Indian Institute of Science

Design of Photovoltaic Systems

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NPTEL Online Certification Course

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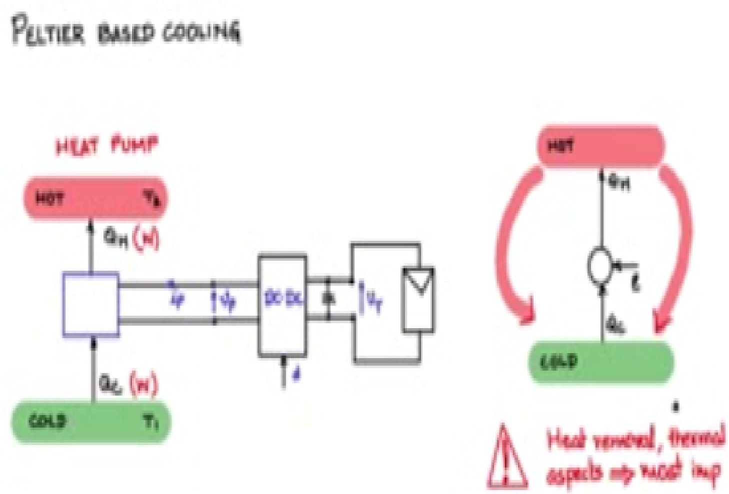

Peltier based cooling, how do we do it. Let us have a look at this visualization, we have seen this before, this is the cold junction, this is the hot junction, in between you have a heat pump which is the peltier element which is taking in the electrical energy and extracting QC amount of heat from the whole junction and passing it on to the hot junction.

Let us replace this heat pump with a square box assembling the peltier element having two terminals electrical terminals are shown like this. Now to the electrical terminals we connect the output of a DC-DC converter. So this is the output of the Dc-Dc converter, power is flowing like this, on the input of the DC-DC converter we have this buffer capacitors and the terminals of that is connected to a PV source, PV module, PV array, PV panel all these are PV sources appropriately sized such that it is connected to this terminal.

There is power flow from the PV module into the DC-DC converter along the DC-DC converter output into the peltier. So this is Vt terminal voltage of the PV module, you have the duty cycle which will be used on the control input, and you have Vp, the terminal voltage of the peltier element. There is also another important parameters It which is the current that is being fed into the peltier element to achieve the pumping action, the heat pumping action.

So we know the thermal, we know the resistance, the electrical resistance in ohms that is offered by the peltier element which is given in the datasheet we saw, and then using that you adjust the duty cycle accordingly along with the insulation the duty cycle can be controlled such that the PV module is operated at the maximum power point, this we know how to do.

So a maximum power point operated PV panel DC-DC controller setup can be used above the peltier element. So the duty cycle can be used to control Ip the current that is fed to the peltier junction and controlled the amount of QC that can be extracted from the cold junction and then fed into the hot junction. So this is the process of heat pumping.

And there is one major problem, let us say that is the hot junction and then I have a cold junction, and in between I am having this heat pump. QC is extracted from the cold junction and given to the hot junction as QH which includes even the energy that is required for pumping. Now this hot junction is at a higher temperature than the cold junction which is at a lower temperature.

When heat has to flow from a cold, low temperature to high temperature you need a pump, it is much more difficult. But from high temperature to cold temperature the heat flow is automatic, you do not need the means of the pump. So automatically heat will find a path like this or like this, and then reach the cold junction. And the Δt what you are trying to achieve will actually come down and the temperature difference between these two junctions will not be that much.

So it becomes very, very important that not only do you have to pump the heat up, you should retain that heat there or remove it elsewhere, so that it does not come back to the cold junction and reduce the Δt. It is like, it is analogous to a water companylet us say water is found from a low level to a higher level and if there is a large leak in the over red tank whatever you pump comes down it never fills and then all the water is still remaining in the bottom the water pumping is not doing much work same way here also if the heat is again coming back the heat pump is not of much use therefore it is important that you retain the heat and the hot side or remove it from the hot side to l^2.

So that heat does not come back into the cold junction so the hole of the design of the peltier based application should take this into account and one of the most important thing is the heat removal and the thermal aspects these are very important and then we will have some look into this to see that how we go about designing peltier based cooling applications.

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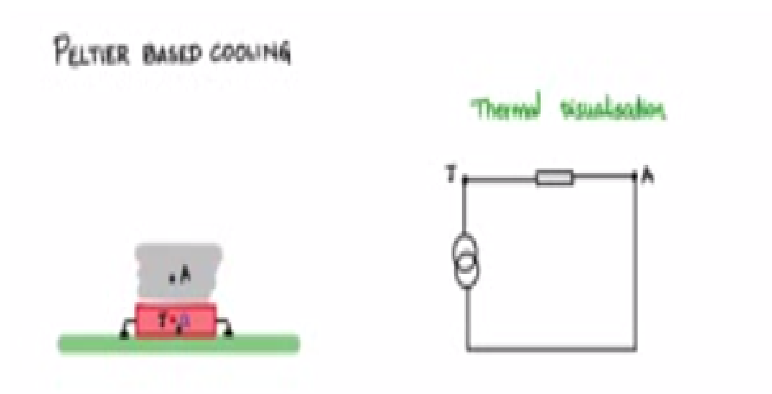

Let us discuss some examples on applications of peltier based cooling consider a PCB this green strip that you see here consider that it is a PCB on the top of that let us have a component which is becoming hot which is dissipating power so let me draw a component mounted on the PCB which is which dissipates power and it is our objective to remove the heat from it and then keep it within a rated temperature junction temperature such that it operates properly.

Now this competent at the center of the component within it is core in the junction it is generating heat because of electric current going through it there is a power that is getting dissipated and that power has to go out and this point here is can be considered as a heat source for that is getting generated and it has to flow out from there in this fashion so this is the heat flow and then we call it has Qc.

So Qc amount of heat is being extracted that much amount of power is flowing out because if dissipation within this component and it is becoming hot now let us see how we will build some relationship to design a peliter based cooling now let me call this central core where the heat is being generated as the junction mostly most of the semiconductor junctions or the central code where the heat is getting generated many of the components.

So I will call that has J and the heat is flowing out into the external ambient here and I will call that ambient and I will put a dot there to represent the ambient and I will call that one as A for ambient so this here is a pictorial visualization of what is happening let us map this into a thermal visualization so let me visualize it in a thermal fashion with the equivalent circuit now I will put a current source the current source is representing the heat flow.

The heat that is generated and that is flowing out is extracted out of this component so this current source is flowing in this fashion this node I will call that one as J and that is the junction representing this core here which is then flowed up by a resistance it is not resistance from the electrical circuit point of view it is thermal resistance and at the other side I have the completion of the circuit.

So that the power flow flows in this fashion just like an electric circuit but it is not electric circuit it is a thermal visualization now this node I will call it has ambient and coming back to this physical picture visualization this junction her is generating Q_C amount of power which is flowing out as shown and it is equivalent to have in a current source here which is having a value Q_C and that Q_C current source is flowing in this direction and there is a drop across this thermal resistance and that is the temperature difference between this and this, so now let us say that Q_Cw is flowing this node is at temperature called T_J that is the junction temperature and this node is at temperature T_A.

And that is the ambient temperature and this element I am calling it as $R_{\theta JA}$ thermal resistance from junction to ambient J_A, so now let us try to see what is a relationship between all these parameters so $T_J – T_A$ I mean interested in that what is the ΔT T_J to T_A what is the ΔT that is what he is the potential cause the heat to flow and that is equal to this Q_C and thermal resistance, so I will call that $R_{\theta JA}$ thermal resistance into Q_C in mode generic form I can say ΔT = thermal resistance into heat flow.

If you want to write thermal resistance in terms of ΔT and Q_C we can write it as thermal resistance is ΔT temperature difference between two points temperature difference across the thermal resistance divided by Q_C the heat flow through the thermal resistance this is an important relationship which will be used in most of thermal visualizations remember this ΔT is in degree Kelvin Q_C is in watts, so thermal resistance is in a degree K/W or degree C/W because when you take thermal ΔT. It is a thermal here temperature difference so you could as well use degree C/W both are numerically okay.

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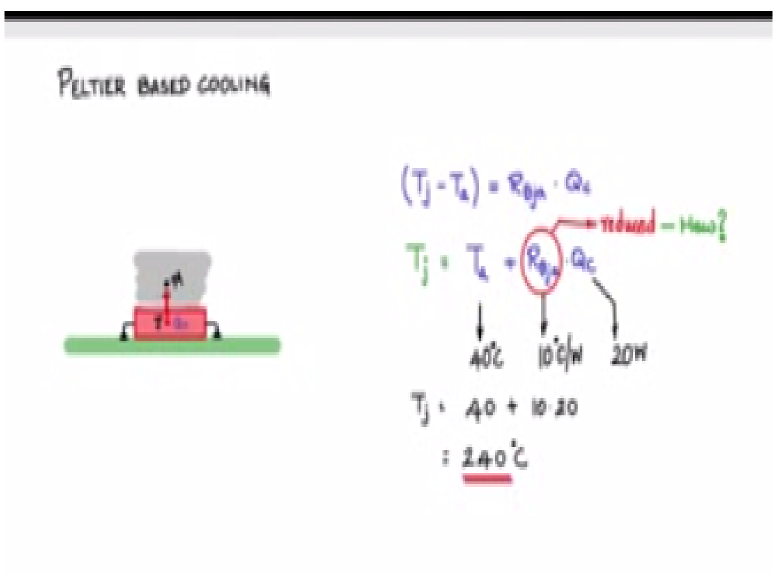

This component mounted on the BCB is dissipating and amount of power Q_C and that is being given out to the ambient and we saw that the equation is given by this relationship this is T_J the junction temperature TA the ambient temperature difference in junction and the ambient temperature ΔT = $R_{\theta JA}$ junction to ambient thermal resistance into the amount of power that is flowing that is the heat flow Q_C in watts, now let me rearrange junction temperature is equal T_A + $R_{\theta JA}$ into Q_C now here we know let us say for example T_A can be found out.

Let us say we will set it at maximum 40^0C or θJA depending upon the component from the data heat we can get Rθ junction to ambient which will be let us say for example 100C/W Q_C the amount of power dissipated within the component is 20W , so we need to remove 20W of power out of this component now using these numbers as an example T_J the junction temperature or sort to be 40 plus than into 20 so 240^0C now this is a tremendously high temperature and most of the time the component would have blown.

By time it crosses 150^0C so we should not allow the junction temperature to raise to that temperature which means we should that the heat is removed out of this component much more quickly, so how do we do that you have no control in Q_C because that is depended on other parameters of the circuit you have no controlled on T_A because ambient temperature is not controlled by you it is decided by the external ambient the only thing that you can control is the thermal resistance so this is what you can do something about and you can reduce this, how do you reduce this, so that is where Peltier cooling comes into picture so we will initially put heat sink and see how the heat sink will reduce the junction temperature and later we will put a Peltier element to cool this component and then see how it will improve the heat removal out of the component. Let us zoom in here, let us magnify this and then look at the thermal resistance here.

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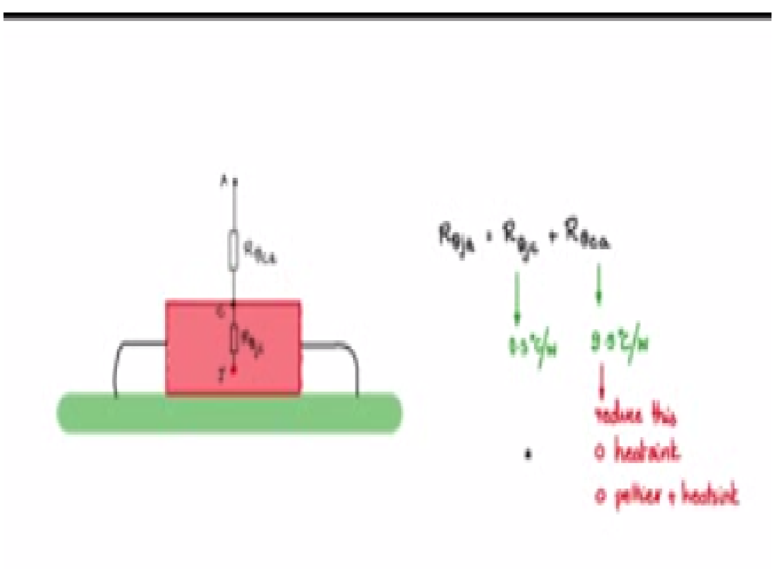

So we have the component placed on the PCV which magnify zoomed in and we have the core where the heat is dissipated and from that core we have a thermal resistance up to the case and that is rθ junction to case, so I will say junction to case then there is a thermal resistance from case to ambient so we call that one as rθ case to ambient, so you can split the junction to ambient thermal resistance into two parts rθjc that is the thermal resistance from junction to case and thermal resistance case to ambient.

The thermal resistance case to ambient will be the major contributor to the entire thermal resistance from j to a, this will be small part this will be given in the data sheets of respective components. So rθja can be written as rθjc + rθca now this will be around let us say 0.5°C/W it will vary from component to component but I am just giving the order of magnitude and the remaining part will be around 9.5°C/W for the example that we had just discussed.

So this is what that needs to be reduced, so how do we reduce this we can try to put a heat sink see that the heat is dissipated heat flows quickly out into the ambient by putting heat sink and we could also improve that by Peltier plus heat sink combination. So we will see how do we go about doing that?

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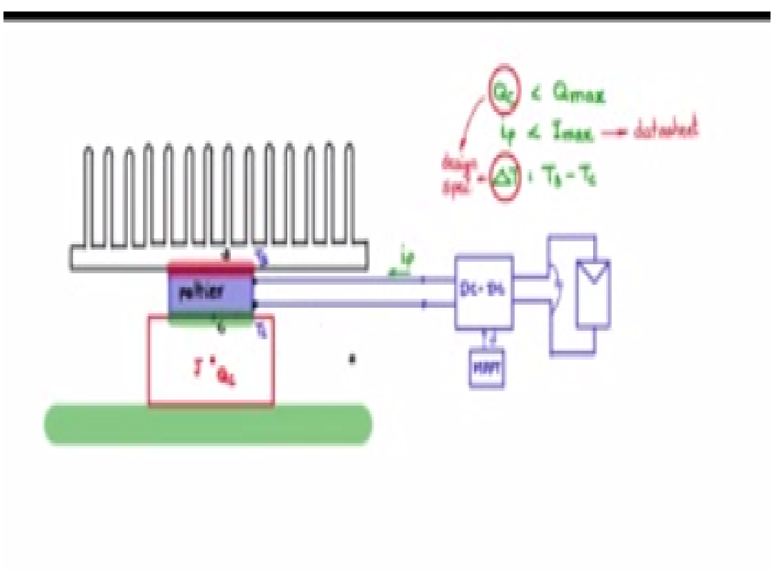

Now imagine this component is sitting on the PCB we will attach a heat sink to the surface of the component such that it dissipate more quickly it enables the heat flow that is generated within the component to reach the ambient in a much more quicker manner, so which means we would like to reduce the thermal resistance from the case to the ambient. So we will draw a heat sink there are many heat sinks in the market you can look into the thermal resistance that are given in the data sheet catalogs of the various heat sinks by the manufactures.

And appropriately choose a thermal resistance, so I make this draw this heat sink so this is a heat sink it has lot of the spins because of the spins the surface area is increased and because the increase in a surface area the heat can more easily go out through a much more larger surface area, and we have this core which is actually generating the heat QC this is the junction this we will call the boundary between the entire boundary which I am representing by this dot where the case of the component comes in contact with the heat sink at that place.

I am putting the symbol c that is the case represents the case and this entire heat sink I am calling it as s and then you have the ambient to which ultimately the heat as to reach to the ambient temperature that ambient will call it as A so if you see that there is a heat you see which needs to be extracted from this junction passed on to the case from case to the sink and forms sink to the ambient.

So if you now visualize the thermal equivalence circuit so I have the constant current source which is having a value Qc now I will put 1 thermal resistance here and calling that one as junction to case or Ø junction to case then another thermal resistance will call that one has case to sink so there is an impedance across the boundary depends upon how nicely the contact is between the case and the heat sink.

So we will say case 2 sink and then from sink into ambient you will have the thermal resistance sow e will call that one has sink 2 ambient and the ambient is the ground temperature reference temperature so the junction case sink ambient and we have Qc amount of power which is flowing heat power that is flowing there is the junction temperature Tj case temperature Tc sink temperature Ts.

And the ambient temperature Ta ambient temperature you have no control because it is dictated by the external ambient so what E is the temperature difference Tj-Ta, Tj-Ta is the drops of the temperature drops of the thermal resistances so let us write the relationship Tj-Ta equals what is the temperature drop across or Øjc it will be into the heat flow Qc so r Øjc *Qc+R Øc is *Qc the same procedure is flowing into this thermal circuit +r Ø Sa*Qc will be the drop temperature drop across this thermal resistance.

So this is our equation each is the thermal drop so this would represent Tj-Tc this would represent Tc-Ts this would represents Ts-Ta so if we use typical values then let say r Øjc is the order of .5° centigrade per watt or Ø cs the order of .1° centigrade per watt R Øsa of course you can buy various different types from the market with the different thermal resistance I will take some typical value 1^0 centigrade per watt.

And we know this is Qc is 20 watts from the previous example that we discussed and Ta is 40^0 centigrade of course this can also vary from place to place for the particular place to put take the ambient or you should take the ambient if it is within an enclosure you should take an ambient with the enclosure normally if the component is within the enclosure the worst case ambient within the enclosure is taken as 50°.
So now you can compute Tj so Tj is 40+this value 40+this value is 10, 10°+ this value is 2°'s + this value is 20° so that come to 72^0 centigrade so compare this with the earlier value that we obtained of a 240° centigrade so by putting heat sink you can actually control the junction temperature to value which is safe which is well within the ratings of the particular component.

Now if we introduce peltier, peltier junction peltier element in between then you will see that the r Ø is Sa improves much better and there by heat removal is much, much improve so how do we introduce the Pelletier junction to this we will have a look at that.

We shall now improve the thermal resistance to seek the ambient S2a or θsa further by introducing the Pelletier cooler in between. So let us introduce this Pelletier junction in between so I will lift the heat sink and in between I will put this Pelletier element. So this Pelletier element will have 2 terminals brought out like this and to the 2 terminals you connect the BC DC convertor and DC DC convertor is getting power from a PV panel like this connected in this fashion.

And the power is flowing from the PV source through the DC convertor into the Pelletier junction which is providing the electric energy to pump heat from the cold junction this component which is supposed to be the cold junction to the heat sink which is the hot junction. So now you could have the DC convertor where the duty cycle is controlled connected to the MMPT controller block the maximum power point controller block.

So this portion would be a maximum power point controller DC convertor interface to a fore hold type pan. Now when you power of the Pelletier junction by passing the current through that now this component which is generating Qc amount of heat the Pelletier junction as to remove Qc amount of heat and pass it out to heat sink. So this block the component block will become the cold junction so the cold junction portion of the Pelletier will come on side.

And the hot junction portion or the Pelletier should be on the heat sink side, the component will be at the case temperature DC the heat sink will be at temperature which is the heat sink temperature TS. How do we select this Pelletier element? you need to look at the data sheet for these important parameters Qc the component is power Qc and the Pelletier has to move this amount of heat power into the heat sink.

So the heat flow will be Qc and Qc passing through the Pelletier should be less than Qmax from the Pelletier data sheet and another important parameter is Ip the current that is flowing into the Pelletier and that Ip should be $<$ Imax as given in the Pelletier data sheet. TS – TC is the across the Pelletier junctions and this is the designed parameter, this is for a particular application. One must decide how much should the t?

So this comes from the speck of this component how much case temperature it can with stand? The designer should appropriate fix the case temperature and the heat sink temperature. So let 15^0 centigrade like that it should come as the design speck. Now Qc is actually the amount of the power dissipated in this component, so it could be among IGBT it could be an IC, high power processing. So the power dissipated here it is dependent on remove it.

So this again is a design speck coming from the other portions of the systems determined by the other portions of the systems. IP actually you can decide from the data sheet after you have chosen the Pelletier element. so keeping this factors in mind designed speck let us look at the data sheet and see what information we can gain in trying to decide on the Pelletier element.
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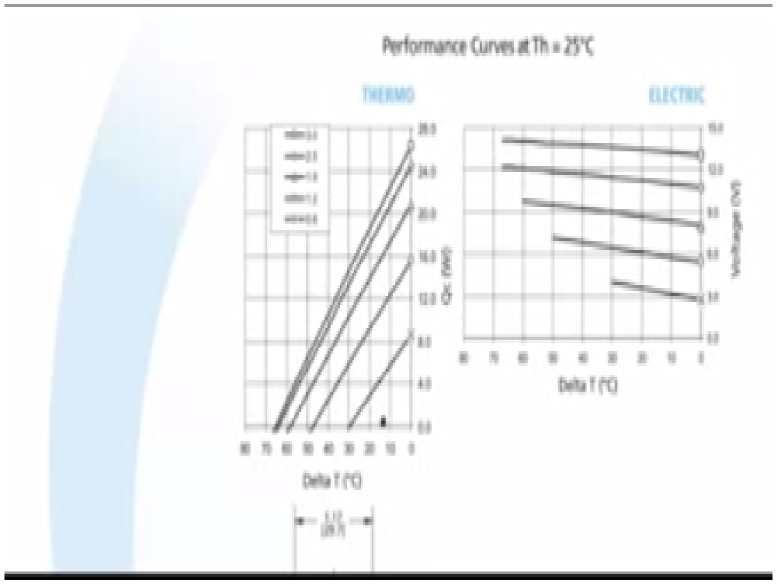

Now in the data sheet consider this thermo graphs now the x axis, now in our application it is TC – TS – case temperature now you can define it some value let us say 15 degrees means somewhere here so let us draw a line up at this 15 degrees so you see that it intersects the at 15 degrees it intersects the no more graph curves which is the family of curves at different IP currents, currents to the wieldier junction so here is another point of intersection here is the another possible operating point so on so if you see from the requirement from the designs pet of Δt we have this now QC is another design pack because QC is the amount of heat that you Pelletier junction will have to remove from the cold junction.

And in this case the cold junction is the component which is deputing heat so the QC we said ion the previous example of 20watts now let us say 20watts you want to consider removing from the component pass it on to the heat thing now 20 watt is of here and almost all the points here are below 20 watts so I cannot choose that the only point is there above 20 watt which is here so if I pass 3amp current then I will be able to remove greater than 20 watts amount of power and push it on to the heat sent for a temperature difference Δt of 15 degrees.

And degrade so this is the operating point that you need to consider which is greater than 20 watts QC and you should pass around 3amps of power 3amps of current through the junction so that it has enough energy to left this heat QC amount of heat flow and pass it on to the heat sent so in this way you can decide that the Pelletier food at least have a power rating of greater than 20 around 24 or 28 watts Pelletier element can be chosen and appropriately from the log graph seeing thermo graph seeing the point of intersection with the QC and Δt you can decide how much amount of IP current should be said into the Pelletier junction.

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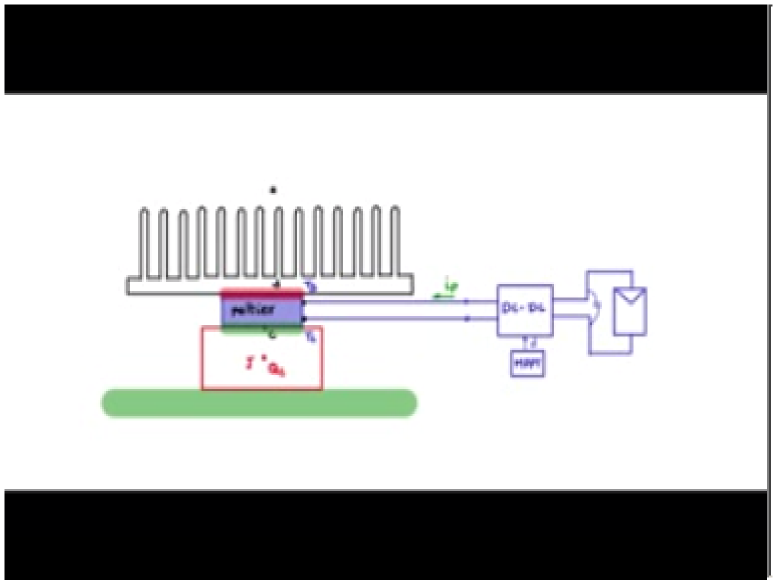

It becomes very important now that the heat sink the heat that is put into the heat sink should be removed at the rate that the Pelletier junction is allowing the heat flow from the junction of the component to the sink so this QC rate of heat flow should be maintained from the sink to the ambient otherwise the sink temperature will rise once the sink temperature rises you will see that the TC temperature will also rise that is the case temperature will rise because your Δt is fixed by the no more graph and the amount of current that you are pumping into the Pelletier element and as a consequents then the J junction temperature TJ will arise.

So therefore it is important that not only enough if you make the Pelletier junction to remove the heat from the cold side put it into the hot side but you should also design your system in such a way that this heat sink is capable of removing the heat out from the heat the sink into the am pliant at that same rate only then the whole system together will work properly as a cooler so you will see that there are many products where just the plan heat sink is not sufficient if sufficient cooling is needed the heat sink as to be made very big.

And that may be it may not fit into the enclose so the heat sink is made small they will add additionally a blower a fan something like this so this fan as two terminals and blades in this fan will be driven from the output of the DCC convertor one more set of terminal is available from the DCC converto0r so this DCC convertor should be a multi output DCC convertor and that will get connected to the fan and control the fan so the fan will enable forced cooling it will enable flow of air through the fins of heat sink.

And remove the heat at a much more rapid phase the fan together with the heat sink will have a thermal resistance are the sink to am pliant which is much lower than just only the plane need sink therefore for given sized heat sink force air cooling will lead to much faster heat flow through the heat sink so this fan coupled with the DCC convertor MPPT all this electronics driving the Pelletier is generally refer to as thermo electric controller so this would be a total Pelletier cooling system that you can find in many products in the market.