Fundamentals of Electric Vehicles: Technology and Economics
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Lecture 10
Electrical Design of Battery Pack

Welcome back, today we will start Electrical Design of a Battery Pack, but before that we would like to know means what is there any question in the last sections, in thermal design of a battery pack or mechanical design of a battery pack. So, what we have covered till now, basics introduction of, or design of a battery pack. And then we have divided the design of battery pack into basically in 4 sections, mechanical design, thermal design, electrical design, and the BMS design.

And we have started with a mechanical design there we have worked towards the base plate, end plates and the side strips, then we have gone to the vibration analysis and we understood what are the test standards we follow in India and how we can simulate that and how can we match them with our test result. And then we have started the thermal design of a battery pack, a very simple approach that heat load would be equal to I square R, I is the current taken or C rate you can say and then R is the internal resistance of the battery.

We have also try to understand what will happen in the bus bar, if the current is flowing then how it can impact the temperature of the bus bar. Then we have seen the various modes of thermal management active and passive and in that active also several ways of doing the active thermal management is force, air cooling, then liquid cooling, then direct expansion or refrigerant cooling and then hybrid of all that. And in passive cooling system use of PCM as well as, use of micro channel heat sinks or heat exchangers.

And then we have seen how this active and passive cooling system impacts the battery cells temperature and some steady state simulation we have done there for, with air cooling, natural convection, force air cooling as well as the cold plate method. Now, in this section in electrical design of battery pack what basically we would be looking essentially, we would be looking for the bus bars or any current carrying system or wires or that. And how to move forward with, how to set up the design, spec all the things will look on in that one.

And what are the technical data we required to move forward, what is the thickness, so it is a, it would be a combination of slightly thermal and slight mechanical what we have done with consideration of electrical design. So, let us move ahead in this section 5.3 electrical design of a battery pack.

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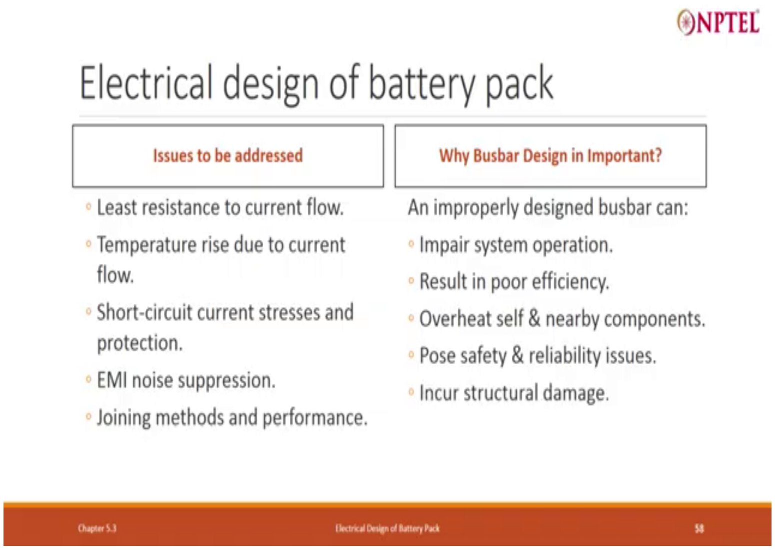

What issues to be addressed by doing the electrical design of the battery pack. Current always flow in least resistance path, so if there is a current flow, we have to also look upon what would be the least resistance path for the current flow. Temperature rise due to current flow, a small portion we have seen in the thermal management or thermal design of the battery pack where we have shown the bus bar, if the current is flowing the temperature will increase.

So, temperature rise due to current flow or it will happen again the same thumb rule I square R, R is the resistance of the current flow path, R is the resistance of current flow path and I is the current flowing through that path. And the temperature rise become very, prediction of temperature rise or calculation of temperature rise become very important, because not only the current flowing path gets heated up it is also impact the surrounding.

If you have some other electronics or cells because current has to be taken from the cells basically, so it is also impact the local, localized heating on that particular area. Then very important factor which comes is short circuit current stresses and how to protect that. What happens in the short circuit, a huge amount of current flows in very short duration. When huge amount of current flows in very short duration, the temperature locally can go very high.

A very high temperature will lead to melting of that particular region and once my circuit is disconnected because of the melting you cannot take the current. Now, the melting is localized for that particular thing, but it can also impact its surrounding area. You have constraint current flowing path either you, generally constraint the current flowing path either by some mechanical constraints or by putting considering that is okay even. And in that case, if let us suppose because of the current, high current flow like in short circuit case, if that parts melted, so now it can move in any direction, remember it is still live.

So, when it moves to some other thing other places, so you may get some false current or even you wanted to disconnect it may not get disconnected. So, that's becomes very important in electrical design. Then the another important factor for electrical design is EMI, Electro Magnetic Interference, should be minimum, otherwise it will impact electronics, it will impact outside, it will impact the signal processing and all that.

Now, joining methods and performance, just now I have talked about short circuit. So, we have to be very careful even and it can happen, it happen, in fact most of the fire in electrical building happens because of the short circuit. So, my joining method and its performance should be robust enough to sustain the even short circuit currents. Now, what essentially electrical design means a bus bar or a cable through which current flows. So we will use terminology bus bar here, because that is the mostly used in the battery pack and the same principle we will apply for if you, if you are using the cable also.

So, an improperly design bus bar can impair system operation, that means your current will not flow or if it will flow very high resistance because of the contact or are not proper overlap, localized heating. If bus bar is not proper, what will happen, most of the electrical energy will get generated, get converted into heat energy and when it is converting into heat energy essentially you are wasting the energy, you are not able to do any useful work from that.

So, what will happen, your efficiency of the system will decrease and that is why result in poor efficiency. Overheat self and nearby components, if my design is not proper, if I have not taken proper consideration of the resistance and that resistance can happened because of anything, it could be joining, could be overlapping, could be threading, so it will overheat, not only it will overheat it will also overheat the nearby system and component.

Pose safety and reliability issue, now current during the short circuit is so high it will melt. If you do not have a proper material, fire-retardant material what will happen? Even if you have a fire-retardant material, fire-retardant material is that its ignition point would be very high, not infinity.

So, it can lead to the fire that is one of the thing, it can lead to the severe damage of nearby component, it can lead to the safety of human who is operating there, because your current path is still may not be closed, completely open, there might be some current flow still going on. And during the short circuit scenario the current flow is very, basically it is huge. And you have design some system for, operation for 3 years.

If electrical design is not proper, what will happen, it may fail in 6 month time. So, your reliability issues comes there. If you remember when we were doing the BMS, MOSFET thermal management, what we have seen, that each 10 degree decrease in temperature would increase the life by two times or 10 degree increase in temperature, operating temperature would decrease the life by half for electronics components.

It can incur structural damage, mostly due to overheating. So, that is what I am saying, so heat a term comes regularly here and then second thing is joining method and design. So, we will talk a bit of thermal wherever is required and a bit of mechanical also in this particular section.

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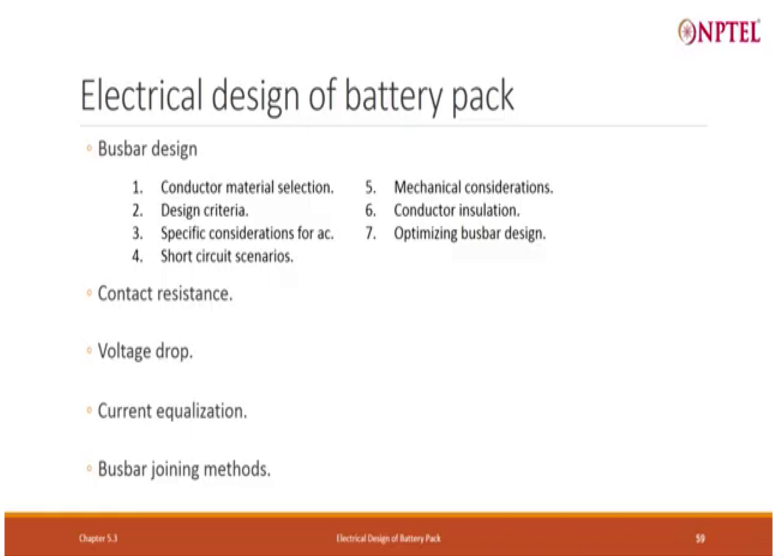

So, electrical design of a battery pack. So, the first things comes bus bar design. In that bus bar design, what are the important parameters, the conductor material selection, you want to have a material which is highly conductive, however should have sufficient mechanical strength also, should to be able to join easily either through welding or overlapping and screwing by nuts and bolt. We mostly deals with DC current in battery pack, in fact we deal only with DC current but however if you go to motors, even though it is DC current going up to controller, but after that it gets converted into AC.

So, we have to be very careful in designing the current flow path for AC currents. In fact, DC currents generally it is consider up to 120 volt DC is safe for human, generally not necessarily, generally. However, any voltage above 120 volt DC is not safe for human so you, it comes in high voltage category. So, you have to be very careful if there is a high-voltage scenario. Short-circuit scenario we discuss it can lead to huge temperature change and very short duration of time because of the huge current flow.

Mechanical consideration, even something goes wrong it still my current flow path should be safe. Then another important point becomes conductor insulation, by mistake if somebody touches or if it is getting overheated it should not damage the surrounding and itself. And at the end optimization of bus bar design, that always has to be done.

Now, second thing what is very important is contact resistance. Contact resistance is unwanted resistance and that’s happen because of the poor workmanship, poor workmanship either you are not following the proper environment that means clean room consideration, that means your moisture content where you are assembling or doing the work should be minimum, it should not have a greasy surface because that would lead to the additional resistance.

The surface has to be very smooth, so that one over other when it joins or you overlap or you weld should be in perfect contact which is not possible, completely smooth surface is not possible, so you try to maximize the smoothness. Then voltage drop, again it comes because of the resistance only, if my voltage drop in bus bar itself is huge I will not get the desired voltage output.

Let us, take example of what we have designed in mechanical and thermal section 2P16S. So, how many bus bars we required, 17 because 16 in series. So, if the bus bar resistance is very high, what will happen, there would be huge voltage drop in between that and we will never be able to achieve the 60 volt condition in that case, we would be fall short of long below then 60 volt criteria.

So, the voltage drop has to be minimized. For that again, what we have to do, the resistance has to be minimized. Current equalization, if there is multiple path of current flow like in that case we are talking about 30 Ampere current, now 30 Ampere current we can divide into, if I have a switching device that I need some time 7.5 ampere, sometime I need 15 ampere so I will put a 4 switches there, I will switch on when I require 7.5 one switch or I will have a 4 path there which each can carry 7.5 ampere current.

So, in that case all the 4 path should have the equal resistance, otherwise if in one path my resistance is low and another path resistance is high, what will happen, the maximum current will flow through the least resistance path and that path would become overburdened or over use. So, we want always the current to be equal in all the paths, if it is multiple path available there. Now, the last in electrical design, the bus bar joining method that is a very important, because current flow get impacted, contact resistance increases all the things we have to look upon in bus bars joining methods.

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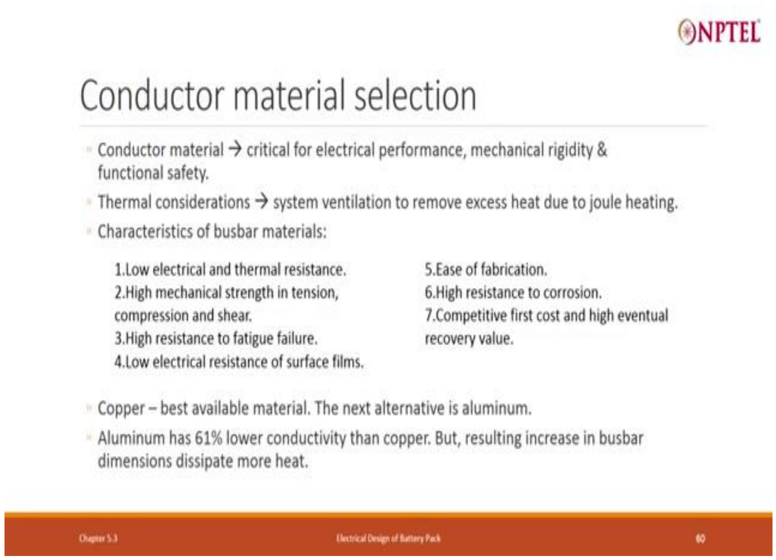

Now, conductor material selection, conductor material is what, it is a critical for electrical performance, mechanical rigidity and functional safety. When I am selecting a conductor material generally, the silver and gold are one of the highest conductive material easily available, but mechanical strength it is much, much poorer to steel. However, the thermal conductivity of steel is lower than silver and gold.

Now, consider copper and steel, copper thermal conductivity is high, it also has a good strength, but not as great as steel. Consider another scenario aluminium, it has good thermal conductivity, less than copper, but has much better mechanical strengthened then copper. So, out of the several material we have to select a material which should be, which should give the least resistance, however should also have a very good mechanical rigidity and functional safety, that means it should not break, because of overheating, because of the stresses develop, because of the vibration.

Thermal consideration, when we are talking about thermal consideration, is it possible to provide venting, because if venting is there, there could always be natural convection as well as, if possible, we can also provide the force convection. And from where that heat is coming, because of the current flow and the resistance. Characteristics of bus bar material, characteristic means, mechanical, thermal and electrical properties of the material and all this together needs a careful consideration or careful evaluation.

A final factor, which comes into design is also cost other than the characteristic of the material. Even the gold or silver has a highest, one of the highest thermal conductivity, I cannot select that one because it is very costly, steel is very cheap, but the resistivity is much, much higher than aluminium and copper.

Copper is good conductor, has good mechanical strength, same way mechanical is good conductor has good mechanical strength, but then sometimes the weldment, when we do the welding on the cell, generally cell terminals are made of generally made of aluminium, so two dissimilar material welding sometimes becomes difficult, so we try to go for a material which has a similar property, so either copper or aluminium.

And many a time we select aluminium, because of its very important property, it has a good thermal conductivity, good strength, cost is very low. So, the characteristics of a bus bar material should have low electrical and thermal resistance, high mechanical strength in tension, compression and the share, high resistance to the fatigue failure. Fatigue is what, the cyclic stress, low electrical resistance of surface film.

So, whenever you take metal in environment, generally a layer of metal oxide get formed. So, when that metal oxide layer gets formed that's what we say that as a surface films, even that should have very low electrical resistance. Ease of fabrication, if it is not easy to fabricate it will add the cost. High resistant to the correct corrosion, it is impossible to maintain the dry room condition, humidity zero, impossible to maintain, you need very sophisticated set up for that one.

Or because of any leakage or any hole in the battery pack, if somehow some air goes inside, it will have some humidity factor. Now, current is also flowing in that, so what will happen, it may corrode, because of the stingrays or because of the humidity in grace, there is always a possibility that it will corrode, so it should a material which we select should have the high resistant to the corrosion.

And last but not least the cost, that plays very important role, because finally you would be able to sell to the customer only when the cost is minimal or optimal. Once the life cycle of the battery packs get over the material what we select should be recyclable also, so that we can again reuse and it should be easily recyclable, so that is add the value. Considering all these things, all these parameters in the available material, copper is generally considered as the best material for bus bar or electrical cables or cable bars. The aluminium is a next alternative, so we will play mostly with copper and aluminium from now onward.

Aluminium has 61 percent lower conductivity than copper, but resulting increase in bus bar dimension dissipates more heat, you have more surface area to dissipate the heat. Even though it has the lower thermal conductivity, but the design consideration allow them to have more surface area, so it is able to dissipate more heat.

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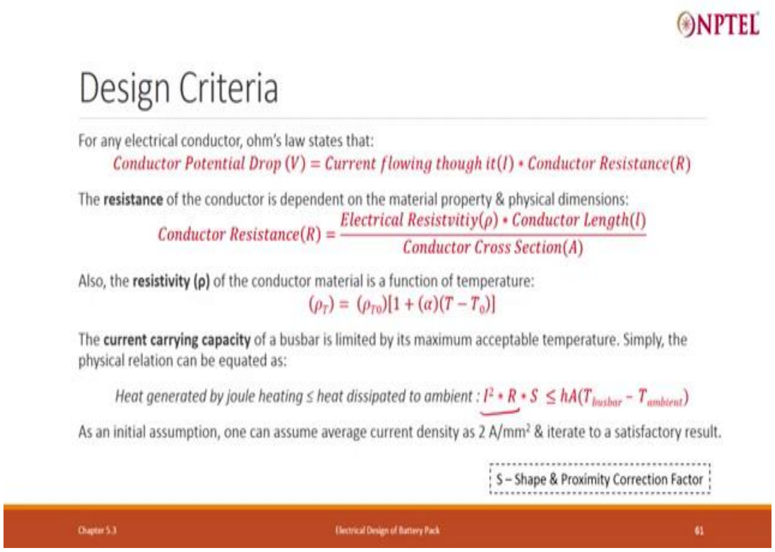

For any electrical conductor Ohm's law states that, now we are going for a design criteria, how to design a, what are the parameters we should look upon. So, for any electrical conductor Ohm's law states that, the conductor potential drop or delta V would be equal to the current flowing in the into it, current flowing through it into multiplied by the resistance of the conductor.

So, it is nothing but V equal to IR, or delta V equal to IR, generally we use delta V as a V in such situation, V is also considered as the voltage drop or the potential difference. Now, the resistance of the conductor is dependent on material properties and the physical dimension, how we will show it. The conductor resistance R is equal to electrical resistivity rho into conductor length divided by conductor cross-section, rho l by A, rho is the resistivity, L is the length of conductor and A is the area of cross section through which current is flowing.

So, the dimension or the area perpendicular to the current is the cross-sectional area. Now, resistivity of a conductor depends upon temperature. Resistivity at any temperature is equal to resistivity at a reference temperature into 1 plus alpha T minus T0, where T0 is your reference temperature, T is where you are looking for the resistivity and alpha is a constant for the particular material.

So, what we have seen the voltage drop or the potential difference across a conductor is equal to the current flowing through it into the conductor resistance. Now, conductor resistance is equal to resistivity into length divided by cross sectional area. Now, this resistivity is the function of temperature, which you can relate resistivity at any temperature T is equal to resistivity at some reference temperature into 1 plus alpha delta T or the temperature where you want to know the resistivity minus reference temperature.

The current carrying capacity of the bus bar is limited by its maximum temperature, maximum acceptable temperature, that maximum acceptable temperature is what we say that I want to go for a change in temperature by 5 degrees C or 10 degree centigrade or 15 degrees centigrade or 20 degrees centigrade. Because we also have nearby components and when we have a nearby component, we have to look upon the temperature rise should not impact that.

Now, when temperature is increasing, what else is happening? What will happen to the length? Have you heard a term thermal expansion, if temperature increases generally metal expand. And if it is constrained at both the end, what will happen, thermal stress will get developed. So, we have to see all those things there and then we have to decide what is acceptable temperature limit, to which I can allow the conductor to work on.

And again, it depends upon the ambient condition, ambient condition means surrounding temperature. How much maximum gain in temperature it can take or should be acceptable to designer or should accept, and how it becomes acceptable to the designer, he will look upon all other things. There should not be any thermal stress, if the thermal stress is here, is it constrained, will it affect the life or will it fail?

So, what it says, heat generated by joule heating, what is joule heating, I square R should always be less than or equal to the heat dissipated to the ambient. So, what we have seen the potential difference that is equal to current flowing into the resistance of the conductor. Then what we see, the resistance of the conductor is equal to resistivity multiplied with the length of conductor divided by the cross-sectional area. Now, resistivity is a function of temperature.

And then finally comes what is the design criteria. What is the acceptable limit, I can allow the temperature to be there. When I say, this is my acceptable limit in that case the joule heating is I square R. Joule heating should always be less than equal to the heat it can conduct to the ambient. And how much heat can be conducted to the ambient, is equal to H A delta T, convective heat transfer.

Why this term S has come here, S is safe factor. It could be circular, it could be perforated, to see factors impacts slightly. So, once you define the safe factor, once you get the safe factor it is a bit, if safe factor is 1, what will happen? Joule heating should always be less than equal to the heat dissipated to the ambient.

Now, this is (())(33:15) process, why, because the resistivity is also a function of temperature. As your temperature keeps on changing your resistivity keeps on changing, your R keep on changing, and then finally you have to balance at some point where both of them, my left turn joule heating should be equal to the heat dissipation. So, for initial guess you can use anything, I can suggest 2 ampere per mm square that is nothing but current density, you can use anything.

In fact, the simplest thing would be you use I square R into S is equal to H A delta T from there you find out what is the R, because you know H, you know the surface area, you know the delta T, because maximum acceptable temperature from that you can put 5 degree, 10 degree, 12 degree, 15 degree depending upon the your other calculations, or experiments. So, you will find out R, from that particular R you get a resistivity and that resistivity you can consider for the your initial guess. Any question in this, because this slide is very important, what we have discussed is very important, any question on this if you did not understand you can ask.