Fundamentals of Electric Vehicles
Technology and Economics
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Lecture 38
Thermal Design - Part 2

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Welcome back. So today we will go through the Thermal Design of battery back. A part of that we have started in the last class where we have talked about why thermal design of what are the things needed in thermal design of battery pack? Why thermal management is important and we have discussed several things and especially about temperature. The temperature impact the pack directly. What are the things?

Electrochemical reactions within the cell that is getting impacted by the temperature, at very low temperature this electrochemical reaction rate is very slow. So we do not want very low temperature, at very high temperature it tend to, cell tend to degrade as well as there could be several other problems associated with that like thermal runaway, failure of component and all those.

Its also decreases if you do not maintain the temperature in the proper range it also decreases the efficiency of the pack, charge acceptance, power energy availability, safety and reliability, life and lifecycle cost, so these all the things depends upon the proper temperature or proper temperature range. What are the required function of thermal design that also we have gone through, the compactness, lightweightness, easily packageable, reliable, serviceable, low cost, low parasitic losses and the optimum temperature ranges that is the required function of a thermal management system or a thermal design.

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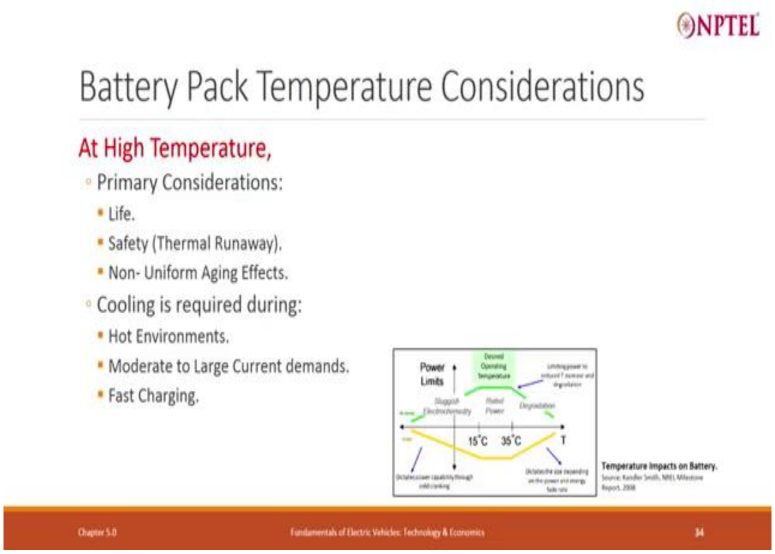

It should also have the small temperature variation among the cell to cell or within the pack, so temperature gradient we say that should be very low and then we have also discussed that what should be the optimum temperature range for the operation of the pack. So for the current cells, for current and (())(02:31) cells or other varieties of cells the temperature range is something between 15 degree to 35 degree C.

So, if a temperature is in between that you can get best out of the it is a life, calendar life as well as cycle life and it will perform well and then we also mitigate different type of accident which can happen. One of them is thermal runaway other things like melting of materials or electrodes here and there. So, then we have divide that there are basically 3 temperature range; normal like moderate, high temperature and low temperature.

At high temperature what are the things required? Mostly you require cooling air that time, at low temperature you require heating. At moderate temperature like 15 to 35 degree so in that case only just whatever the heat is getting generated that you have to remove so that the temperature should not elevate.

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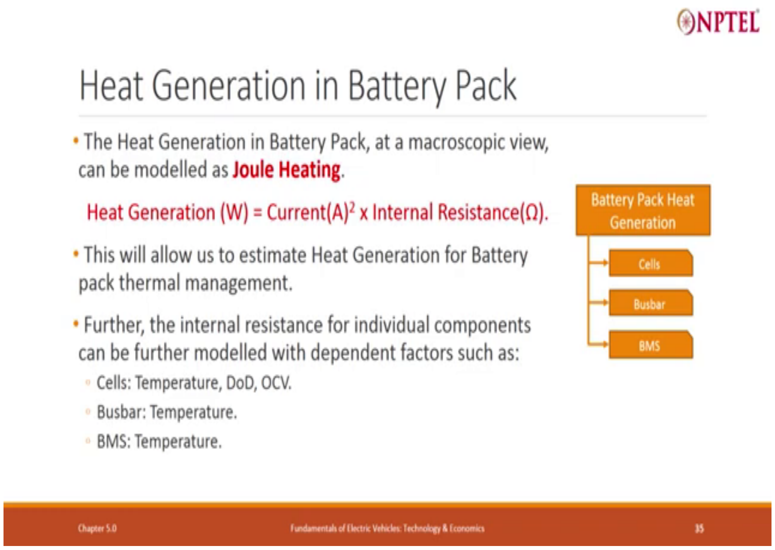

Then we have also talked how heat is generated in a battery pack, so the simplest form of the heat generation which can be written in mathematical form is Joule, like Joule heating is nothing but I square R, so I square is the current drawn from the battery or current fed into the battery during the charging, current drawn from the battery during the discharge and the internal resistance of the cell.

Basically, this will allow us to estimate the heat load or heat generation in the battery. And how does it impact its cell? Wherever the current is flowing in cell we are taking the current out or putting the current back in some side then bus bar current flows through that one. And in the BMS, so these 3 things are basically a major source of heat generation inside a battery pack. Now this can, this heat generation rate can be impacted by several things like DOD, temperature, temperature of bus bar, temperature of cells because the internal resistance is also a function of temperature, DOD, as well as OCV.

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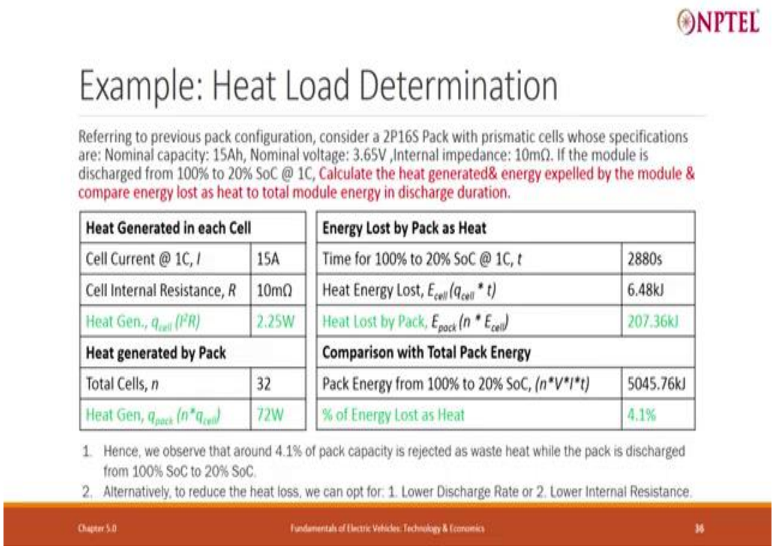

Then we have started a example problem how to estimate the heat generation or heat loss or heat low these all are similar terminologies. So what there we have done that is we have considered a same pack what we have developed during the mechanical design 2P16S with the cell capacity of 15 Ah. The internal resistance of that cell is 10 milliohm or internal impedance is the 10 milli ohm. 10 milli ohm is a generally resistance is at higher side and this you achieve during the end of the life of the battery pack that means then the it has been degraded to 70 percent of its original capacity or 75 percent so whatever we got is approximately it some at that.

However, for a new cell it would be something lie between and fraction of milliohm to 5 milliohm. However when you are doing a thermal design it is not only about that particular moment or only for new cell, it have to take care of the complete lifecycle of the cell also that means at the end of the lifecycle what would be the heat generated that you have to anticipate in early design and then you have to design your thermal management system with that.

So generally it becomes twice at the end of lifecycle of a cell the internal resistance become twice. So for a new cell it is a 5 milliohm however for estimating the things at the end of life we have taken a 10 milliohm. Now the module is being discharge from 100 percent to 20 percent SoC, the battery pack is discharged from 100 percent SoC to 20 percent SoC.

And then at the rate of 1C discharge, 1C discharge means if it 2p then it would be 30 ampere. So what e have to do? We have to calculate the heat generated and energy expelled by the module and compare energy loss as heat to total module energy. So, we are discharging that means we are doing some useful work like by, either by driving motor or something. So, there are some useful work but there is some energy getting lost as a heat that is not a useful.

But still first of all that gets generated because of internal resistance at the same time we have to also remove so we may add up end up adding some extra energy for removing that one means we may be consuming some extra energy to remove that one. So first even before removing first we need to know what would be the estimate, what would be the amount of energy which we need to remove that is as a form of heat.

So, that is what we have done in this example problem. So, if you see the cell current at 1C for 1 cell it is 15 ampere only, 2 cell together gives 15 ampere plus 15 ampere; 30 ampere two parallel. So, for 1 cell it is 15 ampere, now cell internal resistance is 10 milliohm. So, heat generation for each cell would be 15 square into 10 into 10 to the power minus 3 watt, so that is 2.25 watt.

Now heat generated by the pack, how may cells we have in the pack? 2P16S that means 32 cells we have in the pack and each cell is generating a heat of 2.25 watt. So what would be the total heat generated by the pack? Or you can say heat load of the pack this is only because of the internal resistance is 72 watt. So, energy lost by the pack as a heat since it is coming from 100 percent SoC to 20 percent.

Consider a linear behaviour here SoC is however you would have seen in the last chapter 4 that it is not as a linear function SoC is not a linear function of OCV or discharge. However, consider here as a linear function just to simply the problem, so the total time taken 100 to 20 percent means 80 percent of the time is 2880 second.

Heat energy lost becomes 6.48 kilo joule, heat lost by the pack this is for 1 cell multiply with 32 you will get 207.36 kilo joule. However total energy from 100 percent to 20 percent SoC that is around 5045.76 kilo joule, so what is the ratio of heat to the total energy? Is that comes around 4.1 percent, 4.1 percent is a huge energy. If we can save energy my range will go by 4 percent.

Sorry approximately 5 percent and 5 percent range for 100-kilometer battery packet it is a 5 kilometer it is a huge. Now we already know this much heat is being generated 72 watt as a power or if you talk about energy it is a 207.36 kilo joule. So first of all heat has generated now some one has to remove that heat other if it is not removed what will happen? The temperature will keep on rising.

So now the extra energy will be taken from the battery to remove this heat because you cannot simply remove it. You have to use some mechanism either active or passive. So, those mechanism we have to use. Also you see here we have not consider the environmental impact here. Environmental impact means now if we want to maintain between 20 sorry 15 to 35 and my environmental condition is 45 or 48 degree centigrade, what will happen?

There is a possibility that some heat will go inside if you are not taking out heat so that heat will get added up. So, the heat load is not only for the battery pack if there is a any heat coming from outside or if there is any heat going to outside will also be considered for the total heat load calculation and then we have to remove that heat.

Let us see if there is a temperature difference it is impossible to not have a heat flow you can reduce by putting some proper insulation material and all the thing but it cannot be 0, it can be reduced. Will talk those things later part of the class. So, what we see here for a SoC from 100 percent to 20 percent 4.1 percent of energy is getting lost because of the heat generation and why that heat is getting generated because of the internal resistance.

How can we reduce the heat loss? What is the heat loss here? It is I square R, I is the current and that we also say C rate. If we reduce the C rate by half, let us suppose 0.5 C what will happen? Our heat loss would be reduce by 1 by 4 because it is a function of I square. R remains same, we cannot change R because it is the property of the cell but I we can always control.

So, we make a battery pack for lower charge or discharge our heat generation would be less. So, will loose much-much less energy, so in that case I can say if I can reduce the heat load by sorry current drawn or during the discharge and current put during the charging by half. Let us suppose 0.5 C but this energy lost which is right of 4.1 percent will go down to approximately 1 percent. Just by changing the C rate by half.

Secondly, we can select a cell which have further lower impedance or further lower resistance there are cells available which has impedance of 1 milliohm at the end of lifecycle it may go to 2 and half milliohm but still it is 1 by 4 times of that one. However, the impact of the resistance is a linear however impact of current is square.

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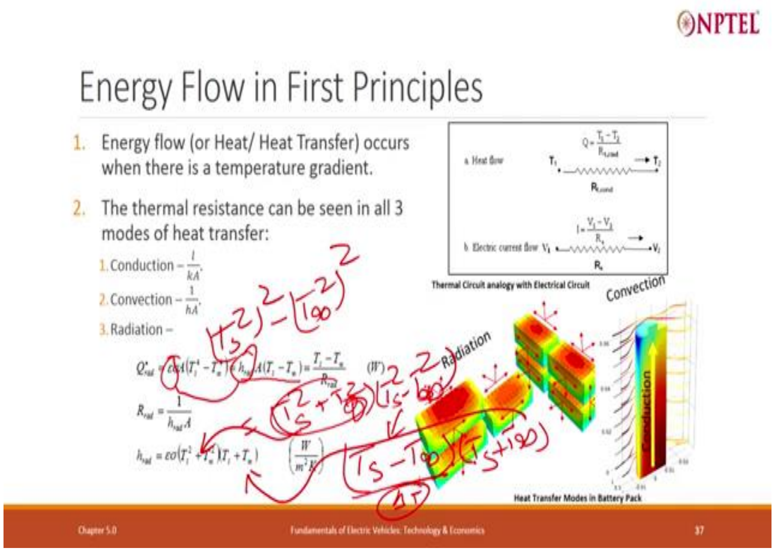

Let us move to the next slide after understanding how the heat is getting generated will try to understand quickly the first principle of energy flow. Energy heat is the form of energy, heat will flow only when if there is a temperature gradient. Generally, we say it is 0th Law of Thermodynamics. Heat will flow only when if there is a temperature gradient.

The similar way in electric current unless you do not have a potential difference you cannot flow the current. There will not be any current. So for heat to flow the temperature gradient is must. Depending upon the temperature gradient how much heat will flow can be defined. So it has basically 3 modes; conduction, convection and radiation. In the simple form conduction will represent the heat transfer due to conduction we represent by KA delta T, where delta T is the temperature gradient.

And conduction generally happens when there is a continuous medium like solid even in fluid, even in liquid it happen. So the temperature gradient within same body. Now there is another mode is known as convection, a lot of researcher or expert there is no mode like convection it is a combination of conduction, it is extended part of conduction. Will not go to that, the convection is by bulk, convection heat transfer happens because of the bulk motion of the fluid.

The temperature gradient and bulk motion of the fluid. So here the convection heat transfer is because of two material; the temperature gradient which comes is because of the two different things, one might be solid or liquid or something other would always be a fluid. Fluid means either liquid or gas. So how do we define that? The Q convection is nothing but Ha delta T, where H is the convective heat transfer coefficient, A again is the cross-sectional area and delta T the ambient and that particular object temperature.

And then radiation is slightly different however will try to put back in that form because radiation heat transfer is proportional to T to the power 4, temperature to the power 4. So, the simple explanation we have put Q dot Q radiation epsilon sigma A T to the power 4 surface and T to the, minus T to the power 4 infinity T infinity to the power 4 and T surface infinity, T surface to the power 4.

Now if you want to convert into Ha delta T or Ka delta T to simplify that one. So, we can put here H radiation into A Ts minus T infinity how that has come? Now, you a square minus b square is nothing but a plus b; a minus b so similar way you can put T square T s square whole square minus T infinity square then whole square. So, that will become Ts square plus T infinity square and then into Ts square minus T infinity square.

And then again you further make it Ts minus T infinity into Ts plus T infinity. So now you have 3 terms so Ts minus T infinity you take out rest of the term you put it back into the H form. So, it is just to convert into similar form, Q equal to K a delta T or H a delta T, so that is how we have done here. Now, it is similar to what we talk about n conduction and radiation.

Now, so the next what we are going to define is thermal resistance. So thermal resistance is nothing but for conduction it becomes 1 by k, for convection it becomes 1 by Ha and for radiation again it become 1 by H radiation into a and which is equal to H radiation is equal to epsilon sigma Ts square plus T infinity square multiplied with Ts plus T infinity.

See here you have Ts to the power 4, yes, so what you see, the question is that why this additional term of Ts plus T infinity come. So here we have Ts to the power 4 so Ts square this will become Ts square whole square minus T infinity square whole square, this will get converted into Ts square plus T infinity square into Ts square minus Ts, t infinity square. Now this term is here, now this term get converted into Ts minus T infinity.

Now, this is nothing but for us it is delta T and into Ts plus T infinity, so this term has come here and 4 Ha, H radiation this term has come. So, the for conduction what would be then it become what is the thermal resistance? 1 by K, for convection; it becomes 1 by Ha and for radiation again 1 by h radiation a where h radiation is sigma epsilon Ts square plus T infinity square multiplied by Ts plus T infinity.

And then Ts minus T infinity again we can say always delta T. So how do you compare with a heat flow and electric current flow? Similar way for heat flow you need to have two temperatures, two different temperatures and there would be a heat flow and you can say q equal to nothing but delta T by r, r is nothing but thermal resistance, it could be conduction, it could be convection or it could be radiation.

For electric flow, I is nothing but delta v by r so gain you should have two different cell, so these two gets correlated mean the similar form, similar equations here the delta T there it is delta v and denominator is resistance, so here it is thermal resistance in that case it is electrical resistance. And to make the thermal resistance to have the similar formation it was easy for conduction and convection however it was difficult for radiation but we have managed to bring the form of r resistance in the same form of conduction and convection.

So, the conduction basically in one, within one object either solid or liquid generally. Convection generally happen between two objects; one could be generally one would be either solid or liquid and the second medium would be either liquid or gases, should be said fluid. And the radiation does not need any medium it can happen. Now I am radiating to you, you are radiating to me.

So net because of the temperature difference that whatever the transfer net heat transfer is happening that could increase the temperature of this room or can decrease. Even I am radiating to the wall, wall is radiating to me. So, the radiation is always present however at the smaller temperature, lower temperature difference it is not very significant.