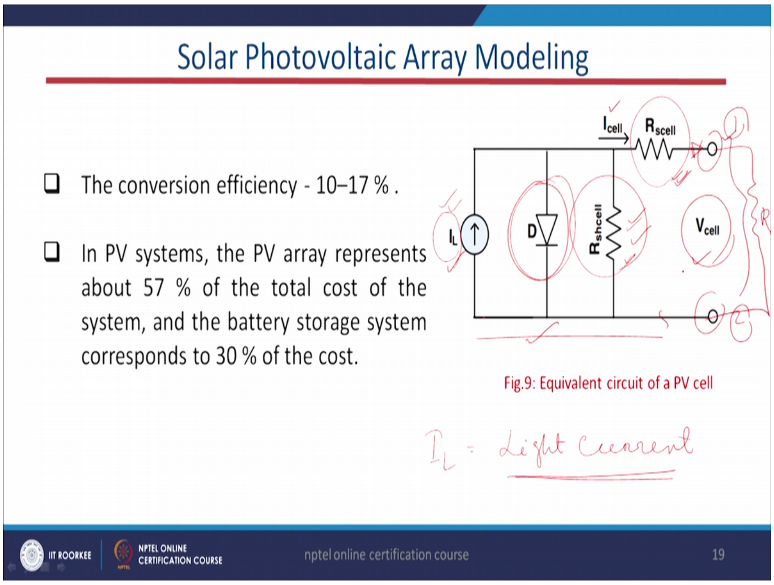
Introduction to Smart Grid
Dr. Premalata Jena
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture – 08
Distributed Generation Resources - II

Good afternoon all of you. In this lecture, we will start from the solar photovoltaic array modeling.

(Refer Slide Time: 00:34)



If you this, figure here this is the mathematical modelling of a single cell. This I L stands for the light current as we have discussed in the previous class, and this is the diode and this is the shunt resistance and this is the series resistance; I want to discuss here that what is the justification what is the physical significance of this two resistances; one is the shunt resistance and the second one is the series resistance.

And finally, if you will see here I have written V cell this is the output port 1, port 2 from where basically we take out the current to the external load. If, it is resistive load so, the current will flow from here and it will flow through the load and come back to this cell. Now, this is (Refer Time: 01:35) I cell stands for cell current and V cell stands for the cell voltage.

(Refer Slide Time: 01:44)

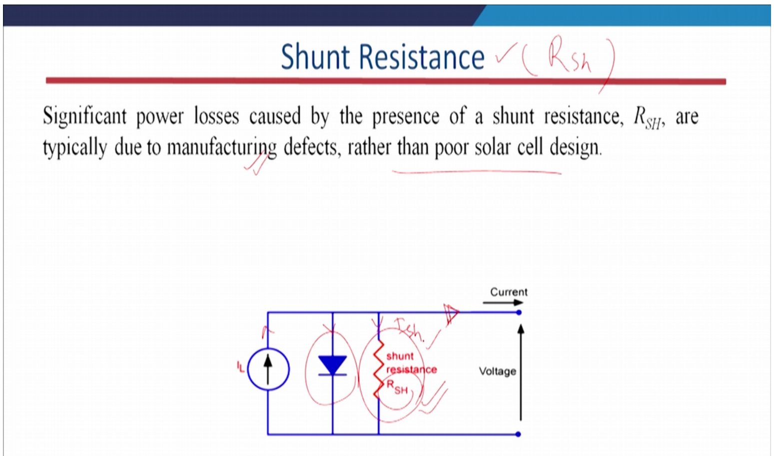


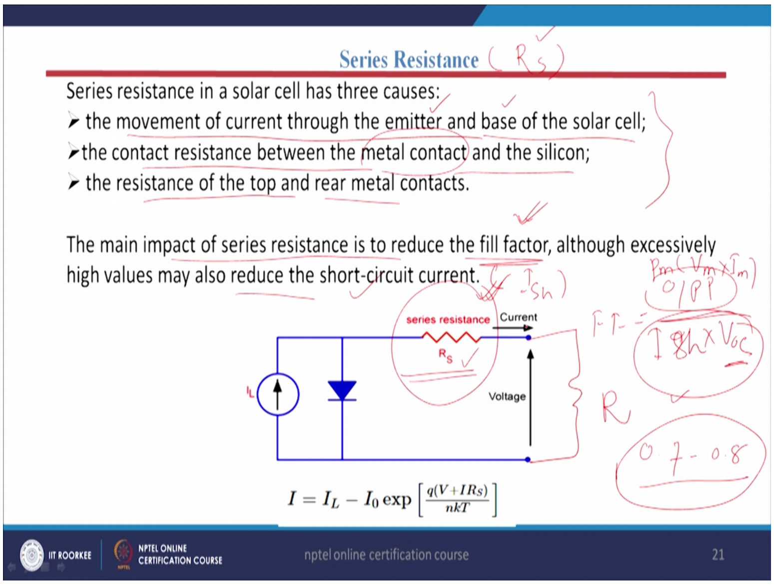
Fig.10: solar cell including the shunt resistance.

First I will come to this shunt resistance the symbol of this is R S H. Why it is shunt resistance? Because, it is connected in parallel across this diode that is why it is called as shunt resistance shunt means parallel. The significance of this shunt resistance is due to the manufacturer defects. In many literatures it is written this shunt resistance R S H comes due to the manufacturer defects, manufacturing defects.

And, rather than poor solar cell design this is very important. Sometimes, we think it is due to the poor solar cell design no it is due to the manufacturing defects, due to that this R S H comes. And, due to the insertion of this R S H or due to the presence of this R S H shunt resistance. The current flow through this particular device I mean, the basically this I L is going to be distributed through this diode and as well as through this shunt resistance.

That means the current which is going to flow through the load terminal will reduce. And, also the voltage drop will also there. That is what the demerit of this shunt resistance. So, it is always desirable that the construction should be the manufacturing process of the solar should be proper should be perfect.

(Refer Slide Time: 03:20)



Now, coming to the series resistance, this is denoted basically R S this is denoted by R S. So, this particular resistance R S is connected in series across the load, if it is shear load resistive load let us say. So, across this load this resistance is in series, that is why it is known as series resistance. And, what is the reason of this series resistance, why this series resistance comes to picture?

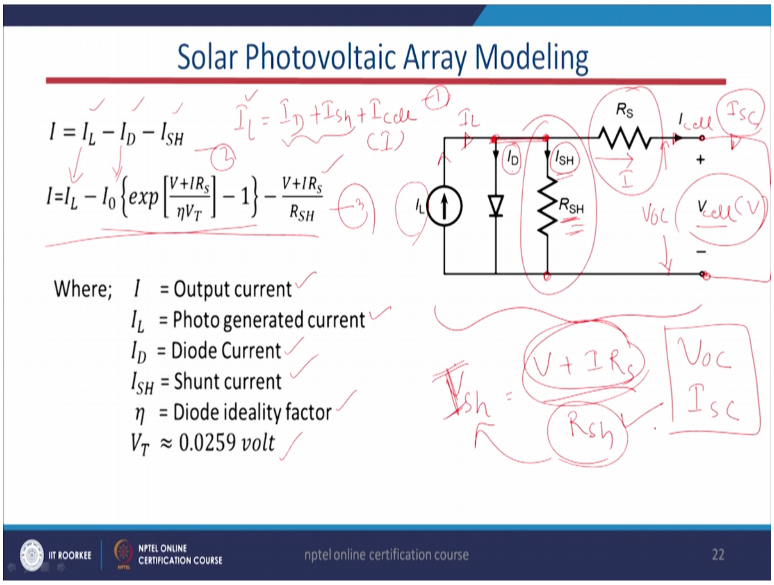
The first one is it is due to the moment of current through the emitter and base of the solar cell. We, have electronic devices there are we have emitter and base due to the moment of current, you know that to the flow of current the current is a basically the opposition is there, that opposition is nothing the resistance. So, due to that opposition there may be some resistance; and, the contract resistance between the metal contact and the silicon. I have shown in the previous figures that we have P N type junction, and there just below the silicon type P type or N type we have the metal contacts.

So, due to that contact some resistances are present and that resistance also contributes as a series resistance. And, the third one is the resistance of top and rear metal contacts. The top we have a metal contact and the below of the solar cell we have one metal contact. Due to these 2 metal contacts we have also this resistance. So, due to all this 3 when these are combined we have this series resistance. And, the main intact of series resistance is to reduce the fill factor this is a very important point. Due to presence of this series resistance, the fill factor will be reduced. Will discuss more about this fill factor when we will come to the characteristics of the solar cell, the fill factor is nothing it is ratio of the short circuit this voltages and current I mean the numerator this is the fill factor.

This is the numerator the output power divided by the as the short circuit I s h into V open circuit. This is the short circuit current and output voltage that is the open circuit voltage power and this is basically the P max basically this is V max into I max. So, this ratio is known as the fill factor, due to the presence of this series resistance the fill factor will be reduced. In fact, if the fill factor is near to one it will be treated as a good cell if it is basically this fill factor varies within 0.7 to 0.8. That means, we will discuss in more detail in the subsequent slides, if the fill factor is closed to one; that means, it is a good sell the performance is better the efficiency will be better.

So, basically this series resistance reduces the fill factor and all the extensively high values may also reduce the short circuit current. If, the series resistance value is very high then it may also reduce the short circuit current, I short circuit current the short circuit current of the solar cell.

(Refer Slide Time: 06:59)



Now, we will just derive the current equation at this point you see this is the incoming current, this is here I L and here it is one node, this is I D outgoing current and at this mode the outgoing current is I S H. And, here the outgoing current is I basically sometimes we also read write I cell and this is V cell. I am talking about a the model or equivalent circuit electrical equivalent circuit of a single solar cell. In terms of model and

I am the place of model we can use the basically the equivalent circuit, electrical equivalent circuit of a single solar cell.

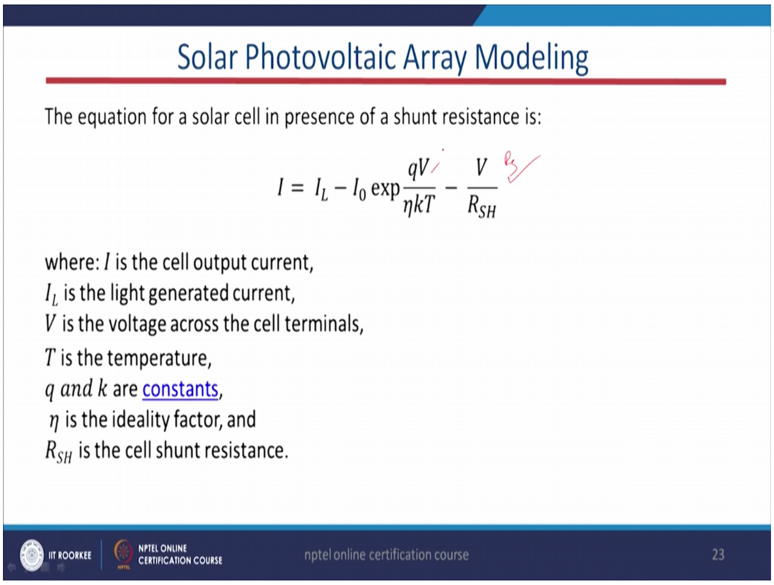
Now, by applying this Kirchhoff’s current law that is k cell. So, at this point of the junctions these 2 points are equal. So, at this junction the I L is equal to the incoming current is I L is equal to the summation of the outgoing currents. The outgoing currents are basically I D I S H and I cell. So, this is how I have written here right. So, if you will just write this I cell first I will write here I L is equal to I D plus I s h plus I cell or here we have denoted I. Now, this I cell is equal to I L minus this I D minus I s h, that is how this is a first equation, and this is your second equation, and this is your third equation.

Now, what is this third equation here it is I L and this is your diode current, basically this I L is the light current and this I D is the diode current I S H is the current, which is flowing through this shunt resistance. Now, this diode current is like this I 0 into this exponential of V plus I arrays divided by this theta into V T. So, that is how this is our output current or we sometimes call it I cell and this is your I L photo generated current, I D is diode current, and this is your shunt current and this is a diode identity factor.

And, this V T is basically the threshold voltage of the diode that is basically the range of 0.0259 volt. And, what about this is basically our I S H how to determine this current basically? The voltage here is plus minus V cell or sometimes we call it V. Now, this is the voltage and here is the current I. So, drop here I mean the after the drop, the drop across this resistance is how much I R S? Now, if I will add this drop and this voltage. So, I will get the voltage across this R S H that is what I have written V plus I R S S.

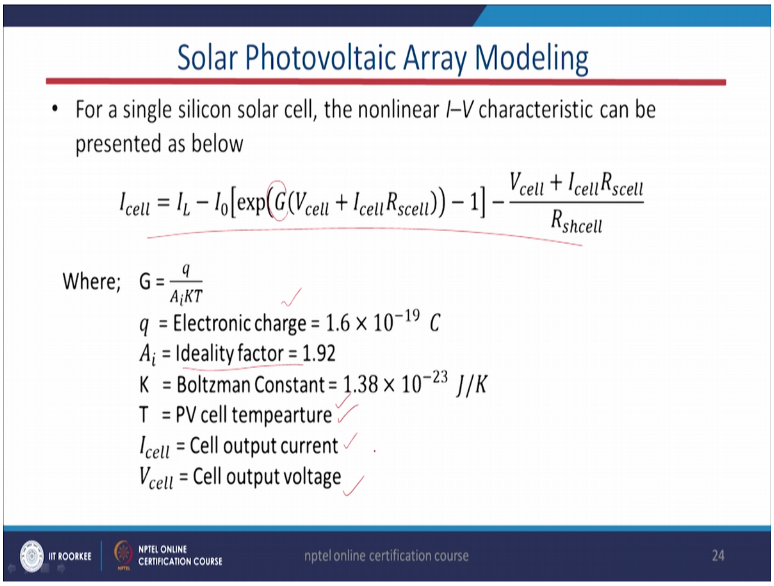
So, this is how we can define V s h is equal to V plus I R S divided by R s h. This is the voltage across this resistance and this is the resistance, this is it should be I s h not V s h. This is the resistance of the shunt resistance and it will divide voltage by resistance will get the shunt resistance current. And, by replacing this I S H in this equation 3 so, the final equation looks like this.

(Refer Slide Time: 11:06)



Now, here the if you have the presence of shunt resistance, which is quite I mean the in terms of magnitude, it is larger than the series resistance. So, we can sometimes neglect the impact of series resistance. So, here in the numerator the R S term will be absent and similarly in this case also.

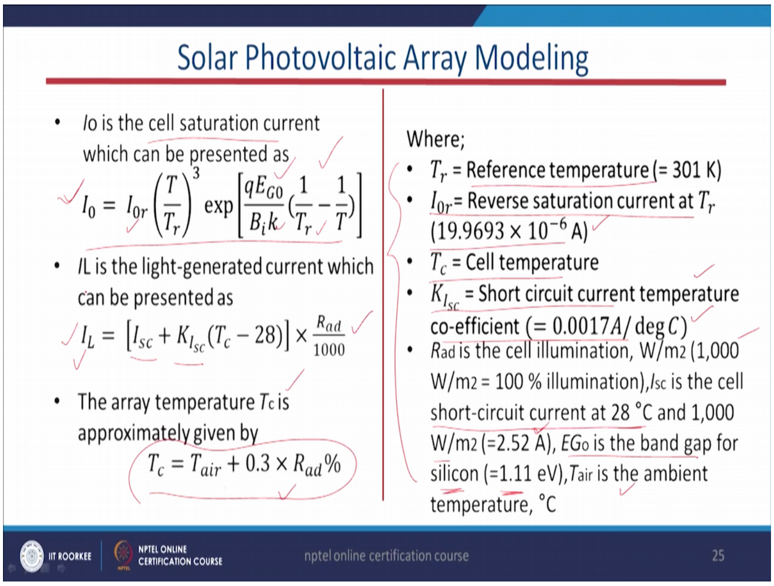
(Refer Slide Time: 11:33)



Now, coming to this one abbreviated equation here the G stands for q divided by A i K T. This is the electronic charge and this A i basically the ideal factor sometimes it is theta some symbols basically use some papers, resource papers differ different notations.

And, K is basically the Boltzmann constant and T is the temperature of the cell and this is the I cell output current and V cell is the cell output voltage. So, already we have discussed in the previous part previous slide.

(Refer Slide Time: 12:16)



Now, what is this I naught we have not discussed till this point. This I naught is basically the cell saturation current, this is very very important cell saturation current, it may be in the forward direction may be reverse direction. Now, this I naught can be written as I 0 r into this T divided by T r to the power 3, into this exponential q is 0 B i k, whole this one upon T r minus 1 upon T T.

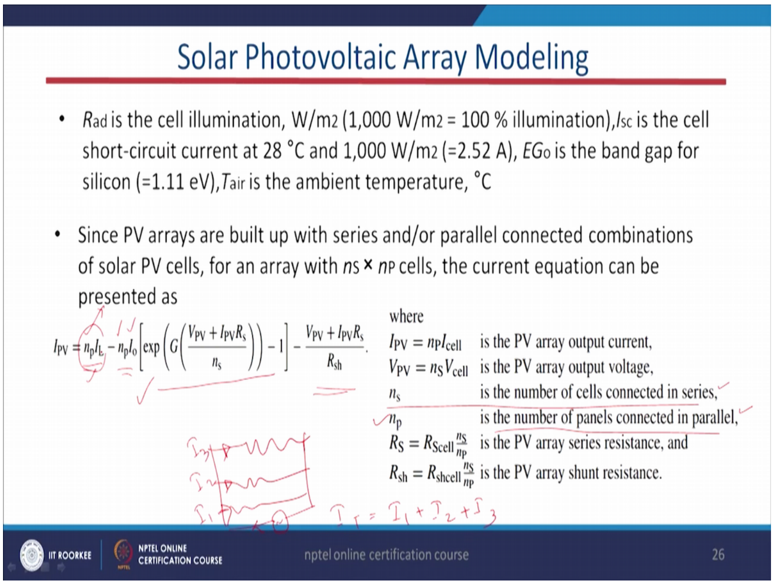
Now, if we will see all this symbols are very easy, which are written here. I can say one by one this T r in these equations stands for the reference temperature basically it is 301 Kelvin and I 0, which is written here that is the reverse saturation current at T r. At, that particular temperature what is I 0 r and the value is this much 19.9693 into 10 to the power minus 6 ampere. And, T c is the cell temperature and we have K I short circuit see this k stands for the short circuit current, short circuit current or temperature.

And, this is basically the magnitude 0.0017 ampere per degree Celsius right. And, then we have next further this if we will explain this I L how does it look like? This is basically I short circuit plus k i short circuit T c minus 28 into r 80 by 1000 right. So, this is basically the T c T c is the our cell temperature and this T c is basically written in this term T a air plus 0.3 into R a d. This R a d is the cell illumination basically the cell illumination rate unit is watt per meter square, if it is 100 percent illumination. So, that will be 1000 watt per meter square.

Also, we have short circuit current and 28 degree Celsius and thousand watt per meter square that amount is 2.52 ampere. And, what is this E G 0, that is basically the band gap for silicon. And, the value is 1.11 electron volt, and T air is the ambient temperature of in degree Celsius. So, these are all symbols and some parameters, we use to express the saturation current of the cell and the light current of the cell. This is very important I will discuss about what is this short circuit current? We will come back to this particular module mathematical equivalent I mean this is basically the electrical equivalent of the solar cell, electrical circuit.

If, I will short this 2 terminals the current which is going to flow is known as short circuit current. And, it will open it this 2 terminals the voltage which is going to be available, that voltage is known as open circuit voltage of the cell. This open circuit voltage and I short circuit these are very essential quantities, when we supply basically the solar panel, when the manufacturer they manufacture the solar cell or solar panel definitely they have to specify the value of these 2 quantities; The open circuit voltage and short circuit current of the solar panel.

(Refer Slide Time: 16:24)



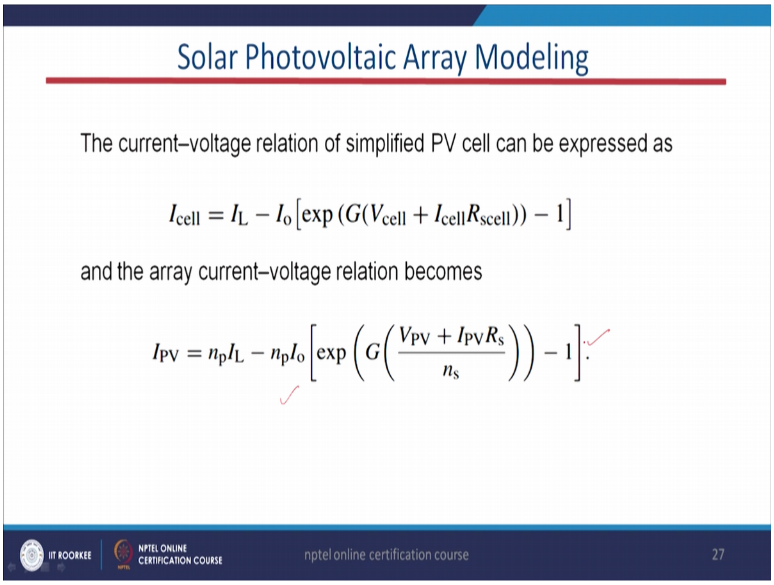
Now, so, these are the basically the expression for this saturation current and the light current, and these are corresponding symbols. Now, let us say we have more number of cells which are connected in series and parallel. To, have more power because the single cell produces 0.5 to 0.6 volt D C. So, if we need more voltage, more power, more current. So, we have to basically make them in series or we have to connect in parallel.

So; that means, if the number of cells increases in series or parallel. So, what will be the expression of our current this is our expression. This I P V or I cell is equal to n p into I L minus, n p into I 0. The only difference here is in place of this light current, we have multiplied one term that is n p. This n p stands for the number of panels connected in parallel I will tell why we have multiplied here n p not n s, n s is the number of cells connected in series.

Let us assume, let us assume in this particular panel we have this n s number of cells connected in series and n p number of cells connected in parallel, let us assume. And, next here minus n p into I 0 and these terms already we have written in the first equation, and this is the basically the current which is flowing through the shunt resistance. Now, here one change I just said why we have multiplied this n p with I L. The light current is multiplied with n p and these saturations current is also multiplied with n p. The reason being if you see, if we have a parallel circuit and we have a source.

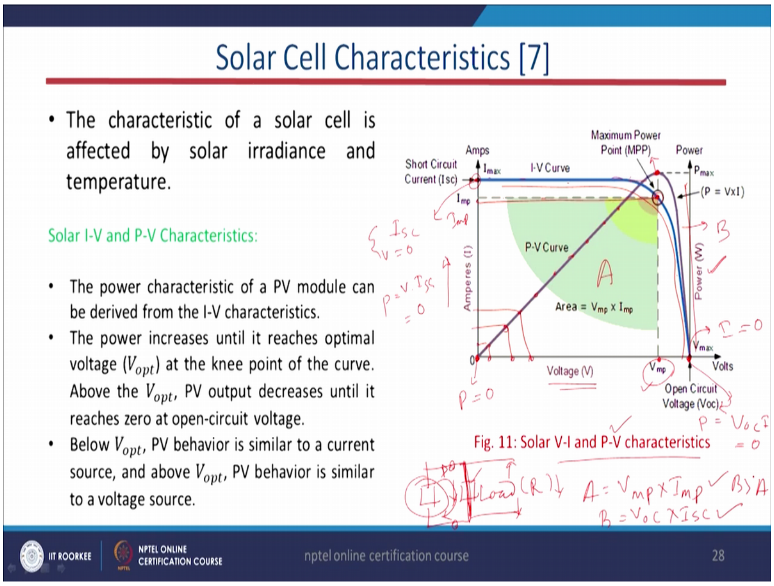
Then, this particular source in this particular source we have like I 1 I 2 and I 3 this is I 1 I 2 and this is I 3. So, current will be added this I total is equal to I 1 plus I 2 plus I 3. That means, if you will connect number of the cells in the series I mean the voltage will increase it will connect more number of cells in parallel then the current will increase, that is why this I L T light current is multiplied it is increased by n p times. And, similarly this saturation current is also increased by n p times. In parallel circuit the current increases and series circuit the voltage increases, that is reason. And, these are the symbols.

(Refer Slide Time: 19:16)



And this is how it looks like I cell is equal to I L I naught exp G V cell plus I cell R S cell minus 1 [vocalized-noise. And, the relationship is like this I P V, if we will multiply this if number of cells are in parallel more, that is n p the expression will look like this.

(Refer Slide Time: 19:43)



Now, I will come to the V I characteristic of the solar cell. This is the curve which shows the V I characteristic and also the P V characteristic of the solar cell. Now, along this x axis we have taken voltage and along y axis we have taken current. Now, I will just explain the blue one this blue one is basically this blue line is basically our V I characteristic. Why this characteristic is like this? If you could see here at this point along the x axis, I will start from here first at these point the voltage is basically how much the voltage is 0 here. And, this voltage the current is 0 here the voltage is maximum, and that voltage is known as open circuit voltage this is the open circuit voltage here the current is 0, I is equal to 0.

If, the current is 0 and the voltage is V o c then the P will be V o c into I is equal to 0. And, come to this point here along the y axis, at this point the current is basically called as short circuit current at this point. And, what is the voltage status the voltage equal to 0. Now, if you will multiply this 2 the P is equal to V into I short circuit, that is equal to also 0; that means, at the starting point let us say from the y axis here it is the power is 0, and where we have the short circuit current position. And, here also the power is 0 where we have the open circuit voltage position. That we share the 2 terminals 2 corners I mean the 2 points of my V I characteristic of the solar cell the power is equal to 0.

Now, you start slowly if you see the V I characteristic remains almost constant throughout, And then it reaches to this point, where there is a circle and this point is known as maximum point MP, maximum power point MPP, we call this point as MPP. And, further it will decrease I mean go ahead the voltage increases; that means, the curve is now following down and it touches to the V o c.

Then, there is a great significance I mean why this characteristic is like this. If, we will see the previous electrical equivalent of the solar cell, let us say we V here is the cell equivalent and here we have the load this is the load. Now, let us say I will just make this load quite large and the resistance of this load will be quite large. May be near about towards it tends towards infinity of course, it will not be infinity it is not feasible basically the open circuit system if I mean open circuit open circuit terminals, basically behave as a Enfield resistance the impedance is infinity.

Now, if this load resistance is very high; that means, the voltage available across these 2 terminals as if it will be treated as the open circuit voltage. And; obviously, as this resistance is very large the current flowing through this circuit will be 0. And, further what I will do I will just reduce this resistance of the load. I will reduce the resistance of this load and what will happen slowly when this resistance value will be reduced. Now, the current will try to flow through this circuit the current will try to flow through this circuit and when the current will flow. So, there will be some drop across this load.

So, how to this voltage the voltage what will happen to the voltage across these 2 terminals, we are measuring the voltage across these 2 terminals. Now, the voltage slowly it will fall, now it will start from this V o c now the voltage will fall. And, it will reach to certain point where it is treated as V m p, why this voltage is V m p I will just come when you will come to the, this particular P V characteristic.

This is the point or voltage where the maximum power exists, that is why this voltage is known as V m p. And, then further the voltage drops and again the voltage drops and comes to this point and here the voltage is 0, when this load is the resistance is almost negligible and path is totally short circuited. What we have started we have started from a very high resistance, to a low resistance almost short circuit path, then the curve starts from here. And ends here at this point we will get the short circuit current and the voltage across the terminal of the this particular 2 terminals the voltage is going to be 0.

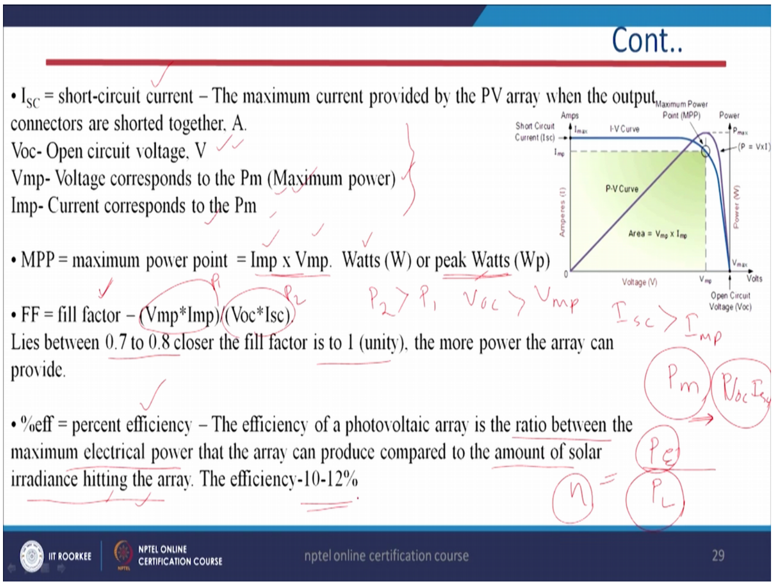
Now, that is how I mean the way I can explain how this I-V curve looks like. Now, if you will come to the P V curve power versus, if you see here we have just written this P P in watt, because output of this solar cell is in watt. This watt is along x axis y axis and along this x axis we have voltage and along y axis we have taken the power, which is in watt. Now, this how to get this P V curve, just you keep on in multiplying this voltage in to current this is basically the current. So, let us start from here this is a 0 point of the this is the power is 0 here P is equal to 0 because the voltage is 0, current is 0.

Now, again I will just multiply this voltage, this current, again I will multiply this voltage this current, again I will multiply this voltage and this current. So, I will get the corresponding power throughout this particular excess this is the trend of the P V curve. Now, at this point I will get the maximum power. And, if you will see here that this is my short circuit, at this point the short circuit current and here is my V, because it is along the x axis V m p at this current. At this point where I got the maximum power at this point this is basically the corresponding current I m p, because I am keep on multiplying the both V and I.

So, at this point I will get the power multiplication of this V m p and I m p it may reach to this point, not necessarily this P V curve will be below my V I curve if you multiply this V m p, I m p I will get this one this point that is known as MPP. Now, if you just see this rectangular dotted line rectangular area. Let us say this is my area number A and this one if I will just start from here I short circuit and my open circuit voltage. So, this area is basically area B; that means, the area A is basically due to the multiplication of V m p into I m p. And area B is basically due to the multiplication of V o c into I short circuit.

So, which area is greater the area covered by this V open circuit I short circuit is greater than this area; that means, B is greater than A. This is how this V I characteristic V P V characteristic and V I characteristic of a solar cell looks like.

(Refer Slide Time: 28:14)



Now, coming to this these are the few specifications basically provided by the manufacturers. The first one is the short circuit current and the second one is the open circuit voltage, already we have discussed and this is basically the maximum power point voltage, and this is the maximum power point current. I just want to mention here one point or one thing I just want to share with you, that as far as the solar cell is cornered it is operation, it is efficiency is concerned, these 4 quantities are very very important role I mean they play a great role. When there is a word will not discuss in this particular module the maximum power tracking controller MPPT; M P P T maximum power point tracker.

We, have developed a I mean different type different researches they have developed different controllers to develop I mean to access to harness the maximum power from a solar cell, because obviously, we have designed some solar cell or solar array or solar module we have to harness the power at the maximum point not at the minimum or below that. So, for that we have to have a control strategy. So, very time we should take at the maximum point I mean maximum power should be available to the load.

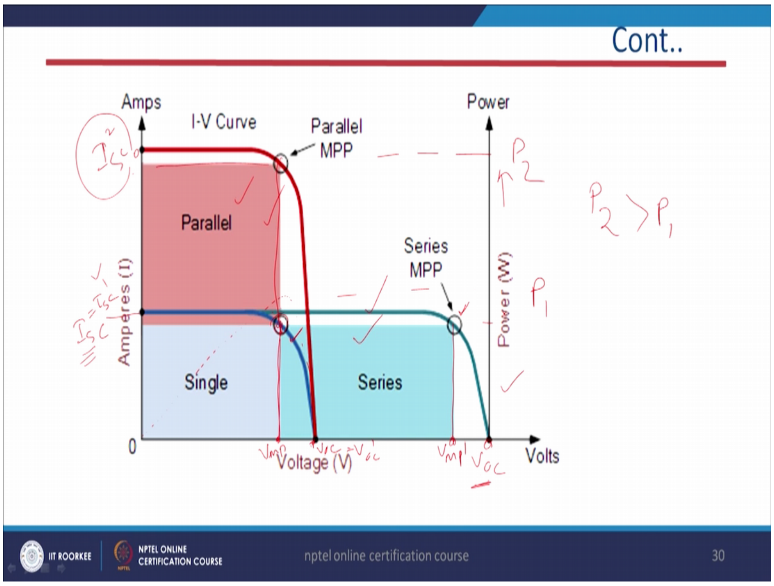
So, that is what the MPPT stands for I mean the function of the MPPT algorithm maximum power point tracking algorithm. And of course, if every manufactures they basically all the manufacturers, they provide the specifications seats and where this I short circuit V open circuit and maximum voltage power point and current all are mentioned. What is this maximum power point? This is the multiplication of this 2 quantities I m p and V m p and this is basically the sometimes peak watt, sometimes you write W p peak watt also the you need sometimes it is also peak watts, the unit is watts.

And, what is this fill factor? The fill factor is the ratio of 2 factors; I mean the first one is this one power ratio of 2 powers. This is power P 1 and this is P 2, the P 1 is the multiplication of V max P and I max P and this V o c into I short circuit. Remember, always this P 2 is greater than P 1 and; obviously, this V o c the open circuit voltage of the solar cell is greater than the V max maximum power the voltage corresponding to the maximum power. And, similarly I short circuit is greater than I m p, the maximum current I mean the current correspond to the maximum power point. It is not maximum current it is a current, which correspond to the maximum power point.

The ratio of these 2 powers basically knows as the fill factor. And, this specification is also provided inside the I mean solar panels or seats. And, this particular factor lies between 0.7 to 0.8 and this if it is closed to unit; that means, we are using more power the P max. If it is P max is much more I mean closer to this V o c into I short circuit then; that means, if it is very close to this we are harnessing more power from the solar panel.

Now, what is the efficiency of the solar cell, a solar array or module. The, efficiency is nothing that is ratio between the maximum electrical power. The output of the solar cell is electrical power that should be the maximum power, with respect to the compared to the amount of solar irradiance hitting the array this is the important. The irradiance we will discuss in the next slide the irradiance that is the maximum what is the amount of solar irradiance hitting through the array? That means, the electrical energy the electric P electrical is the output and P light, that is the irradiance means the power intensity of the solar cell I mean the sun light. So, that is the input power and this is the output power that is what the efficiency of the solar cell? And, this efficiency particularly lies in between 10 to 12 percent.

(Refer Slide Time: 33:01)



Now, this is very interesting characteristic here I just want to explain that, if let us say more number of cells are connected in series or parallel how this V I characteristic will look like, or how this p V characteristic will look like? Let us say this is the single this blue one is the V I characteristic when the cell is single. This is the maximum power point characteristic I mean the point and this is the corresponding V M P and this is the V o c and this is the corresponding I short circuit. Now, also we can we if we multiply the voltage and current then of course, we can always obtain the power P V curve. Similarly, also we can do for the other 2.

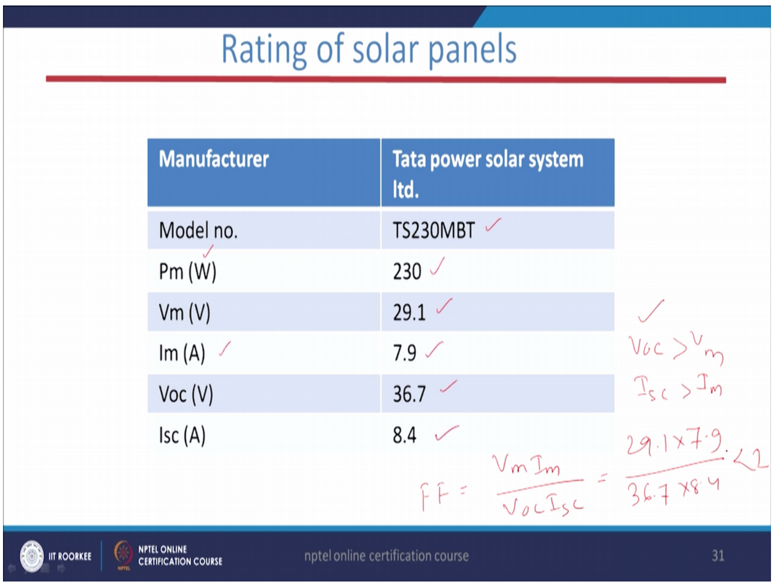
Now, you come to when the cells are connected in series this is how it looks like the curve V I characteristic. Now, what will happen? This V o c will shift to this point and here this I short circuit remains constant, this is very important. That when the cells are connected in series? Then the voltage increases and the current remains the short circuit current remains almost constant. However, the power the maximum power point shifts to another point. If we could see here a single cell this is the maximum power point position , but here in this case the maximum power point position is here. The area covered here is less and the area covered here is more.

Now, this is how this M P 1 this is M P M P 1. Now, if the cells are connected in parallel then what will happen to the I short circuit and open short circuit voltage, if the cells are connected in parallel. So, this is how the short circuit current at this point I s e 2 this is I s c and I s e 1. Now, this is the V o c point this V o c is equal to V o c 1. And, what about maximum power point that point also shifts to another is it shifts no it is a same as our previous maximum power point here it is. So, only the magnitude changes I mean the voltage remains V m p remains constant I short circuit changes, V open circuit remains constant for this.

So, what is the basic difference between this parallel series combination in case of series, we have this different V o c because in series connection the voltage increases and because of parallel combination the current increases. So, that is why the I short circuit 2 is greater than this I short circuit one or I short circuit. And, similarly you will see the power also jumps to another level here is the power axis and the power was here P 1, now the power is here P 2; obviously, this P 2 is greater than P 1 right.

So, that is how the series and parallel combinations are basically decided to get how much power we desire? How much power we need for our particular load? So, accordingly we can design or we can place the solar cells or modules or arrays in the proper manner. This is one of the specification sheet provided by the Tata power.

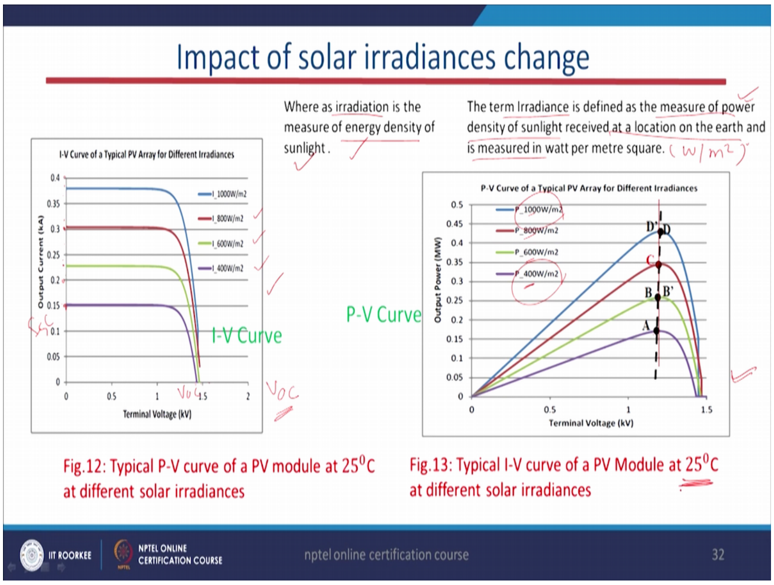
(Refer Slide Time: 36:51)



The model name is T S 2 3 0 MBT and the power output this is the maximum power output 230 watt, W stands for watt and the V m stands for the maximum voltage that is 29.1 volt, and the I m is the maximum current that is 7.9 ampere, and V o c is in volt 36.7, and I short circuit is basically 8.4. If, will go for the fill factor here, it will be how much it is the multiplication of V max into I max divided by V o c into I short circuit. Then, this V max is 29.1 into 7.9 divided by 36.7 into 8.4.

So, more or less this value will be; obviously, less than 1, because if we could see here in this case the V o c is greater than V m and I short circuit is greater than I m. So, that is why this value the fill factor will be less than 1.

(Refer Slide Time: 38:04)



Now, the subsequent 2 3 slides will discuss about what are the impacts of temperature and the irradiance on the V I characteristics or p V characteristic of the solar cell? First of all I just want to explain first the impact of irradiance, what is irradiance? The term irradiance is defined as the major of power density of some light received at a location on earth and is measured in watt per meter square, the unit of this irradiance is watt per meter square. This is basically measure of power density of some light that is irradiance.

Now, what is the difference between irradiation, it is the measure of energy density of the sun light these two are two different terms or phenomenon. This is the energy density of sun light and this is the power density of the sun line. Now, the question comes if I will increase or decrease the irradiance of the sun I mean irradiance, then how it will affect my I V or V I characteristics and P V characteristic positions, whether it will remain same or it will be different.

Now, let us come to this I V curve first here you could see here we have blue red green and purple color lines I V characteristics or V I characteristics. And, if we are increasing the first one is this first characteristics blue one is 1000 watt per meter square the radians. And, second 800 watt per meter square, third one 600 square watt per meter square, and the fourth one is 400 watt per meter square. Now, if this irradiance increases this increase from 400 watt to thousand watt; that means, my short circuit current level will keep on increasing. And; however, here the open circuit voltage this V o c, you know this is our V o c and these are my short circuit current positions these are my short circuit current positions.

Now, why it is so, what is the reason behind it? Why this short circuit current increases in a wider range?; However, this open circuit voltage remains almost constant, but increases this V o c also increases, but in the logarithmic scale the change is less in comparison to your short circuit current. What is the reason behind it? The reason behind it is when this irradiance increases means, the measure of power density. The power density in the short light increases that is called as photons, photon increases I mean this power density increases means; that means, the current I mean electron pairs increases more. And, then the current flow will be more, that is why this short circuit current manager is going to be increased and the voltage remains almost constant here.

Now, coming to the P V characteristic in case of P V characteristic here you see, that if the irradiance increases that is from 400 600 800 1000 watt per meter square. Then the corresponding maximum power point also will increase. In the first case it was not A position, this is B position C, then D position. Now, that means, if the if the power which are getting at 400 watt per meter square will get more power at 1000 watt per meter square. And, here you shall see the temperature is remained constant 25 degree Celsius the temperature is not varying only the irradiance is varying. Now, we will come to the impact of temperature how this I V curve and P V curve will look like.

(Refer Slide Time: 42:11)

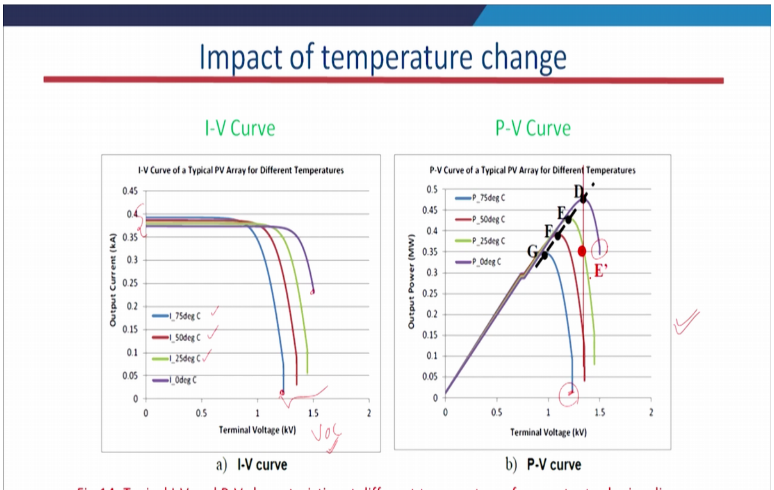


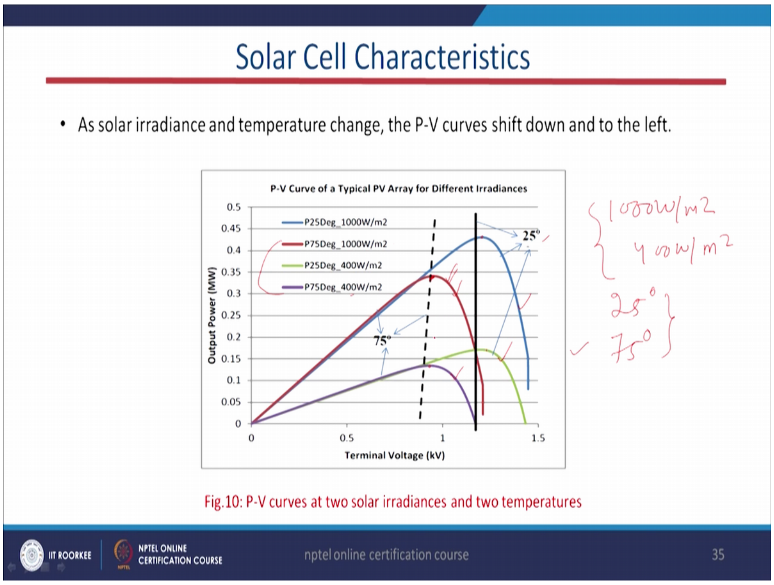
Fig.14: Typical I-V and P-V characteristics at different temperatures for constant solar irradiance

If the temperature see here we have taken degree Celsius 0 degree 25 degree, 50 degree, 75 degree. The temperature varies then the V I characteristics if you see, the short circuit current remains constant and your open circuit voltage V o c will vary. The temperature is high, then the open circuit voltage will be less and if temperature is low then the open circuit voltage will be high. This is because during the temperature, the photons rate increases and the reverse saturation current through the diode increases. As, a result the band gap will also reduce due to that this V o c will be reduced more temperature, the less open circuit voltage and the less power basically.

The temperature increase in temperature is not desirable for the solar cell, if you see many literatures it is written I mean it is also obvious that, if the temperature it is a very cold and sunny day that the power generation will be more. And, which a very hot and sunny day then the power generation will be less that is the meaning of this particular I V curve as well as the practical system is concerned. Now, coming to this P V curve the similar thing happens that if you just increase. So, this purple green red and blue one, this blue one is for basically 75 degree Celsius, the higher temperature, the lower temperature.

Now, similarly if the temperature is higher the power generation also will decrease, because our V I characteristics says that, because o V o c decreases and here basically the corresponding power also decreases

(Refer Slide Time: 44:09)



Now, this is also important characteristics, where both will vary, if the temperature and irradiance both will vary, then how this V I I mean the P V characteristic looks like? It is here this 75 these 2 curves are for 75 degree and these 2 curves are for 25 degree. And, we have taken here thousand watt per meter square and other one is 400 watt per meter square. And, this is these 2 are the irradiances and the temperature one is 25 degree other one is 75 degree.

If, the temperature see this is the 75 degree temperature this 2 red and the purple one, the red one and the purple one, this is the red one and this is the purple one. So, here the temperature is 75 degree, that is why the peak current and the power is basically reduced. In comparison to the green and blue one where the power is higher than this 2, it is obvious and as far as the irradiance is concerned 1000 watt basically this one this thousand watt is the blue one I mean the red one and the purple one is 400 watt.

So, what is the meaning of this if the radiance irradiance is higher; that means, 1000 watt per meter square and the irradiance here is 400 watt per meter square, then the power basically decreases it will go for the lower irradiance higher irradiance means the more power.

(Refer Slide Time: 45:49)

Now, these are the references what we have covered here in this particular module. So, let us come to the conclusion in this particular lecture, we have covered the electrical equivalent of a particular solar cell. And, we are also we have discussed that what are the significances of the series and shunt resistances, which are present in the solar cell. And, also we have derived the corresponding saturation current and the corresponding light current, which is basically present inside the solar cell. This I naught is basically the reverse I mean the saturation current and I L is the basically light current.

Now, also we have after that we have discussed the V I characteristics P V characteristic of the solar cell. And, also we have discussed if the solar cells are connected in series or parallel, then how this two characteristics will vary and also in the last we have discussed what are the impacts of this temperature and irradiance on the V I and P V characteristic of the solar cell

Thank you all.