Sustainable Material and Green Buildings
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Lecture 41
Solar Photo Voltaic Cells

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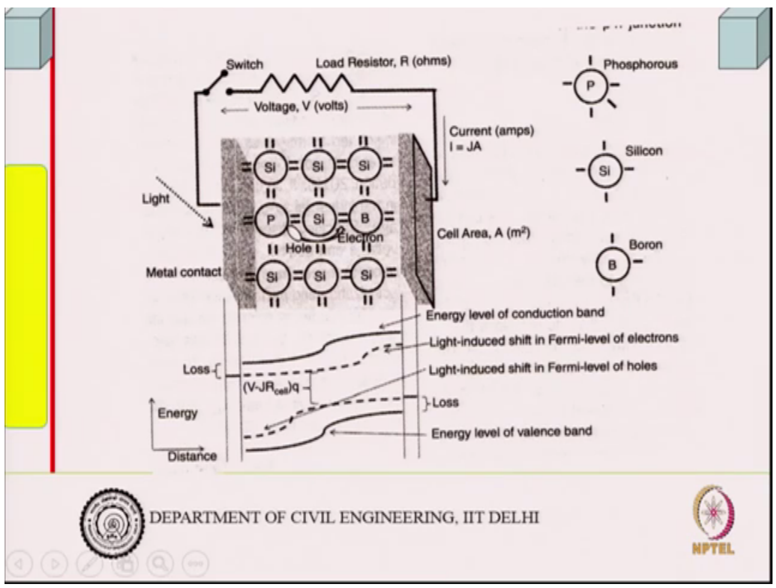

Okay, so we will start from what we were discussing in the last class. I will go back a little bit to this, beyond this point. beyond this point, yes. So, when you are when you have you know this is your PB cell with potassium sorry phosphorus and boron doping, right phosphorus and boron doping etc-etc and then the metal. So basically a voltage is generated here as soon as the light falls onto it that we have talked about and if the, if do not put a load and keep it off, switch off then that potential we call it open circuit potential.

That will be maximum potential because when it gets shorted or connected let us say through the load itself. The current will pass through the whole thing some (you know) EMF is lost in driving through the current through the cell itself. So, therefore open circuit potential is the maximum potential and current too depend upon the load and when you short-circuit it no load here that is the current is maximum because there is no load, right.

It is something similar to you would have remembered from battery cell. So open circuit one is because potential when you measure, open circuit potential, potentiometer or voltmeters their resistance is very high practically no current passes. So, therefore the you know it gives you what is the available total voltage but the moment you short it or connect it through a load or otherwise the current is you know there will be some EMF would be lost in driving the current through this, so that is what it is.

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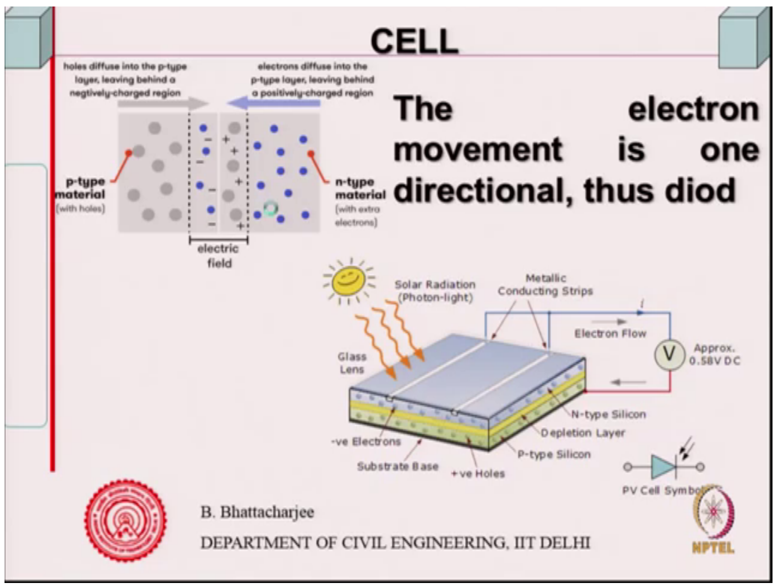

So this is why, this is what we looked into in the last class I do not think I am going to look it right now.

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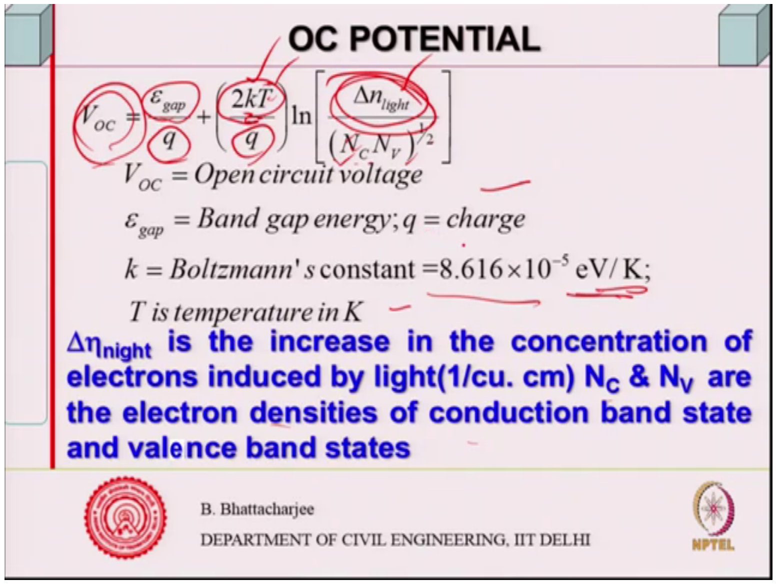

And this open circuit potential, the expression for the same is something like this. If this is the band gap, this is the band gap, this is the band gap energy, energy of the band gap energy. So, because it would depend upon band gap energy, right as we have discussed earlier and q is the charge so for volt (voltage) potential is energy particle it is a work required to move the charge in an electric field by unit distance if you remember that.

So, basically energy per unit charge is the potential, so this is one part. Second part is related to basically the temperature and the light that is falling on, right. So, this is actually number of electrons is the number of electrons increasing the concentration of electrons induced by light. So, number of electrons that jump or concentration changes and this is the NC and NV are electron densities of conduction band and valence bond respectively.

In fact, this is related to probability I do not think I am going to go into that and this is Boltzmann constant in electron volt. Now, you can see that this is actually dimensionless, this is the electron density because of the light, this is also number of electron or electron densities both in the conduction band and (valence bond) valence band. Therefore root over multiplied by 2 so the root over.

So, this dimensionless anyway this is in Boltzmann constant electron volt, right per kelvin. So, multiplied by kelvin temperature that means this gives you electron volt which is a measure of energy and if I divide by the number of charges then I get volt. So, this is the expression for VOC open circuit potential, this is temperature in kelvin and band gap energy etc-etc.

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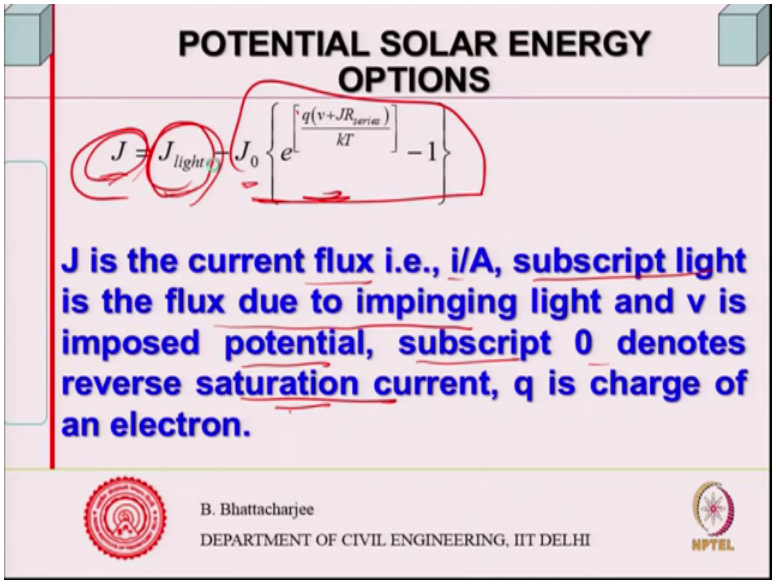

So one can actually find out the open circuit relative voltage from the fundamentals but we do not need really for our purpose but we must understand this. Now, if you look at the current flux now current flux is defined as i divided by A (you know) it is i divided by A, i is the current per unit area because I have a cell area through which current passes. So this is the current flux and that must be that due to light and there is some amount of reverse current generated, right.

When it tries to move there is a kind of reverse current generated and this is related to the you know J is the current flux subscript light is the flux due to impinging light this is due to light and V is imposed potentials, subscript 0 denotes reverse saturation current. So there is a reverse current generated because as you increase the as you increase the voltage as you increase it is asymptotically it tends to you know it will not increase proportionally, so there is a reduction.

So this reduction reverse you know this is reverse saturation current as it is called and q is the charge of an electron ofcourse this is the charge of q is the charge of an electron. So you know as the light passes the current flux would be reducing J 0 stands for this is the saturation current, so as you increase the current there will be a reduction and this is that you know J 0 is reverse saturation current. So, this is basically there will be reduction and that gives you the reduction because whatever if everything is not converted.

So, current that you get is that you get from the light plus there is some kind of a reverse current and which reduces down and that is what it is.

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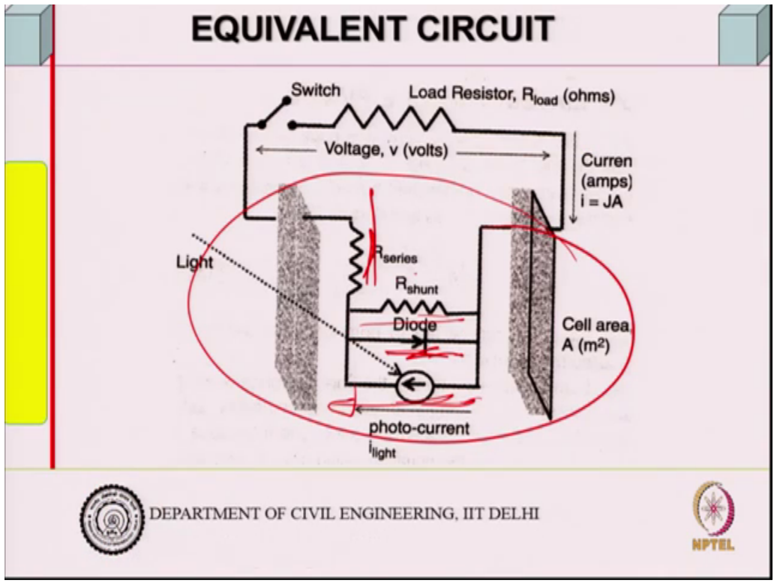

So, that is what it is and it is modeled as I mentioned earlier that the light J light would be something like this and since it is one directional there is a diode and there is a parallel resistance and series resistance that is how it is modeled. So this system is modeled with photo current, a diode and a shunt there is parallel resistances as a series resistance, right.

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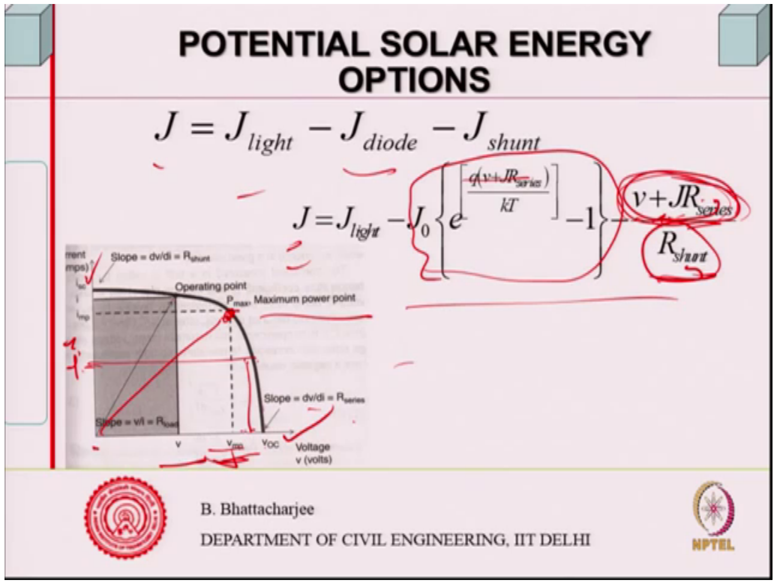

And one can write like this J light, J diode and J shunt that is in a macro level expression for it. And this was that reverse saturation current and this is the current because you know because this is the current generated series this is a voltage because there is a flux multiplied by per unit area multiply so everything is per unit area. So per unit area multiplied by this, this is the total voltage drop because you know this is the total voltage drop in the circuit, this is the light, this is that diode is at reverse current reverse saturation current and there is a series resistance and you know the shunt because this is the total potential along the line and this is divided by R that gives you the.

So this is simply from this equivalent circuit one can get this from this equivalent circuit one can get this, alright. So, what one sees is when your current is 0 open circuit potential voltage is maximum and when it is shorted the current is maximum and in between at different loads this keeps on you know this keeps on changing it reduces you put some load it would reduce that this would reduce and say let at this point this is the current and this is the potential you will get.

So there is a point where it is maximum power is maximum, power is basically nothing but i into V. so this point where i into V is maximum P max maximum power point, i into V is maximum and generally operating point could be somewhere away from this not only the maximum, right and obviously slope is V by I, slope is V by i potential you know so V by i is the slope i is this side, V this sides, so slope is given by this. So, maximum is this operating point which is i into V. So, this is maximum i into V, dv, di is equals to R okay in series at this point so that is what it is.

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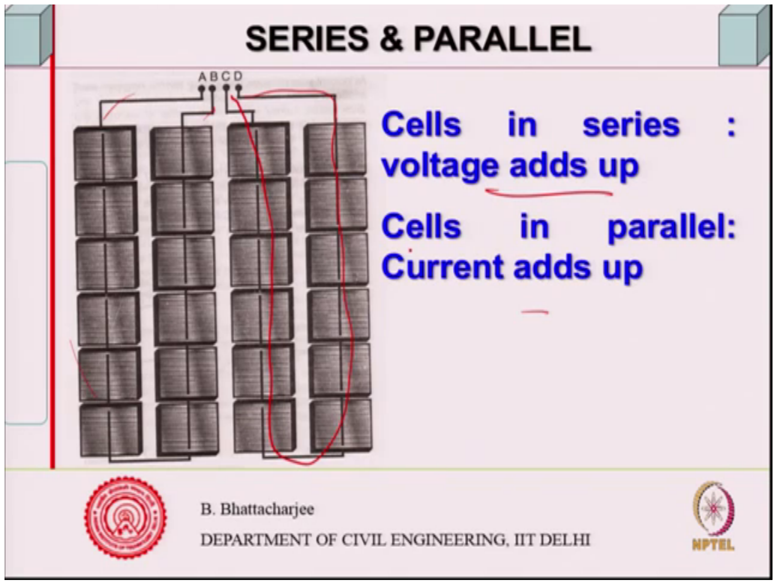

So, you can correct them in series and parallel and number of them and sum total one can find out. So, there will be just for example there are several cells so these cells are all in series, these in series and this set is parallel to this. So total voltage generated you can actually find out from the sum, right and total current will be sum through each of the parallel paths, total current will be through each other path.

So this is what it is to start with. So that is what it is. So, cells in series voltage are sub cells in parallel current will head up. So, this is as you can say this is all in series CD, AB they are in series. So, voltage total voltage will be from number of them as you have added and the total current would be sum from all of them. So this depends upon how the what is the layout of your cells in the overall.

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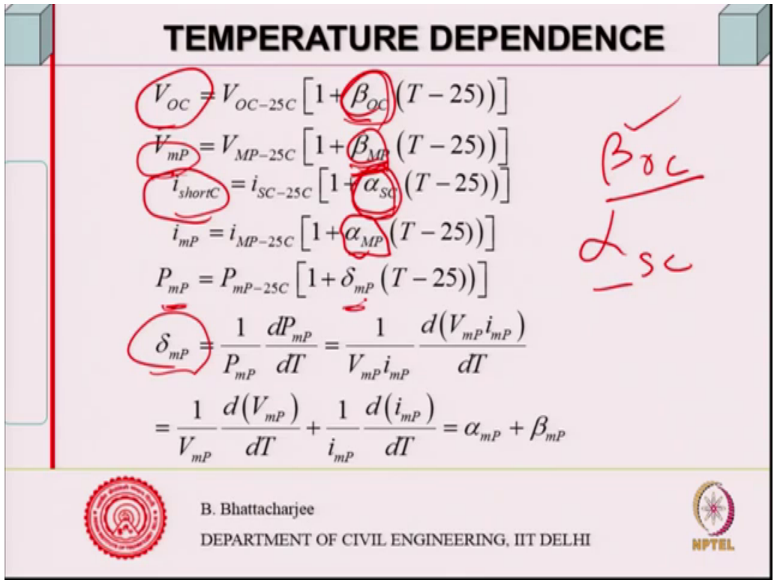

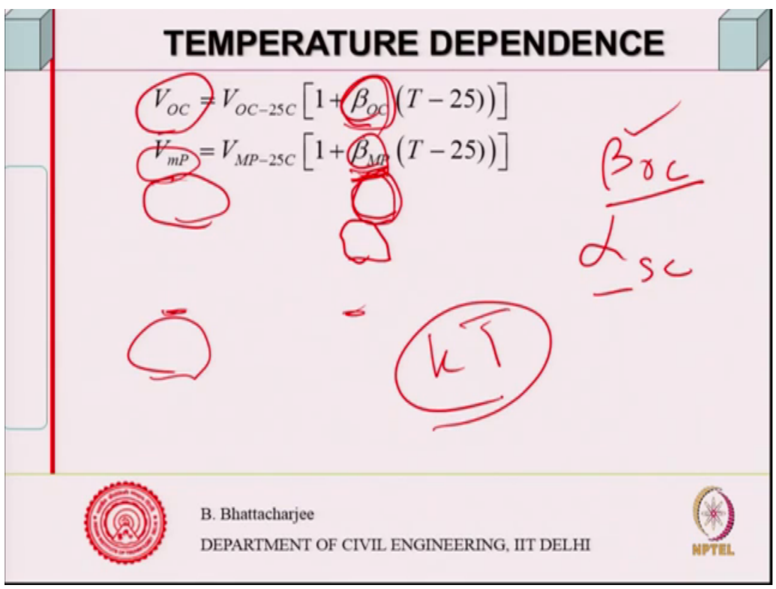

Now this once depends on temperature, you know this one actually depends on open circuit potential as well as short-circuit current these are all function of temperature, these are all function of temperature, these are all function of temperature and this is a kind of a coefficient for voltage and this is a kind of coefficient for current. So alpha short circuit beta open circuit these are coefficients, temperature coefficients and this is for power, you know this is for beta OC maximum power and so on, delta for power and so on.

So sorry this voltage corresponding to beta MP corresponds to beta corresponds to voltage temperature coefficient for voltage alpha for current alpha MP is for maximum power condition, alpha SC is for shorter short-circuit condition this for open circuit and this is for again maximum power and for power similarly one can write temperature coefficient because these are function of temperature as you have seen earlier we said that it was if you recollect it was k T etc-etc so it depends upon temperature the you know VOC is a function of temperature.

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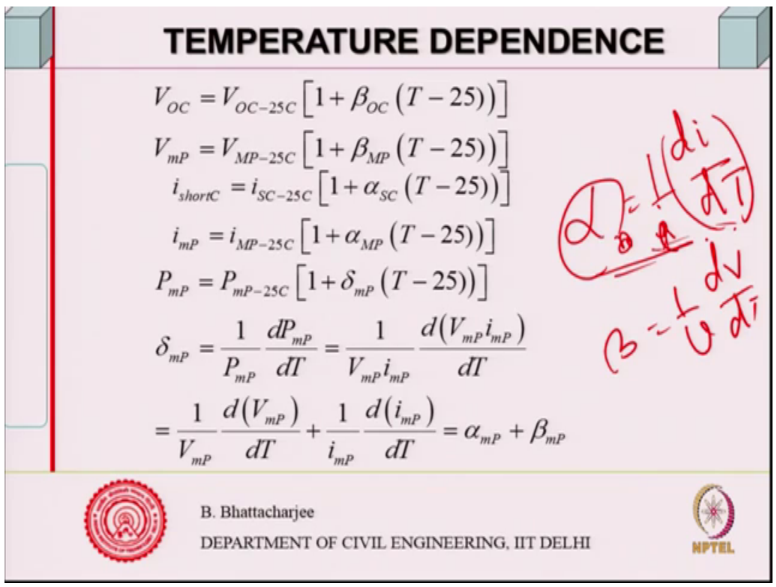

So, one of the simplest way of dealing with it is through assuming that basically assuming that say alpha is 1 by i di dT. So you know the alpha is a coefficient which is proportional to rate of change of the current with temperature divided by the temperature itself that means these will divides normalized with. Similarly, beta is nothing but 1 by v dv dT and if I talk of power then it will be similar.

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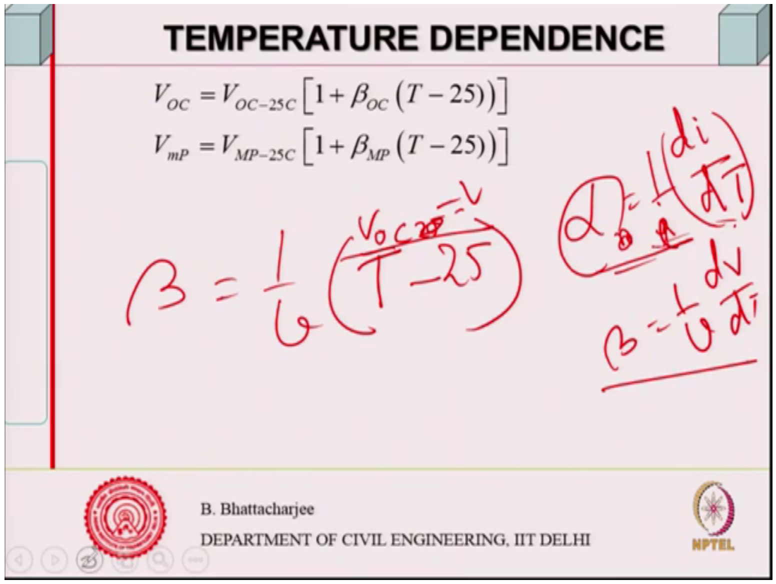

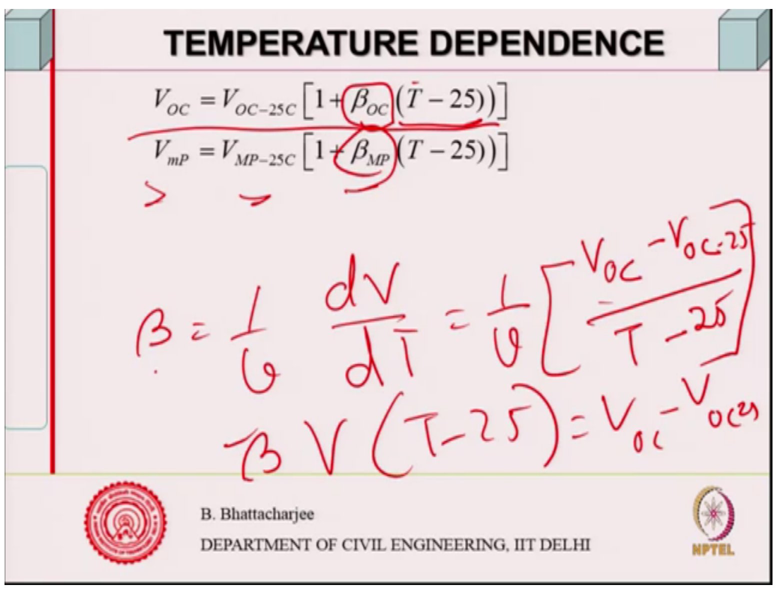

So, if I expand this if I expand this, say if I expand this part, if I expand this part let us say let me give this so voltage part first let me look at it. So beta is 1 by v I said and let us say my temperature is with reference temperature is 25, so this would be voltage corresponding to open circuit voltage corresponds to 25 or let me write it here this is the this is how I write it minus VOC at yeah V this is V OC at T minus V OC at, okay let me clear it up and write it again.

Beta can be written as because we said it is 1 by v dv dT. So, I can write as 1 by v and say I am interested in 25 degree centigrade and some temperature. So, V OC at temperature T minus V OC 25 divided by t minus 25. So, therefore one can so beta can be relate from this you will get this kind of a linear relationship because you can write it as beta V T minus 25 is equals to V OC minus V OC 25.

So, if you rearrange this you will get this kind of expression. Therefore, these coefficients allow us to find out the open circuit potential at a given temperature if I know at some standard temperature already or if it is standard if because measurements in the lab or in the factory would be done in standard condition, measurement of the factory. So, at any other temperature I want to find out I can find out. At maximum power this is similar equation. So, this is defined one at the open circuit stage another as a maximum power stage.

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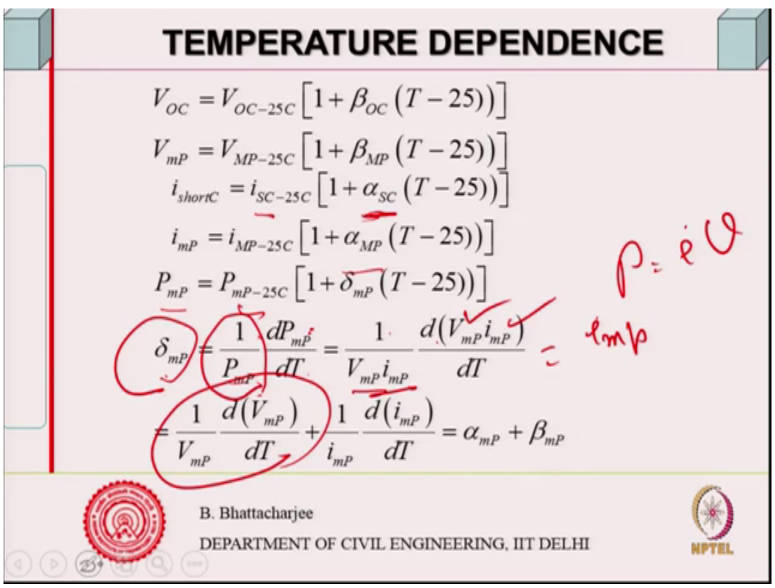

Similarly, for current one is drawn, you know one is written it is short circuit another maximum power. Now, P mP therefore one can express in a similar manner P mP one can express in the similar manner. So, delta mP will be maximum power situation 1 by P mP divided by D mP dT and P can be written as V mP plus i power is nothing but I into V. So, I can write it like this and then so divide this, this power also is written as V mP by i mP.

So, this can be written as two sums of these two because d you know partial derivative. So, i mP so this will be written as i mP if I derive do it just this find out this derivative of this one i mP or let me write it in a better manner.

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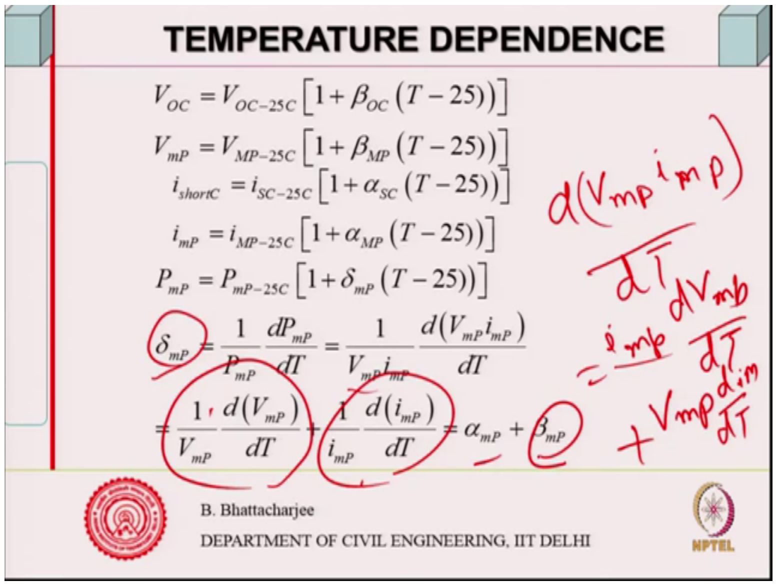

This d V mP i mP divided by dT will be written as first i mP d V mP dT plus V mP d i mP dT is chain rule. So, this divided by these two i mP will cancel, so I will be left with 1 by V mP d V mP by dT this what it is and this is nothing but one of them is beta another is alpha. So the temperature coefficient for power is the sum of temperature coefficients for current and voltage. So this is also another thing known, alright.

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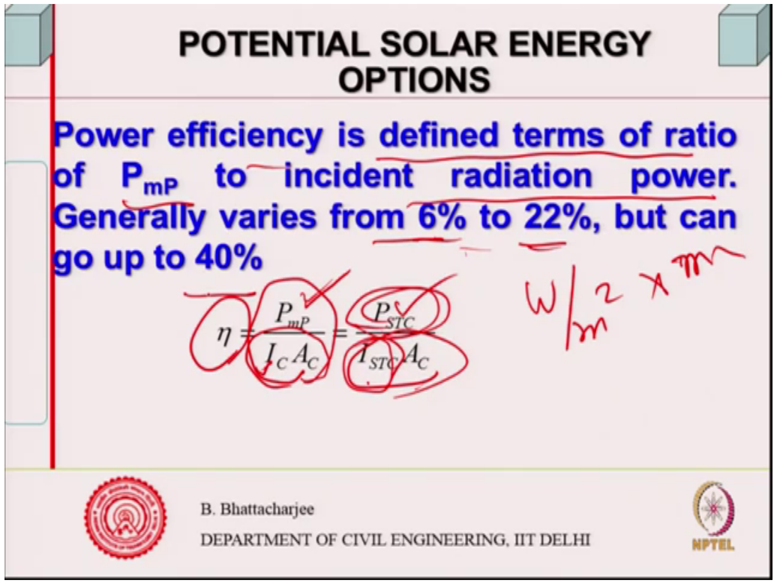

So, power efficiency therefore more or more important. So this is the some basic fundamentals and let us look at this. We define power efficiency in terms of the ratio maximum power to the incident radiation power, right generally varies is from 6 to 20 percent but it can go up to 40 percent. So, generally 6 to (20 percent) 22 percent for varieties of them that is there. So, first let us look at the definition this is the efficiency corresponding to maximum power condition, right power that you can get, electrical power you can get divided by incident radiation multiplied by area because this is in watt per meter square multiplied by meter square area.

So area of the cell and incident radiation on it and maximum power generated this is the maximum power efficiency, this is same as in the standard condition. So, if I take a standard condition I know what is my IST that is the standard the incident radiation I am considering then this is how I define the efficiency, you know efficiency is defined is a. So, this is the electrical power, this is the actually radiation power that is coming in, radiation that is coming in solar radiation that is coming in. So this varies from 6 to 22 percent some cases can be 40 percent or so.

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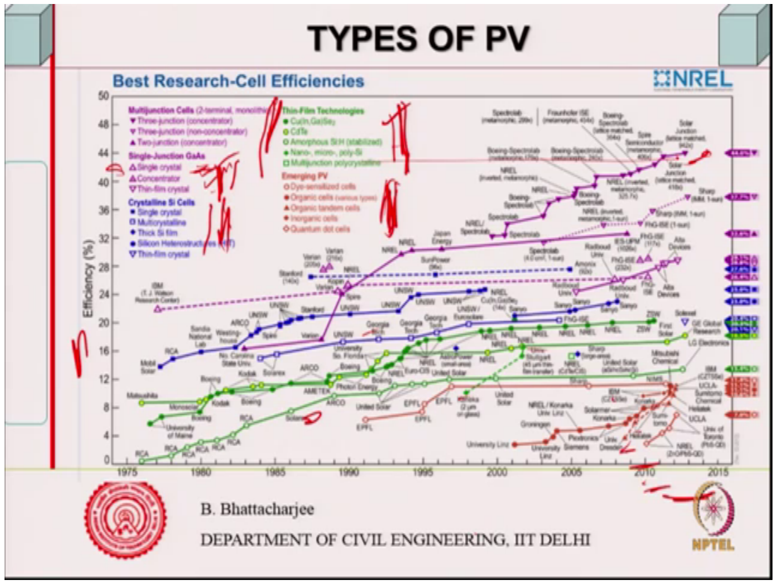

Now, this I think will have a diagram of this kind this diagram is available in Net or books or anywhere varieties of you know for varieties of types of solar cell what is the efficiency? So we can say that maximum somewhere go to 40 and this colors single junction, right single crystal concentrated thin film crystal etc-etc and the lower ones are the green ones amorphous stabilized Nano-poly silicon and so on and red ones are somewhere there.

So depending upon the types of cell, this kind of a diagram but this is available in Net anywhere books or Nets you will get it. So one can choose for example these types of one multi-junction cells, single junctions ones and crystalline silicon cells germanium and this is single junction germanium and inner germanium and air cells this one gives you high multi junction cells, this gives you high, these are the next ones crystalline silicon cells and thin film technologies of the various kind there somewhere there and emerging previous somewhere they will be there.

So this is 2015 or 2010 this is the scenario, so that is how the efficiencies also. Generally, you can, one can look into what is available in the market and choose accordingly, okay.

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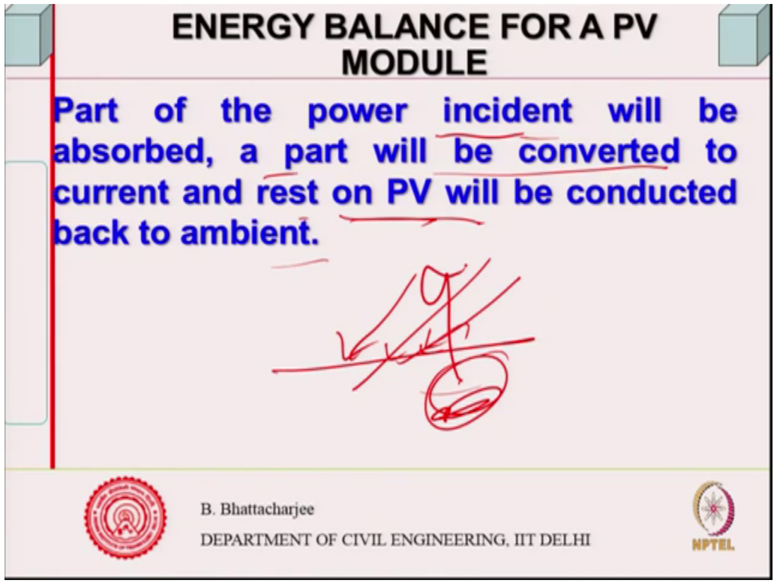

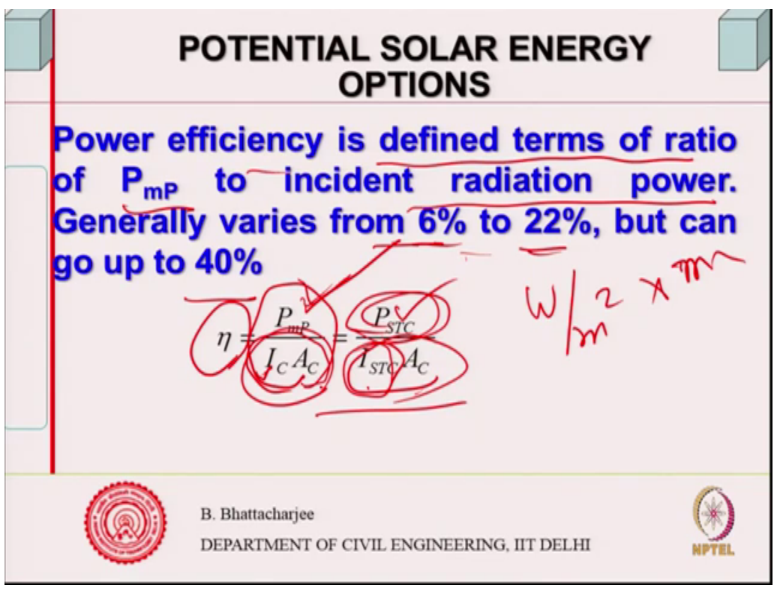

So, this is one aspect then let us look at how what are how do we, how should you specify and how do you calculate let us say if there is? Efficiencies to be calculated. We have defined the efficiencies now, we have defined the efficiency now which is the electrical power generated divided by radiation multiplied by the area solar radiation multiplied by the area what is from the solar radiation.

So, part of the power incident will be absorbed whatever comes in on to your panel let us say horizontal panel for simplicity purpose part will be absorbed by it, part of the radiation will be able part and rest of will be some part will be converted to current and rest will be conducted back to the ambient because this will get heated up, so there will be some amount of radiation back.

So, if I look at energy balance, right because a part of it is only coming. So efficiency is related to that because finally what is the electrical power I am generating divided by whatever is coming in but whatever is coming in all will not be converted into electrical power. A part will be absorbed in the system and part will be radiated back to the atmosphere.

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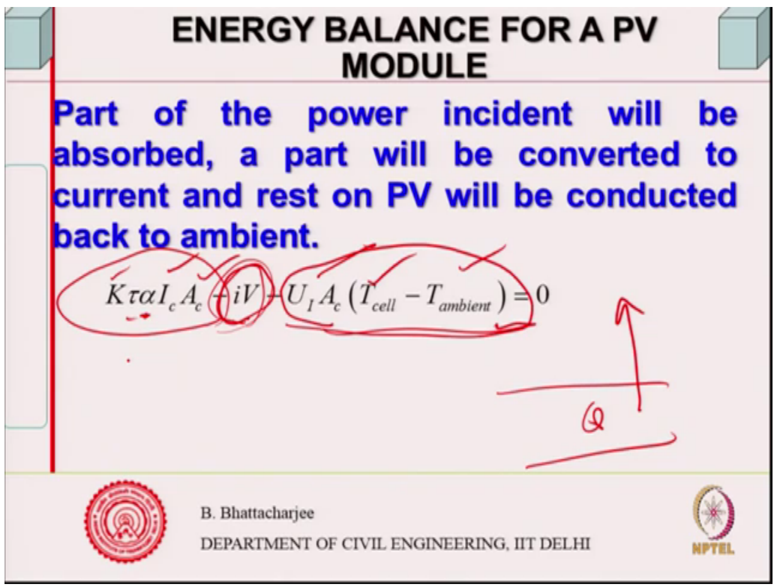

So, this is a this is the kind of equation which shows the energy balance, this is the incident radiation, this is the area of the cell alpha is a absorptivity Tau is a term, this is a term this is what actually net it is coming and K is a factor for angle, K is a factor for angle this is the power generated photo voltaic power generated and this is what is lost to the ambient this is that U value of the cell.

So if it gets heated up and cell temperature is will become higher which is actually an unknown for us and ambient is known to us so the heat conduction will take place because this will get heated up from these two back to the ambient. So this is loss to the thing and this is a power generator and this what is received. So your efficiency will be this divided by the actually this, okay let us see how it is.

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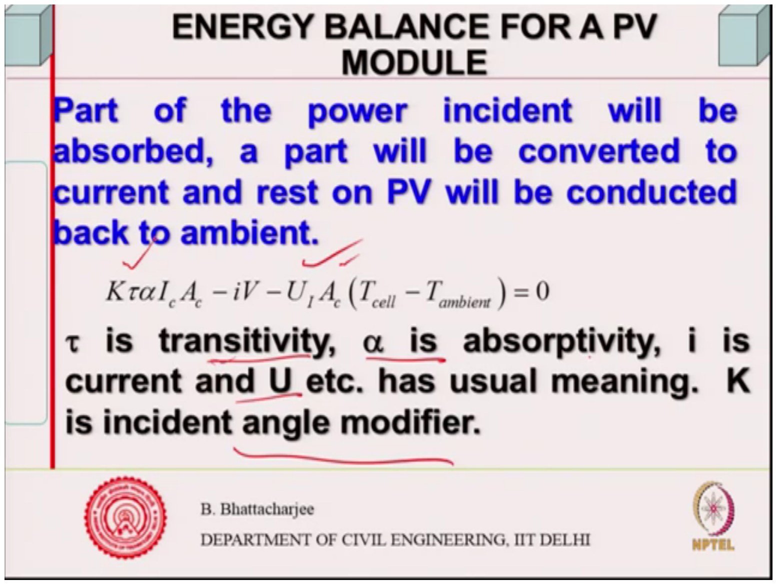

So, tau is transitivity, alpha is absorptivity, i is a current and U as I said U value I think we have would have discussed sometime 1 over U is the insulation, area of the cell and K is what is called an incident angle modifier.

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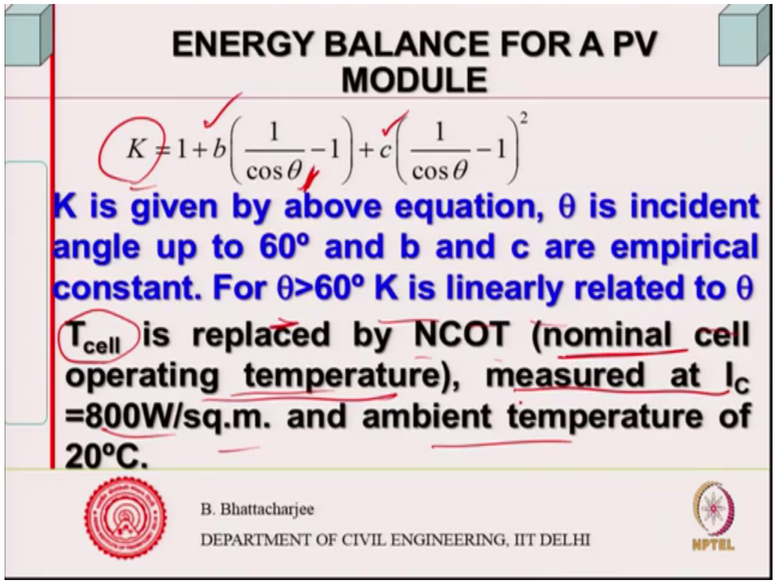

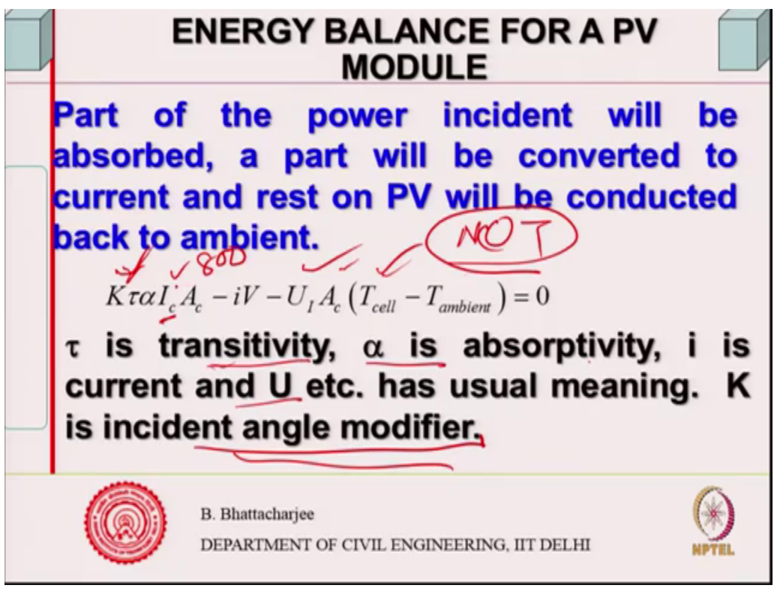

So, K is given by a formula like this K is given by a formula like this where theta is the incident angle, b is a constant and c is also another kind of empirical constant, right. For theta greater than 60 degree K is linearly related to theta not in this manner. So, there is an empirical constant this values should be available to us generally and so this is the depending upon your angle of incidence at which the radiation is falling.

This is you know this is basically what we are calling? We are calling it as a incident angle modifier. So, amount of radiation that will fall in will depend upon the incident angle because there is both diffuse direct everything is involved so we are not simply calculating out the beam radiation but in radiation I am multiplying by a incident angle modifier otherwise it have been simply Cos i and things like that but we are multiplying with an modifier.

So, this is what it is and T cell is replaced by nominal cell operating temperature, T cell is a cell temperature which is unknown actually because how much it will get heated up. So, one ways to nominal cell operating temperature on an average basis measured at I c at 800 square. So, this is this can be I can replace this by NCO T in standard condition when I is equal to 800. For I equals to so if in the factory or laboratory if I have to measure factory laboratory I measure then I find out what is the c so the T cell that is called NCOT and when I is equal to 800.

So, that is how because that would be known to me that would be known to me, you know NCOT is a standard condition so actual cell condition I might be able to calculate out from this let us see if we can do that. So, measure at I c 800 and ambient temperature of 20 degree centigrade. Now everything will change as soon as your ambient end changes and ambient changes and radiation changes.

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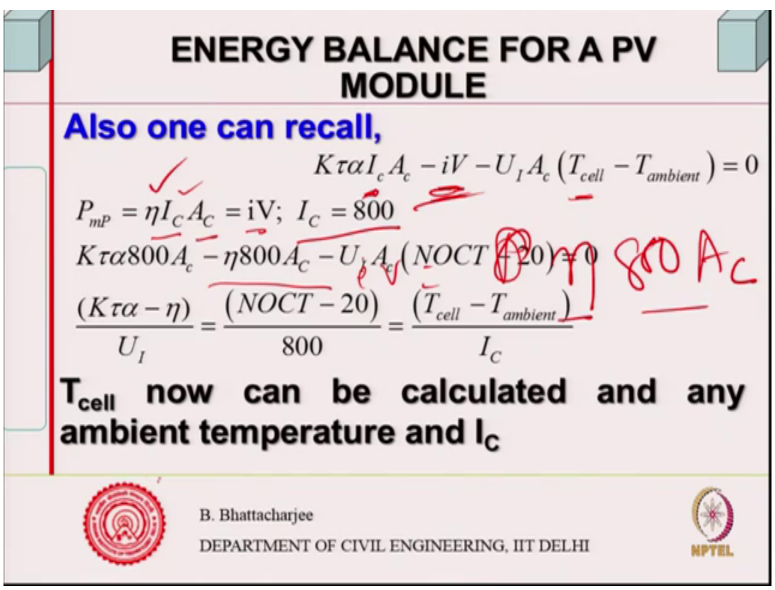

So, I fix a radiation and under that condition we found out this once which will be available to us the manufacturer will give us. So, if I put it here in this one since iV is nothing but power and this can be written as this can be written as power generated. So, if I know efficiency is nu and 800 under standard condition 800 is a watt per meter square is the radiation intensity multiplied by A c I can replace this by efficiency multiplied by 800 to arrive at certain things which you should see, right.

So this I can replace, this I can replace by 800 under standard condition and then this will be NCOT then this will become NCOT. So if I take a I c is equals to 800 Mu I c A c is equals to the power generated this efficiency and so I write it like this, right.

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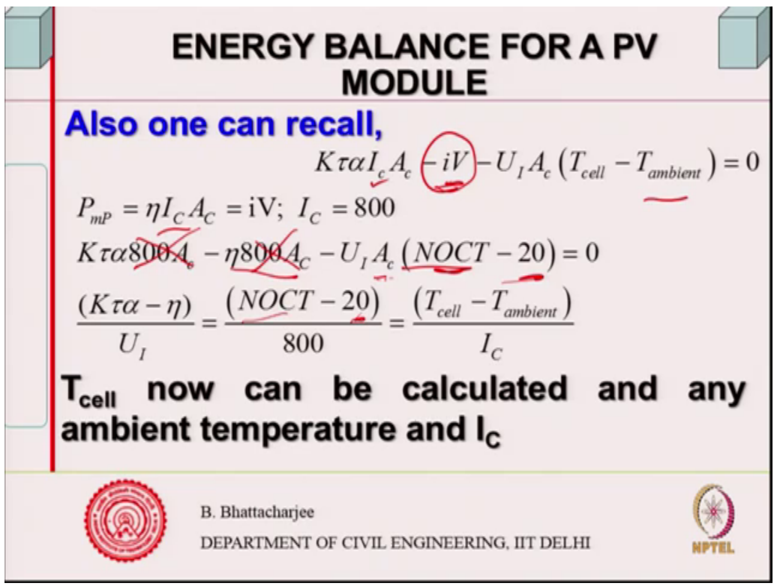

If I write it like this if I write it like this replace this by 800 this is my new I c A c because this efficiency multiplied by the input radiation which is 800 into A c then you can see that I can get an expression for NOCT and this T ambient has 20. So, at 20 which is the laboratory condition and this is the nominal operating cell temperature I can write an expression like this and you can see that from everywhere this will these terms will cancel out, right A c this terms will I mean A c cancel out not this, these two terms will cancel out. So, U NOC I can take this common so let me just redo it to again.

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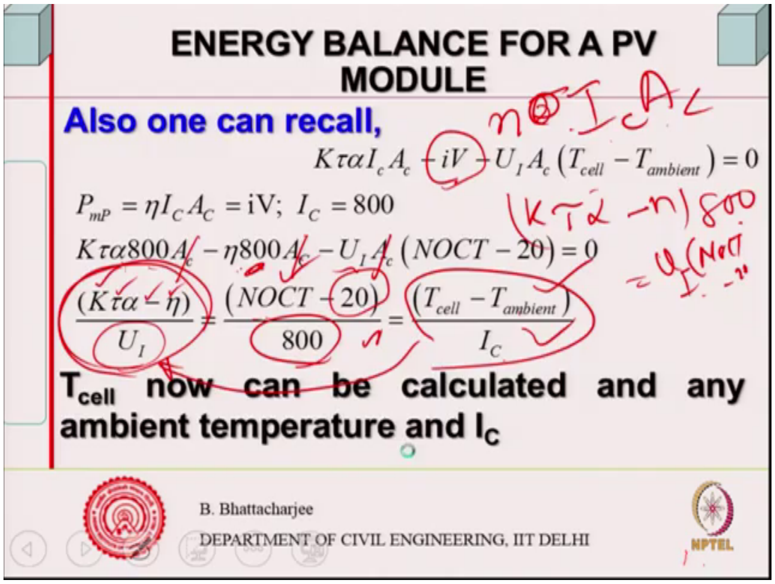

So, A c will cancel out from all of them and if I take it out U I on this so I take 800 nu common nu into 800 common from this. So, I get K tau alpha minus nu into 800, right equals to NCOT U I, U I NOCT minus 20. So, NOCT 20 divided by 800 is equals to this expression you can get you can get this expression, right you can get this expression, okay. This is, this depends upon angle of incidence, this is the property, this is also the property absorptivity transitivity etc.

The efficiency of the system and U value is known U value of this cell should be known, so one can obtain this. Now, supposing instead what I do is I put I c not this 800 in this condition I put and replace this by nu into I nu into basically I c into A c nu into because this was for standard condition, this was for standard condition where I put this as 800 instead let me write this as nu into I c into A c again I c A c will get cancelled and I will get an expression of this one and this equals to this because T cell minus T ambient in instead of nominal operating cell temperature minus 20 I will get T cell minus T ambient divided by I c.

So, this T cell now can be calculated you see if you if this is known NOCT is known nominal operating cell temperature when standard condition of 20 degree ambient 800 is the incident radiation then if I know what is my ambient, what is I c coming in T cell I can calculate or because the actual performance will be at the T cell level, right.

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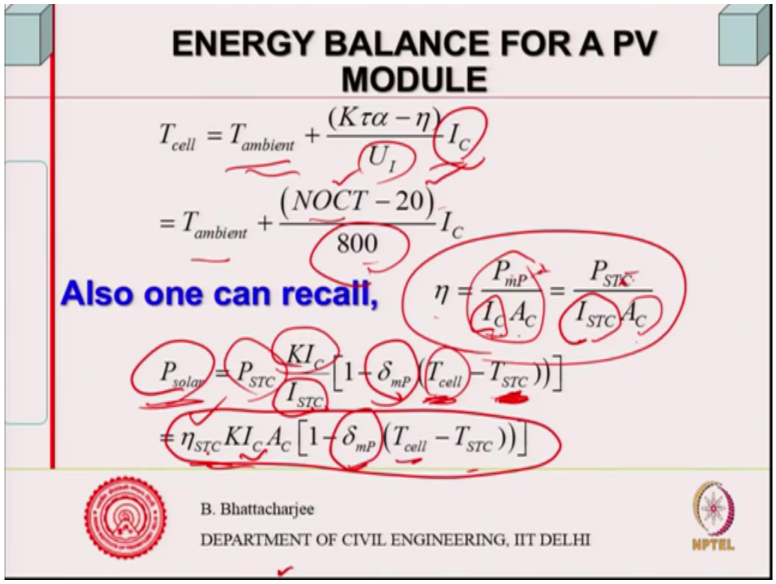

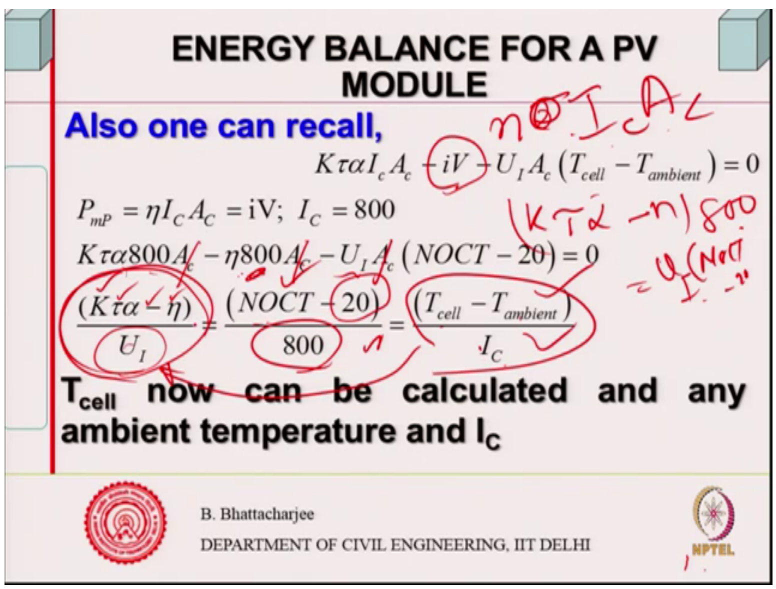

So, this is important actually T cell is equals to T ambient from this expression from this equating this to T cell will be equals to this multiplied by I c plus T ambient so that is what it is T ambient I c, right. So, also this is equals to T ambient NOCT 20 800 is known to me, this will be known because this is a laboratory state where I have measured everything and 20 degree I have kept 800 is the incident radiation I have this is for the given radiation that I will have in actual condition and actual efficiency inside that I can find out or so U I is a U value of the whole thing so that is how I can find out, right.

So, T cell I can find out provided I know also efficiency was this and P solar is equals to P mP if you remember it is a function of temperature and this was T cell minus T standard condition for standard condition T cell minus T STC 1 delta mP because standard condition I know and cell temperature I know so p solar will be given by this P mP and remember this power this efficiency we have written in terms of P mP divided by I c.

So, this if this is standard if I take I STC and A c and this one power I replace by P STC multiplied by this basically P solar I can relate like this because I c standard condition I c set standard condition this since this is P STC by I STC into standard conditions this I can find out and for solar if I want to find out I have to multiply it by K into I c how much is that coming? How much is a incident actually? So, this will be given by this formula.

So, P solar power solar available by will be given by this formula where this is the (intense) intensity of radiation falling in this is the cell and delta mP is the temperature coefficient power for power T cell minus T STC and this is the standard condition efficiency which will be known to me but what do not be known to me is of course in this will be this I mean otherwise this would not have been known but this two are equated so that is how we can find it out.

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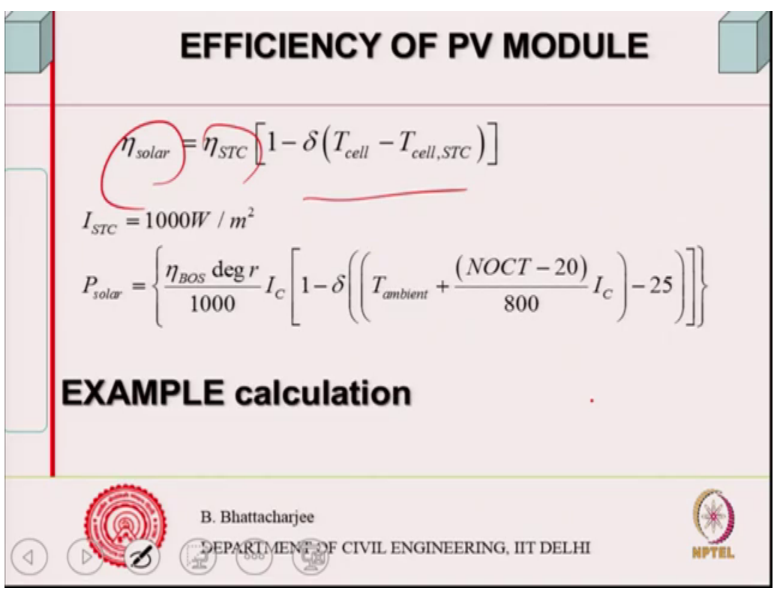

So, you see nu solar one can find out nu STC minus 1 minus etc-etc as I said. So, consider let us say I STC is equal to 1000 watt per meter square then one can get use this expression to obtain P solar from this particular one like this so this is what it is. Now we can look into the specification, what the specification will get it and one simple calculation of the efficiency out from this.