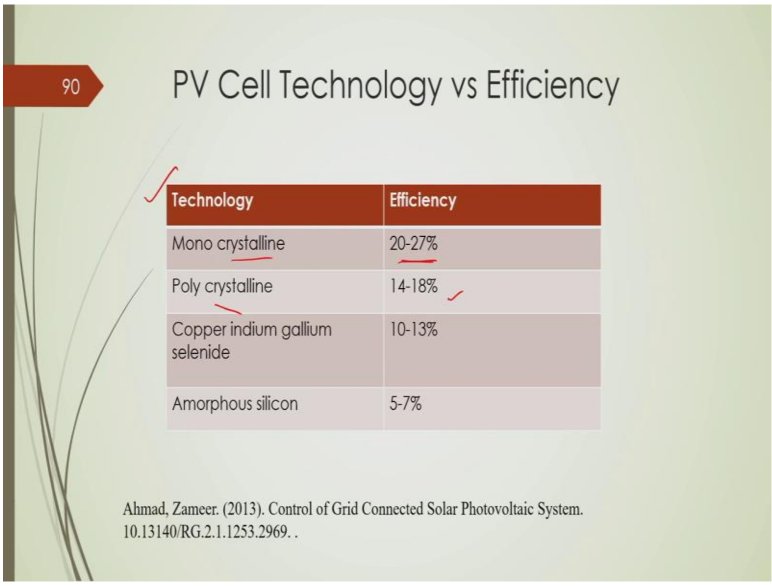

And based upon that we have different types of solar PV cell and their efficiencies are given, mono crystalline solar cell having typical efficiency 20-27 percent, poly crystalline is 14 to 18 percent and so on ok. So, there are different types of solar cell and accordingly the efficiency will also vary.

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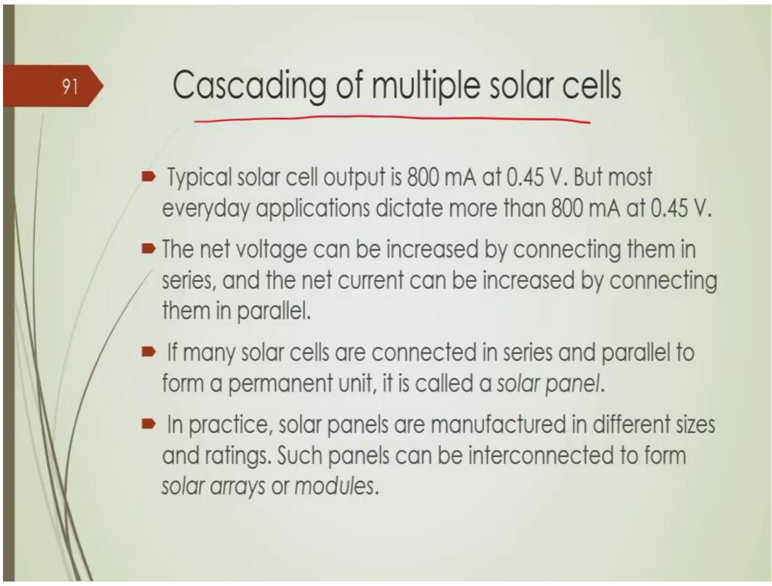

Now, as we know that we need to cascade because one typical solar cell will give you only a fractional voltage lesser than once. But in order to use them for typical applications in different, for a different point of a network or a different, for different customers we need to have a cascaded form of the solar cell and that cascading is done in order to achieve a desired value of voltage and in order to achieve desired amount of power ok.

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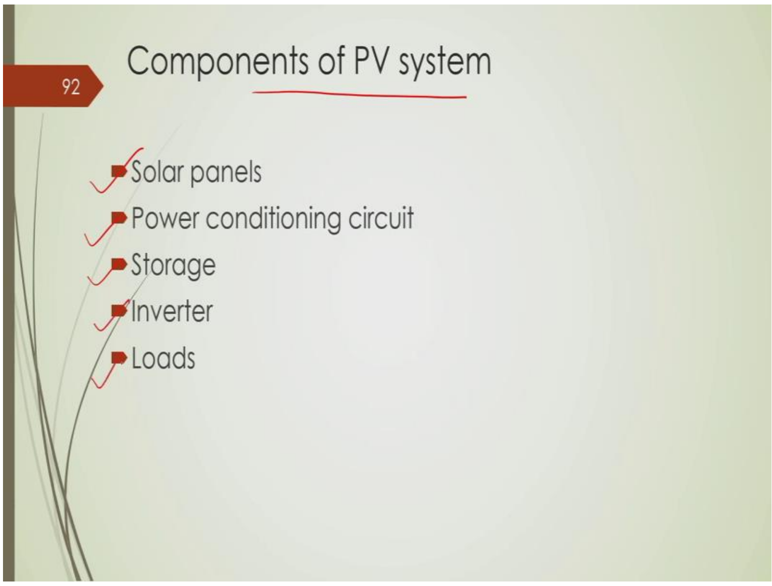

So, with a typical example that would be clear. But in typical photovoltaic system, we also have different other system along with the solar panel. One is called power conditioning circuit, storage, storage is required particularly if it is operated in isolated condition, without this connection with the grid, also inverters to convert this DC to AC and loads which is of course there.

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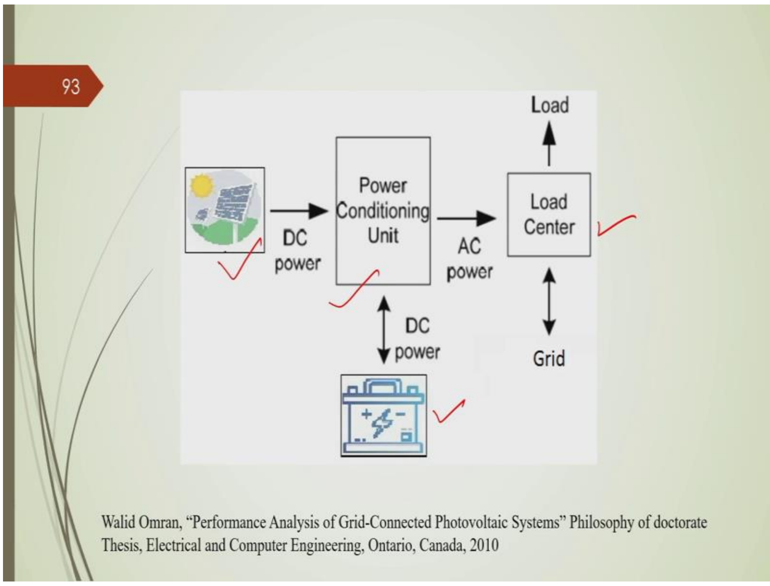

So, this is a typical, you know solar PV conversion system as a whole, which includes this solar cell, which includes power conditioning unit which includes this, you know inside power conditioning unit to converter is a, inverter is there in order to connect with the load ok. Also, this storage is an optional option which is required sometimes to store the surplus energy and to discharge when there is deficit energy ok.

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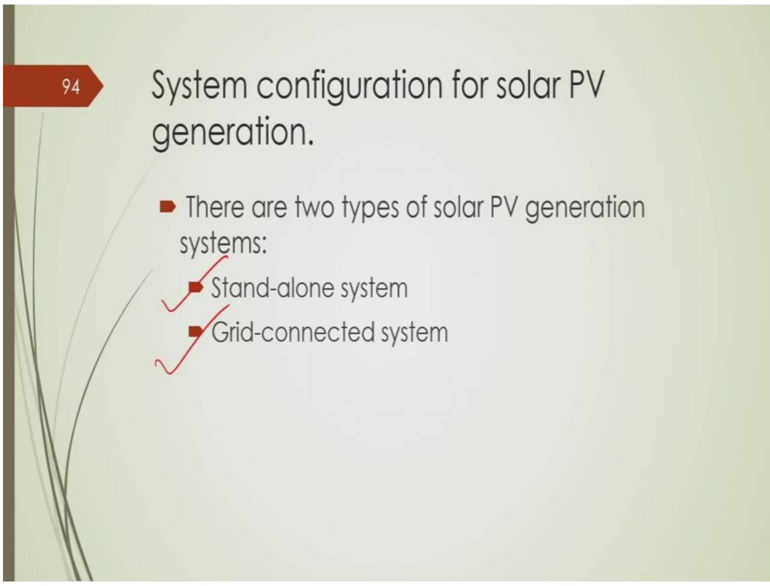

So, there are two modes of operation as we know, one is stand-alone operation, another is grid-connected operation. In standalone operation it is not connected to the grid and in grid connected operation of course, it is connected to the grid.

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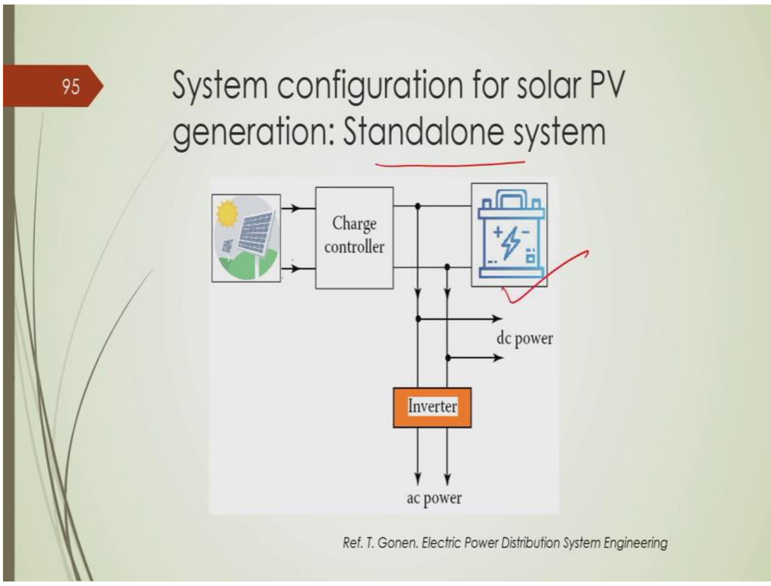

So, standalone operation particularly needs this storage.

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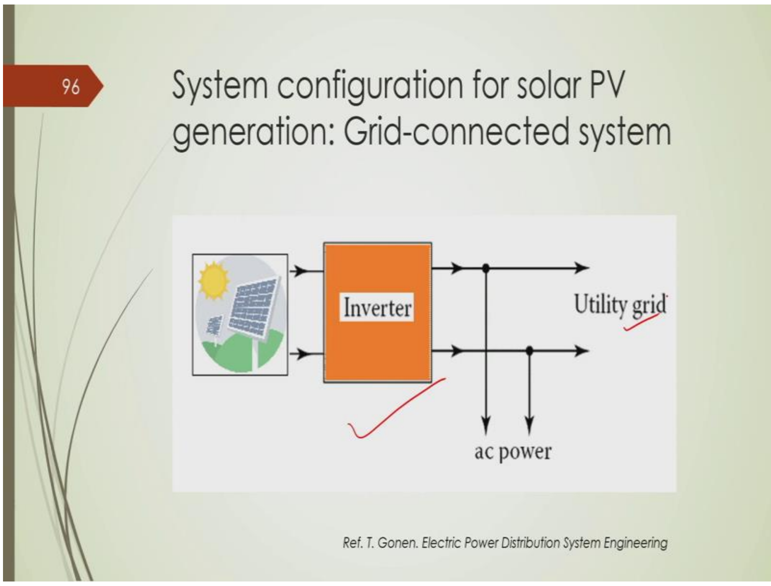

And grid connected mode does not need any storage, it can be directly connected to the grid and maximum and mismatch power that is surplus power or deficit power would be sent to the grid or to be imported to from the grid.

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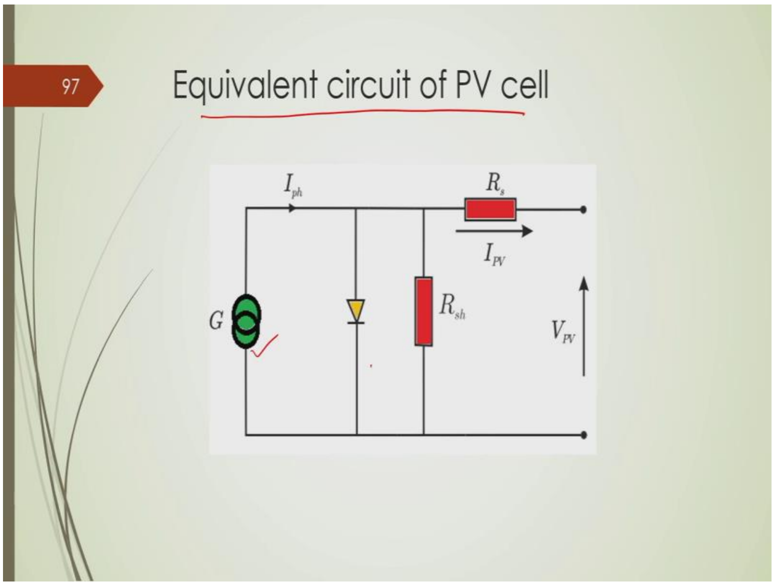

This is the equivalence electrical circuit form of this PV cell, it gives a current source, some diode and some resistances. This is required to devise the control of the solar PV and in order to do the further research on solar sensor.

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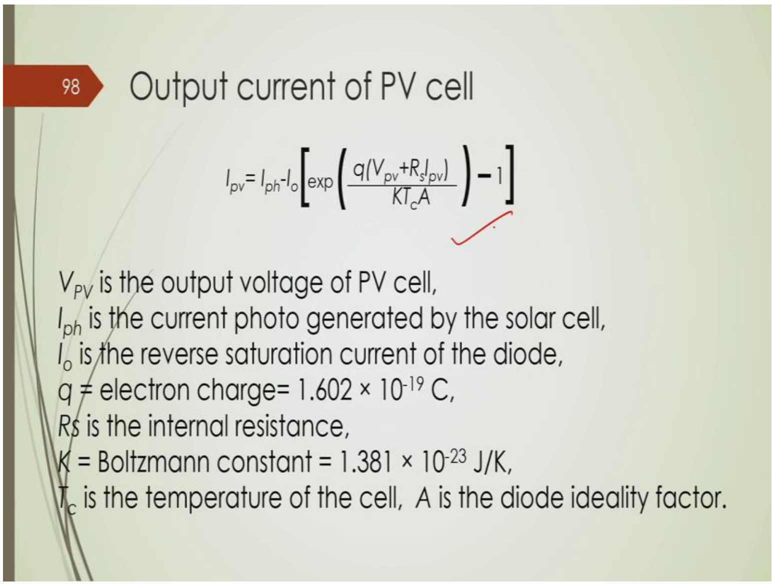

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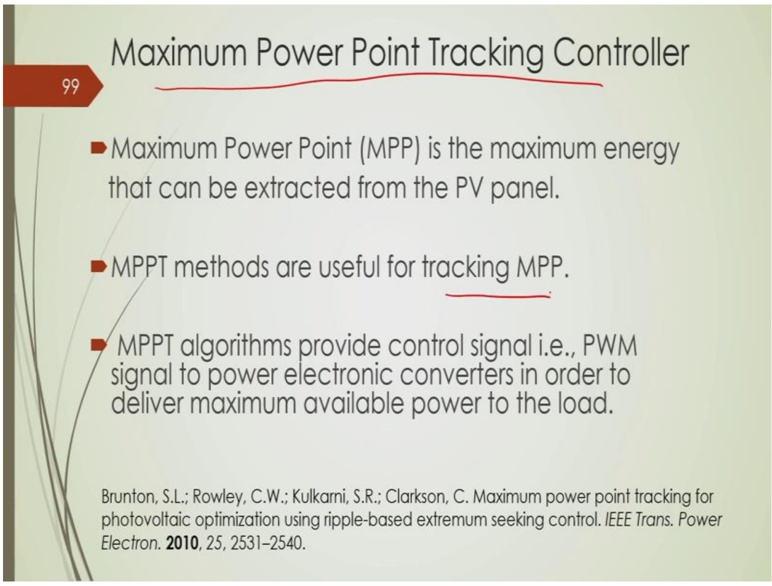

I am just keeping on, this is a typical output current characteristics of PV cell, and this is the point which I was trying to mention one, that is called maximum power point tracking, which means that where we intend to operate any solar PV conversion system to its maximum power point correspond to this maximum value of power from here, from which we get. And there are many approaches to track this maximum power point ok.

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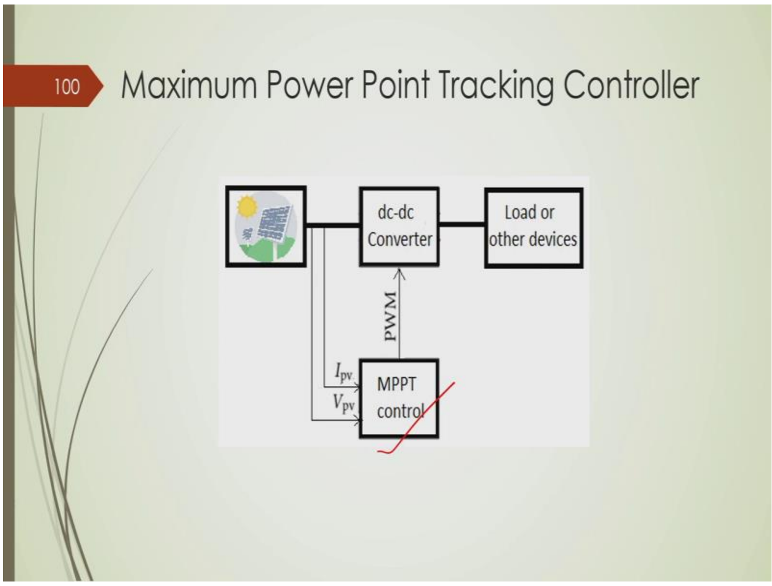

In fact, this is an area of research and people do use many types of MPPT control, MPPT stands for Maximum Power Point Tracking control so that we can always operate the solar PV system to its maximum power point ok.

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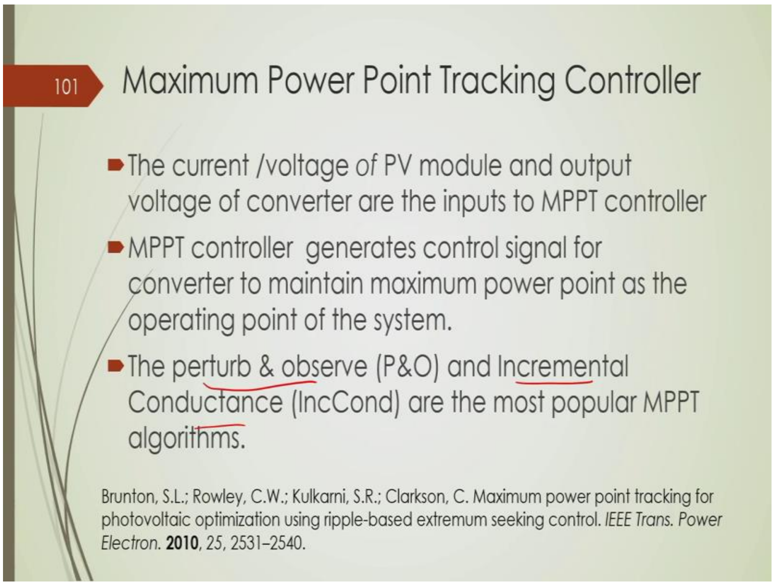

There are some typical MPPT techniques available, one is called perturb and observe technique, another is called incremental conductance technique, there are many other techniques as well which typically, which are typically employed to operate the solar cell to it maximum power ok.

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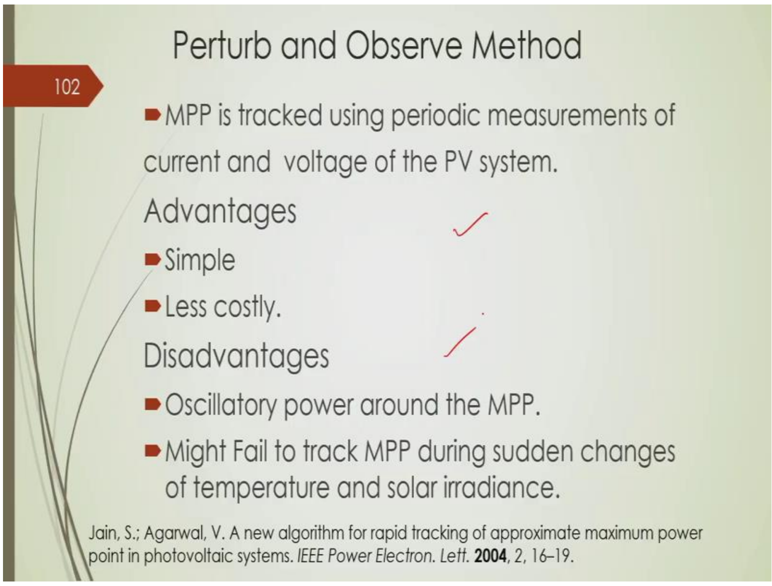

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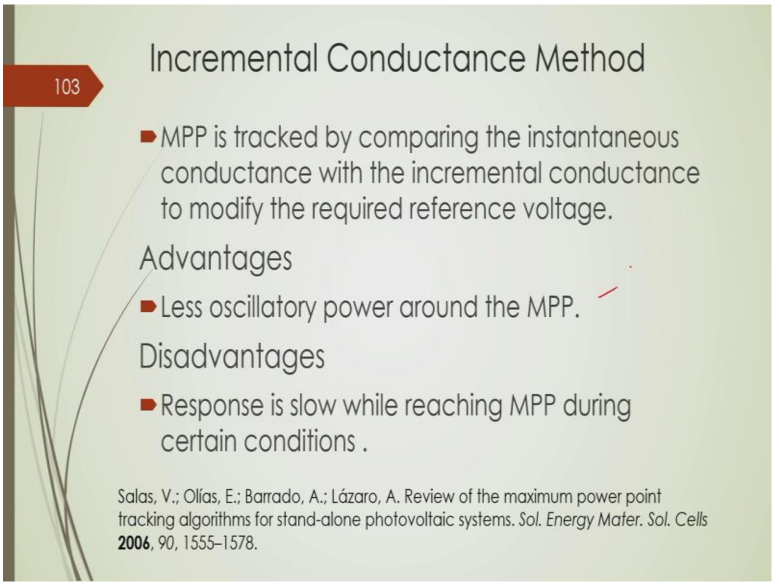

Some advantage, disadvantages are there in both the methods.

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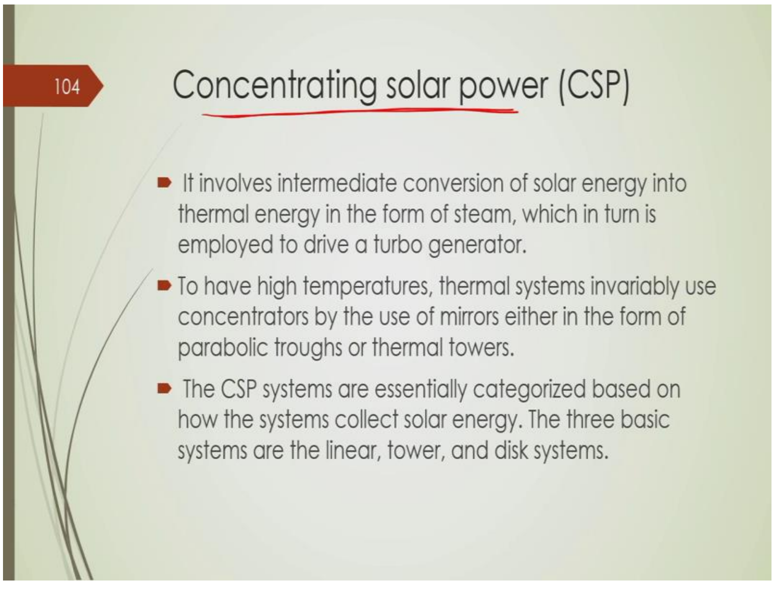

I am just keeping this; you can take a look. And finally, we also have some concentrating solar power in which the basic operation is something different than the photovoltaic. We utilize the heat of the solar and that heat is accumulated and then that heat is utilized to generate power ok, it is similar to this type of thermal power generation except that in thermal power we use burning of the coal or burning of the gases to generate steam.

But here, it is something different; it is by utilizing the heat available on the solar irradiation or by concentrating the heat we generate power. So, I am not going into detail.

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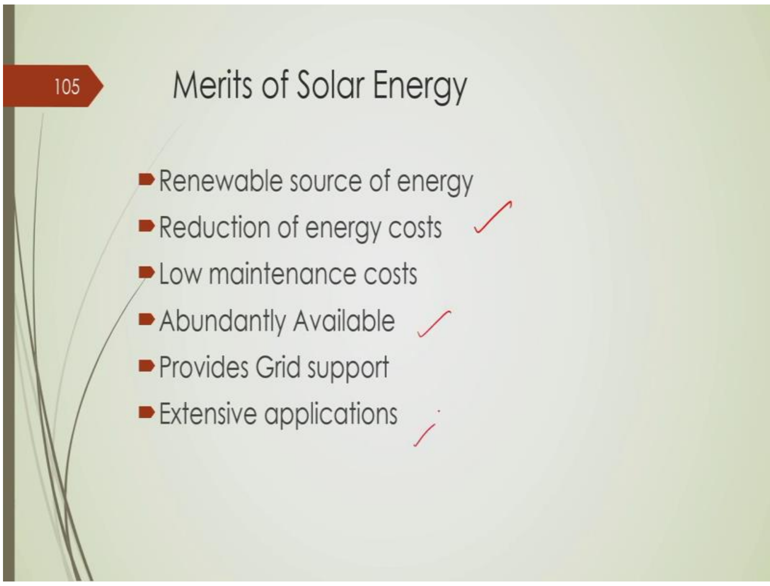

So, there are some merits of the solar energy conversion system as a whole. In fact, it is extensively used because the reduction of its installation cost and also it is abundant, it can be used for extensive applications.

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But again, these demerits are intermittency, if you use energy storage, energy storage is the costly. And of course, initial cost, investment cost, one needs to incur in order to install that.

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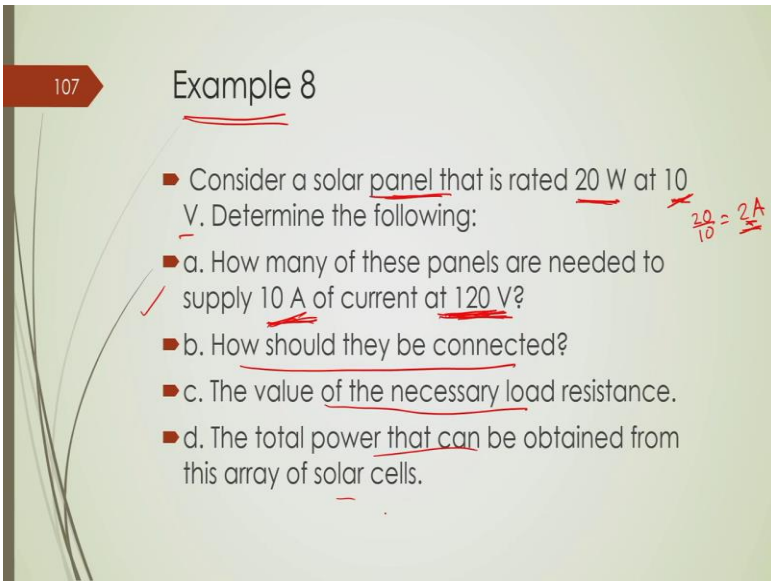

Now, here we have some examples, numerical examples, first numerical example is, suppose, we have a solar panel which consists of many solar cells which are rated of 20 watt and can produce 10 volt ok. Now, you have to decide that how many such solar panel we can make in series parallel combination in order to determine, in order to supply 120 volt at 10 ampere ok.

So, as I said many individual solar cells will constitute a solar panel and many solar panels are used in series parallel combination so that we can get desired voltage and desired amount of power from that. So, in order to have a 120 volt 10 ampere of current source so how many panels we need to connect?

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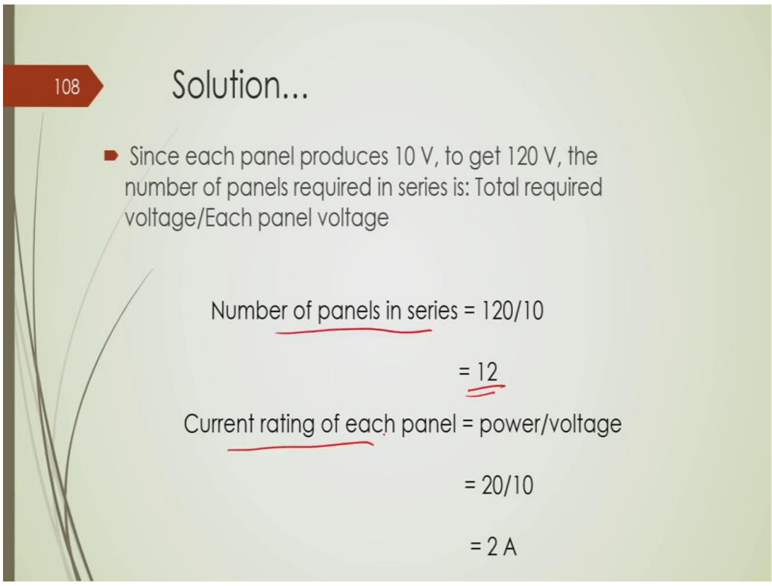

So, it is very simple, first you find out that since you have a 20 watt 10 volt solar panel so that means, it gives its output voltage is 10 volt and it can max provide 20 divided by 10 that is 2 ampere of current ok. So, we need 10 amperes of current so we have to connect 5 such unit in parallel ok; so that each of them will give two ampere and you will get 10 amperes. But in order to have 120 volt you have to connect, 12 volts such panel in series ok. So, that you get 120 volts. So, what we will get?

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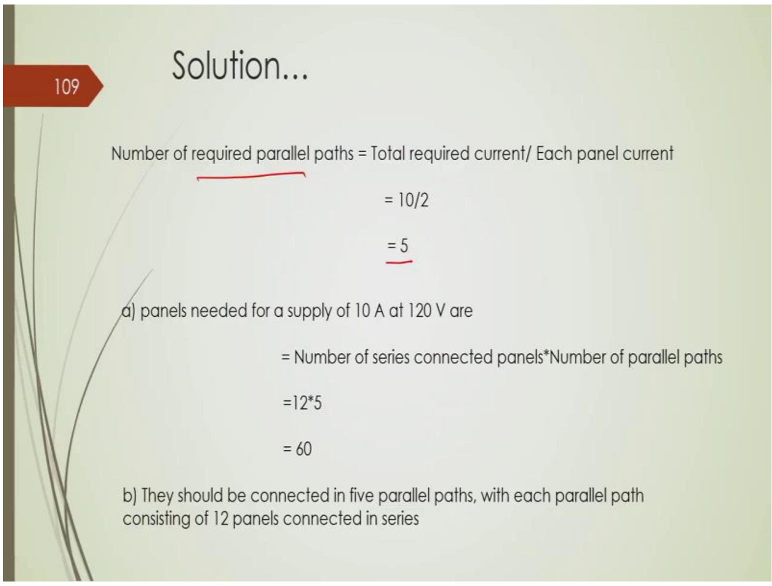

So, number of panels to be series is 12 and number of parallel paths that we require 5. So, it will be at 12 multiplied by 5; 12 solar panels would be connected in series and such kind of unit, 5 such kind of unit needs to be connected to parallel in order to have this required voltage and power ok. Now, another question is how they should be connected? So, you already determined that and the value of the necessary load resistance and total power that can be obtained from the solar cell.

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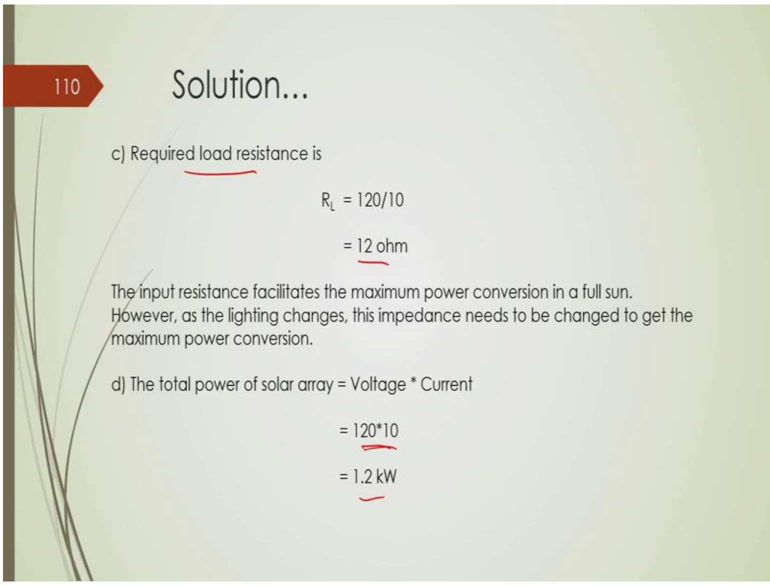

In fact, total power that is 120 multiplied by 10 that is one 200 watt that is 1.2 kilo watt, that much of power can be available. And we need a load resistance of 120 by 10 at least 12 ohm to be to connect, to get connected with that.

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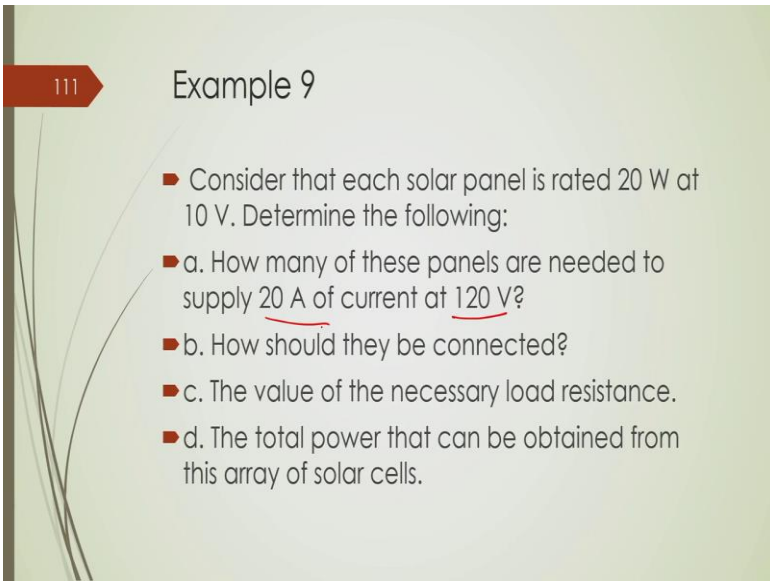

Now, similar examples are given with different values of desired voltage and current.

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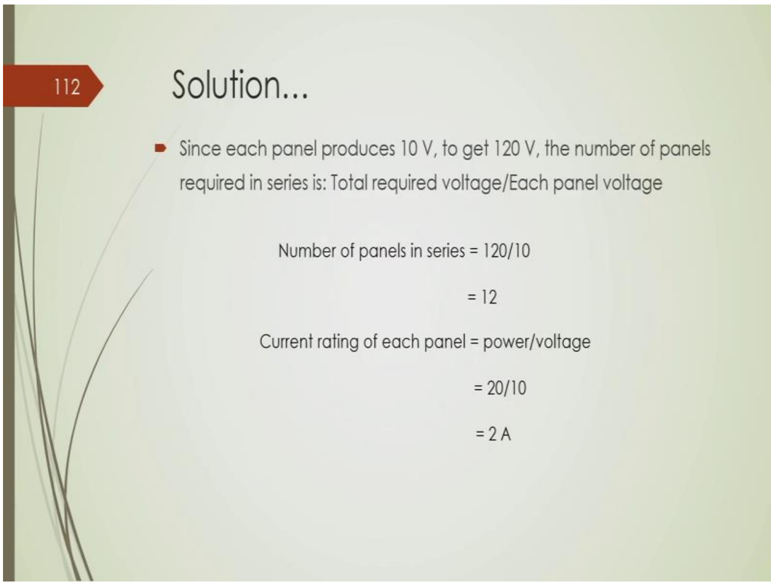

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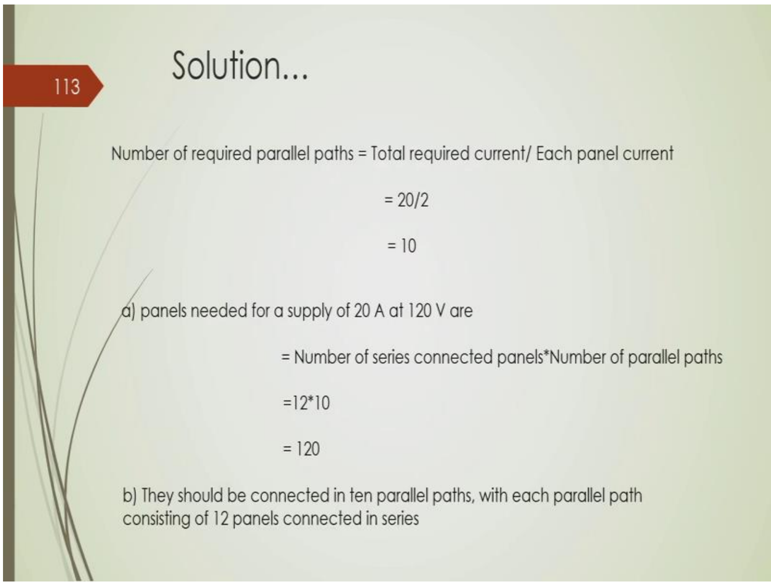

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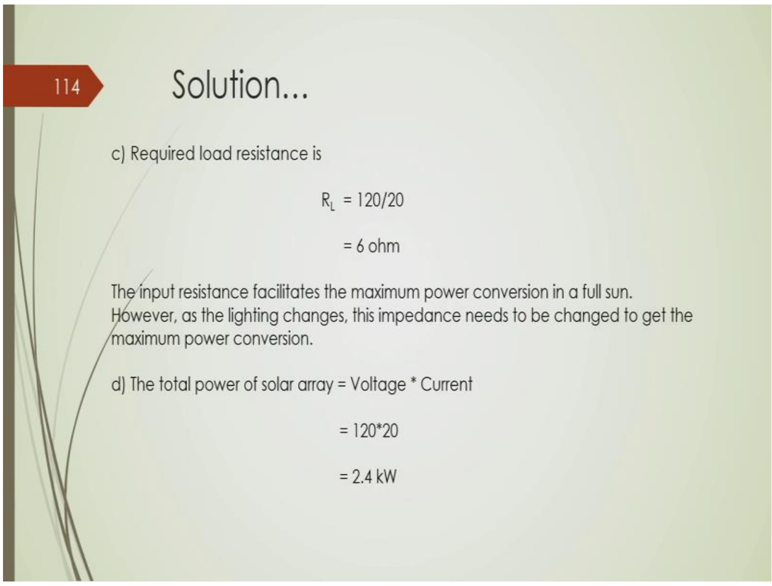

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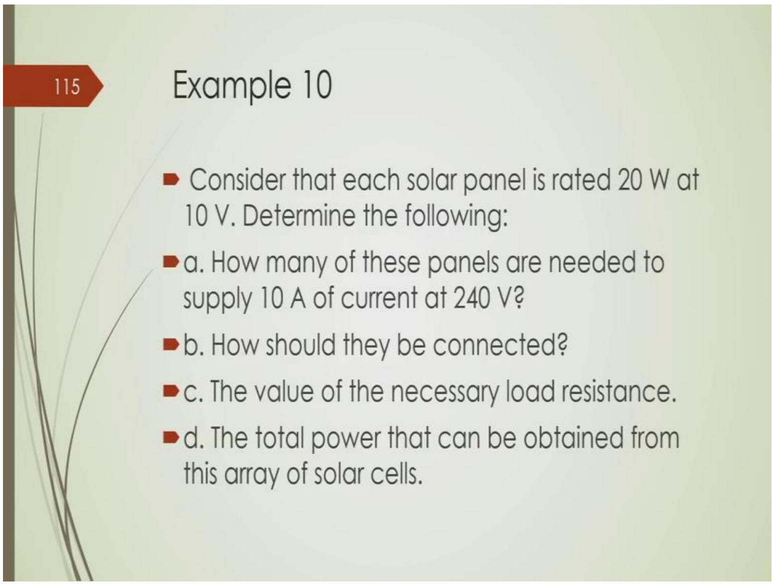

And accordingly in the similar fashion you can find out that how many solar cells need, solar panels need to be connected in series. Basically, series connection, how many panels need to be connected in series that is basically dominated by, that is basically decided by the voltage requirement, from this overall unit. And, how many such kind of unit needs to be connected in parallel that is decided by the current requirement or power requirement ok. So, one needs to understand that this is very simple.

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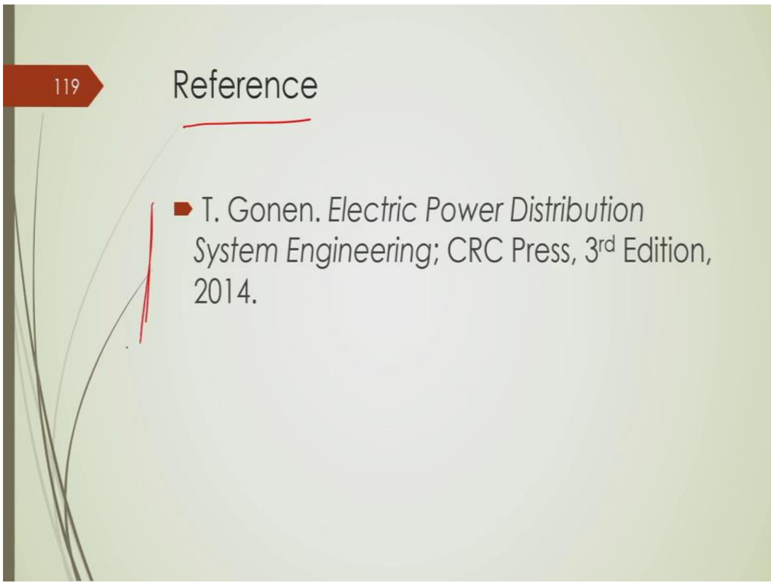

And in order to follow this particular part of this lecture, one can go through Gonen's book ok. So, with this I will stop today and this part of module 7, is finished here.

Thank you.