Fundamentals of Electric Vehicles
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Lecture 6
Thermal Design – Part 1

So, shall we start thermal design of battery pack, it is a very interesting chapter, subsection basically of battery development design of the battery pack, here we will talk about different types of first we will see why thermal management is required or thermal design is required, then we will see what are the types of thermal management system available, how can we utilize in our system, where and what type of thermal management system we require, what is the benefit, merits and demerits of those thermal pack thermal design, so, this all we talked about extensively in this subsection.

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So, before that I just want to take some water, so let us start with thermal design of battery pack.

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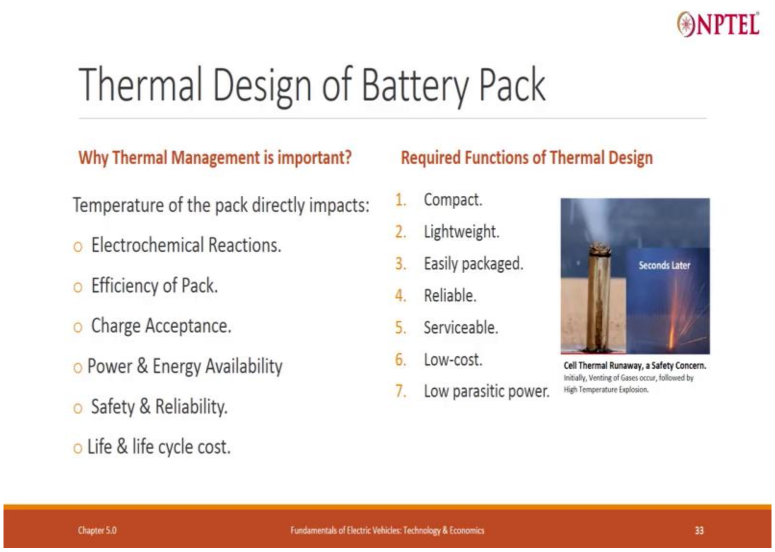

It is my favourite chapter because I know a little bit more on this than anything else. So, thermal design of a battery pack, why it is important? Have you heard about thermal runaway? Thermal runaway is a process where whole battery burns without giving you any much indication and then physics behind the thermal runaway still not known fully, we know only in bits and pieces.

And it we have more like a bomb explodes, what we know generally this happened because of some impurities in chemical composition or because of the improper charging and discharging even some time with proper charging and discharging everything within control and if batteries aging something known as dendrite formation, since batteries made now you cannot scan every day the battery that what is happening and it can lead to the thermal runaway.

But what are the indicator which we know, the one indicator which we know the temperature start changing rapidly, till certain level the temperature goes smoothly and then it changes rapidly, very fast change in temperature, what we also know before thermal runaway happen you may get a gas leakage, combustible gas leakage, if you are able to identify the combustor full gas leakage and if you have a proper arrangement you may be able to mitigate thermal runaway or you may be able to isolate all the things.

This is one of the reason safety reason why thermal management is very much needed in a battery pack, we will talk about all other reasons because before going to the other reasons I wanted to show why it becomes extremely important, the temperature of the pack why a thermal management is important? The temperature of the pack directly impacts what electrochemical reaction.

Any reaction is generally a function of temperature the rate of reaction is generally a function of temperature, we also know that Arrhenius equation, rate equation, efficiency of the pack, a battery pack works most efficiently between some temperature limits, below that also it will not work efficiently after that band it also again it would not work efficiently. Charge acceptance, a battery pack need to be charged it can take full charge at some particular temperature or in band up temperature, beyond that the temperature the further increase in temperature may lead to the situation like thermal runaway or the efficiency of the battery pack you lose by some percentage.

Power and energy availability, it is completely dependent on temperature, if my battery pack temperature is going from some certain limit, because that could lead to the failure of the battery pack with stop any inflow or outflow of the energy. So, the temperature of the pack should be in certain limit if it is going beyond or below both sides we cut up the battery from the external work, means there is no energy flow in or out.

Safety and reliability, if temperature keep on going up the material the pack material what we have talk may lose it is its strength even the cell will lose it strength, it's life and the cycle, the number of cycle if it can run let us suppose 1000 cycle in some particular temperature band and if you are not maintaining that temperature band my life cycle will drastically come’s down, what are the required function of a thermal design? It should be compact, it could be lightweight, because weight always impact your energy availability, more the weight your range will come down.

So, you always try to reduce the weight of the pack, when you try to reduce the weight of pack thermal design also need to take care of the thermal part like cooling plate or if you are doing active cooling the compressors, heat exchanger should have a lightweight, it should be easily package able. Reliable enough it should lock till the battery last, if there is any problem like a temperature sensor is not working or if there is some leakage somewhere we should be able to service it quickly, the cost should be low, as low as possible.

Because we already have the cost of cells which we cannot reduce, it should consume the minimum power to give you the maximum efficiency, if a active thermal system is here, it should use minimum power of this, because again the energy comes from the cell only, it should function between the optimum temperature range and it should also maintain the optimum temperature range of the pack.

So, that my cycle life and calendar life can be increased and this way we can reduce the capital cost of the battery. It should be able to handle or minimize the temperature gradient across the cell or across the pack, if I am reducing the temperature gradient again that translates into higher cycle higher calendar life.

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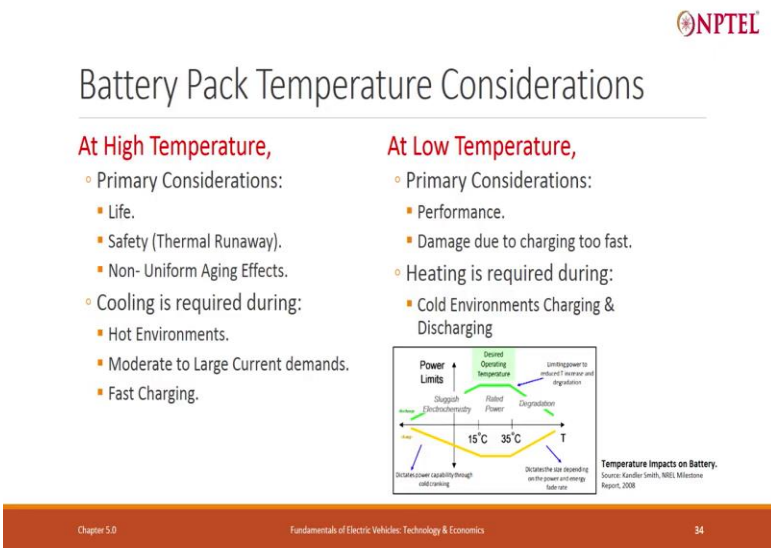

So, what is the optimum temperature we are looking for? Generally a lithium ion battery gives its optimum performance between 15 degree to 35 degree centigrade and on an average we say 25 degree centigrade, below 25 degree what happens internal resistance increases (())(10:13) 35 degree, what happens? The cell life decreases, so here because internal resistance increases, so you get more heat that will locally mailed some of the portion inside the cell itself that could lead to the complete degradation or at the chemical reaction is started happening inside itself uncontrolled could lead to the thermal runaway. So, at high temperature, what is our primary consideration? Is a life, when at low temperature.

Student: (())(11:04)

Professor: But then your temperature is higher, so your chemical reactions and other things start degrading, the life you have several parts inside several chemicals you have separator you have chemical again you have a separator, so those think so lower part its internal resistance that is why we do not want to go for low temperature.

Student: (())(11:31)

Professor: No, but that would be locally local heating.

Student: (())(11:38)

Professor: Local heating is very dangerous, if I am able to track that heat and if it is able to spread well, well and good no issue, but that local localized heating would create much problem, generally we do not want to go below 15 degree, the another problem is that the solidification of the electrolytes which is in gel form, if that solidify the transfer of energy from cathode to anode means transfer of.

Student: (())(12:16)

Professor: What do you say ions will not happen, so that is why we do not want to go too lower temperature all, we do not want to go for higher temperature because cycle life drastically comes down, because of the degradation of the reaction and the life both, temperature the temperature impact for life for electronics it is said very nicely a bit 10 degree increase in temperature would bring the life bring down the life by half, that means if my resistor is certified for 1000 hours at 25 degree centigrade, same resistor life would be 500 hours at 35 degree centigrade.

Now, bus bar, now when we design a bus bar for a particular temperature weldment welding joint is designed for some particular temperature limit, if temperature goes high, what will happen? That will melt, if there some plastic part the temperature maybe 60 degree of 65 degree or 70 degree, it will fail, there is no moving parts inside the battery, but the battery itself is moving when your temperature increases what happens, strength reduces generally.

The chance of failure becomes more, so you always try to maintain the temperature, so that is what is life. Safety thermal runaway I do not want anything to be locally melted, because of the high heat, so I do not want any local heating, hot spot, I do not want that hot spot to be there anywhere, if the temperature is going beyond, let us suppose 100 100 25 degree centigrade because I am taking the high current or because of the some defect in the cell.

If I can still maintain the temperature of 25 degree or 35 degrees, it would not go for thermal runaway, or if the temperature started increasing and somehow we are able to track that heat we can still save our battery from going thermal runaway because the first (())(15:04) runaway is uncontrolled temperature.

Now, cells are packed, what we have seen in mechanical design cells are packed, all the cells are all most release in the equal heat, when I am taking the same current, it is supposed to release the same heat, but what happened that the cell act middle, it does not has surfaces for heat transfer, so that cell would be heated more than the outermost cells.

So, it is responsibility of thermal design also to maintain the similar same cell temperature across, that means the non-uniform heating or cooling should be avoided, because that is again lead to, if my one cell is at 35 degree and another cell is 25 degree, so as per the theory my 25 degree cell would be will have higher life, will degrade less, then the 35.

But in the battery pack where the cell is highly degraded is considered as the life of the battery pack, means if out of 20 cells the once in life is still 100 cycles left and another cell has only 10 seconds left. So, I will select a cell of 10 which has only 10 cycles left, that would be the complete cycle life cycle of the pack, the lowest the cell which gives the lowest cycle life or calendar life is the parameter for whole pack life cycle.

If that cell fail anyway pack fail, so the non-uniform aging effect because of the temperature has to be considered in to thermal design and this all are at high temperatures I am talking about. When we require cooling? When we require cooling of the battery pack? In the hot environment moderate to large current demands like 2C, 3C, 1C, there I require cooling, during the fast charging here I am taking energy out 1C to 2C, if I am pumping also energy, at that time also we require cooling because I need to extract the heat produced by the battery pack and the electronics in the battery pack.

At low temperature, what are the primary consideration, performance, degrades, why? Basically because of the increase in internal resistance, if you charged or discharged too fast what will happen? There will be high localized heat because your resistance is very high so that can permanently damage some particular cells or whole battery pack, so when heating is required in the cold environment like Leh and Ladakh, Jammu and Kashmir, Ooty, during winter, where your temperature is tending towards 0 degree or Sub 0. So, at that places, we require heating arrangement to be in the battery to maintain the temperature between 15 to 35.

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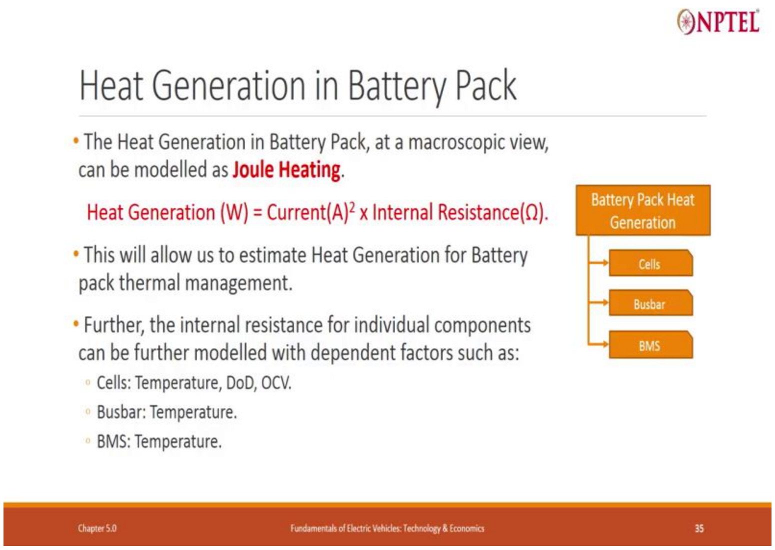

Now, how the heat is getting generated in the battery pack. So, we will try to understand how the heat is getting generated, because unless we do not understand how the heat is getting generated in the battery pack we cannot remove it. So, first we need to understand how it is getting generated, then only we can think that's how to remove it, where it is getting generated.

So, generally in the battery pack, we generally model this as a Joule heating that means heat generation is the nothing, but I square R, where I is the current, while charging or discharging and R is the internal resistance of the battery. So, here this thing where the Joule heating is happening generally? It happens in the cells because you are taking it has an internal resistance and you are taking either current out or you are putting back the current.

In bus bar because again you are taking the current and it all even though it is metal it has very good thermal conductivity and electrical conductivity is still it poses some resistant, so because of that and there is other things contact resistance, because of that it can heat up by Joule heating I square R, BMS, MOSFET, (())(21:08) high amount of current flows there, it also has some internal resistance because of that heat is getting generated, to once you know where and how much heat is getting generated then only you can design a system to take away those heat or once you know which would be the coldest reason then only you can provide the heat to maintain the temperature.

So, the basic formulation is I square C be would be using in whole this in this subsection I square C, sorry I square R, where R is the internal resistance, with this formulation we can mostly estimate how much heat we need to remove or how much heat we need to add up, now this internal now what's, one parameter is current, that is depending upon charge and discharge rate, the another parameter is internal resistance.

Now, internal resistance as a dependency of lot of things, it is not always content, it has a dependency on OCV depth of discharge, it is also dependent on temperature, similar way for both bar, it's temperature dependency resistant changes with temperature for BMS again it is a temperature dependent the BMS tracks or MOSFET’s, a contactors, resistance changes with the temperature. So, if you have really very accurately measure or accurately estimate you also have to worry about at what temperature it is working.

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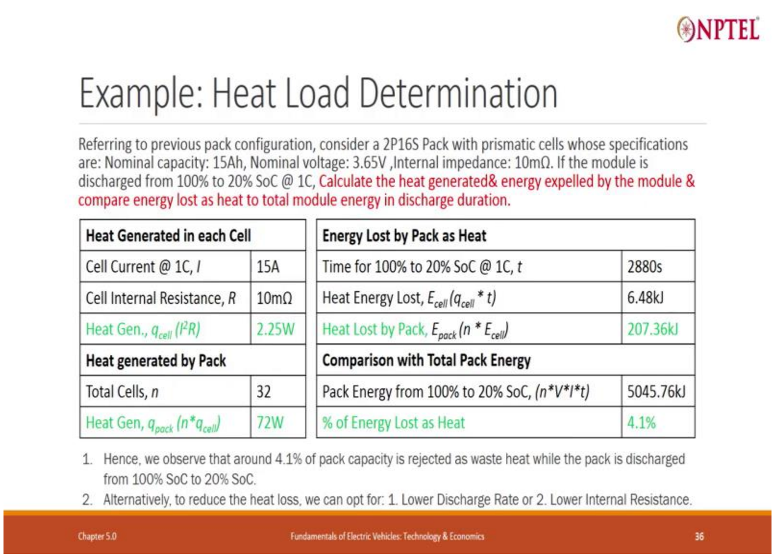

So, example problem here, the heat generated which need to be removed, what we say? It is a heat load, it is a load which we need to take out or we have to put it. In simple terms, we say it is a heat load. So, what we have done in mechanical it is a 2P16S configuration, where nominal capacity of the cell was 15 AH and the nominal voltage was 3.65 volt, the internal impedance or internal resistance is 10 milli ohm, generally for cells the 10 milli ohm internal resistance is very high.

If the cell is new, a good quality cell will have some 2 milli ohm, 1 milli ohm, not more than that, a medium quality cell will have up to 5 milli ohm, internal resistance. However, this cell resistance also changes with the life or with the degradation, when we talk about end of the life of the cell that is around 70 percent energy when it can take or give at that time the impedance becomes almost twice.

So, when I am designing a thermal management system it need not to be only for new sales it should also serve when the cell is degraded, till the end of life cycle and at that time the internal resistance becomes almost double. So, that is why even though for a new cell the internal resistance is 5 milli ohm, but end of the life till that time thermal management system had to work becomes 10 milli ohm.

So, when we calculate the heat load we calculate always worst case scenarios, worst case scenarios worst case design scenarios means if I am going to run the battery for 2C maximum I will while calculating the heat load I will always considered 2C, I will not consider average 1C, 1.5C, 2C unless I do not have a complete data.

If somebody says even though for 50 percent of the time it is going to work at 0.5C only and rest 50 percent we do not know, it can go to 2C, then heat load is always calculated at the worst case scenario, that means it would be calculated at 2C, so the internal resistance is 10 milli ohm if the module is discharged from 100 percent to 20 percent SoC at the rate of 1C, calculate the heat generated energy expelled by the module and compare energy lost as a heat to the total model energy in this chart duration.

So, my battery is 100 percent charge. SoC is 100 percent, now am I a discharging this to 20 percent SoC with 1C rating. 1C discharge, that means in this case it is a 2P to 30 ampere continuous current. Now, what is cell current at the 1C? For 1 cell it is a 15 ampere, what is cell internal resistance R? 10 milli ohm, for in 1 cell for 1 cell what would be the heat generation? So, I square R it is a 2.25 watt. How many cells we have total in the pack? 32.

So, even it is 1C the 2 cells together gives 30 ampere current. Now, 1 cell is always giving 15 ampere only at 1C, so the total cell is 32. So, what is our total heat generation impact? 72 watts, time for 100 consider the linear assumptions, the SoC is decreasing in linear with time, so 100 percent to 20 percent SoC at 1C rate, in 1 hour it is about to go for 100 percent to 0 percent, so it takes 2880 second that means 3600 seconds it would have taken for complete 1C discharged, but here for 100 percent.

Now, it is 100 percent to 20 percent, so it is the 80 percent, so it takes 2880 second, so heat energy lost total so here it is Joule per second, what is nothing but Joule per second multiply with time, so this much kilo Joule of energy is lost, heat lost by the pack, it is not heat energy, its energy taken out from that pack, it is not heat energy, it is a total energy taken from the pack, is 6.8 kilo Joule and the energy loss due to heat is 207.36 kilo Joule, I think some number is Garber I will come back to you on the next class.

So, pack energy from 100 to 20 percent SoC, so heat energy lost by 1 cell is 6.48 kilojoule in 2880 second. So, how many cells we have? 32 cells we have, so the total heat loss by the pack is 207.36 kilo Joule, now the how much energy we have taken out from the pack either heat or electrical, is 5045.76 kilojoule divide this by this we will get the percentage lost as a heat, it is a 4.1 percent huge.

So, what we see the 4.1 percent energy is lost because of the internal resistance and if I do not remove this heat what will happen? It will keep on increasing the temperature, we can reduce the heat loss, how? By either by selecting a better cell which has better internal impedance or internal resistance or by discharging at lower current, which will be more helpful by discharging at lower current, because it is a square of I.

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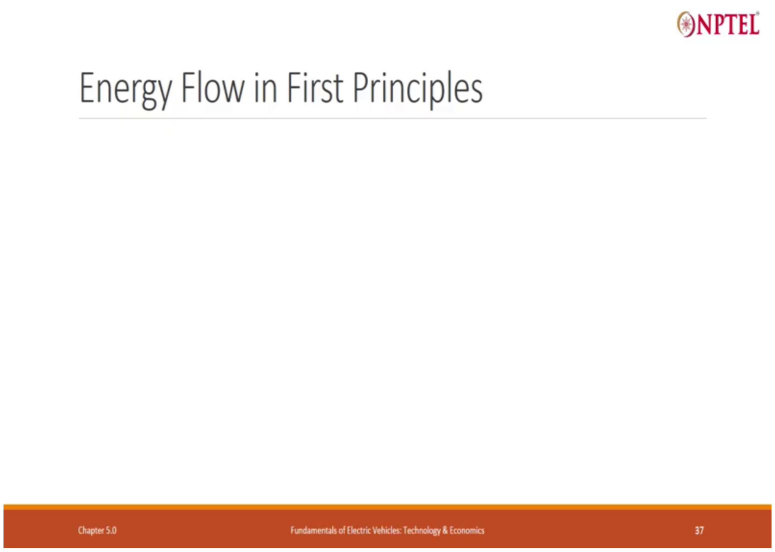

So, we will end up here next class we will see energy flow through first principle and thermal management techniques and at the end we will see some case studies.