Fundamentals of Electric Vehicles: Technology and Economics
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Lecture 11
Electrical Design – Part 2

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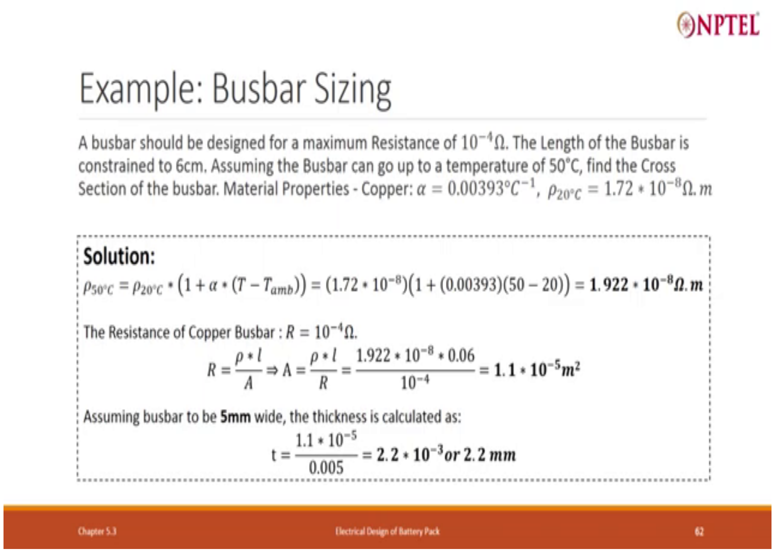

One of the example of the bus bar sizing. What it says, a bus bar should be designed for a maximum resistance of 10 to the power minus 4 Ohm. The length of bus bar is constrained to 6 cm, because length of the bus bar will be constraint depending upon my cell architecture, so here in this case it is constrained to 6 cm.

Assuming the bus bar can go up to the temperature of 50 degrees centigrade, my bus bar can go to 50 degree centigrade without creating problem, find the cross section of the bus bar, find out the, you know the length, you know the temperature, so find the cross section of the bus bar, cross-section means length you know that other two dimension through which the current flows.

Material properties, we are selecting a material copper which property alpha is given, resistivity is given. Now, how to design this Bus bar. Now, rho 50 from rho T naught into 1 plus alpha delta T, T naught is 20 degree centigrade, so we found out rho at 50 degree centigrade. Now, resistance of copper bus bar R is 10 to the power minus 4 Ohm, so R is what, rho into l by A. Now A is what, area of cross section, this is what we need to find out.

So, it becomes 1.1 into 10 to the power minus 5 meter square, area of cross section. Now, we can assume what would be the thickness of width of the, width of the bus bar. Once we know one parameter because that again bus bar width would depend upon how much space I have. Now, once we know what is the thick, now we already know the cross section area, which this is what it is a bus bar should be designed for maximum resistance, the length of bar bus is this one.

Assuming the bus bar can go find the cross section. So, our problem is solved now. But now what would be the thick, now area of cross section A when we are talking. What does it consist of, it consists of width and thickness both are important, the thickness would be high we cannot weld or join properly through welding.

If width is very high, we may not be able to accommodate. So, but width can be seen by packaging of the cells, we know this is what I have at cathode or this is, this much space I have at cathode and this much space I have at anode. So, assumptions means it is a realistic assumptions, okay this much width of bus bar is possible. You look upon the complete possibility what width it can go.

Because you always try to reduce the thickness, so let us assume in some particular case my bus bar width is 5 mm, the thickness is calculated as T equal to nothing, but you have the cross section area divided by width, so it is comes 2.2 into 10 to the power minus 3 meter or 2.2 mm. Now 2.2 mm is still very high, very thick, if you talk about welding 2.2 mm is very thick because your other surfaces inaccessible, so generally you go for laser welding and in the laser welding you have to penetrate the heat from the top, means complete thickness of the bus bar as well as, the terminal of the cell.

So, 2.2 mm thick bus bar would require a laser power of approximately 6 to 8 kilowatt it is a huge, so we try to reduce the thickness. So, then what we will see, do we have more than 5 mm, if I can go 7 mm, or if I can go to 9 mm. My thickness will proportionally reduce, so we always try to reduce the thickness.

Student: (())(04:54)

Professor: Yeah, so that also we have to look upon, parallelly we also have to look upon the strength should be also within the limit, this is what we have done during the mechanical design of the battery pack.

The another good thing about bus bar is generally you do not load anything over that one, it would be at the top most surface, so generally external loading in the sense continuous loading would be absent there. However, you need to still worry about vibrations, shear because of the cell movement and other thing, that you have to worry about.

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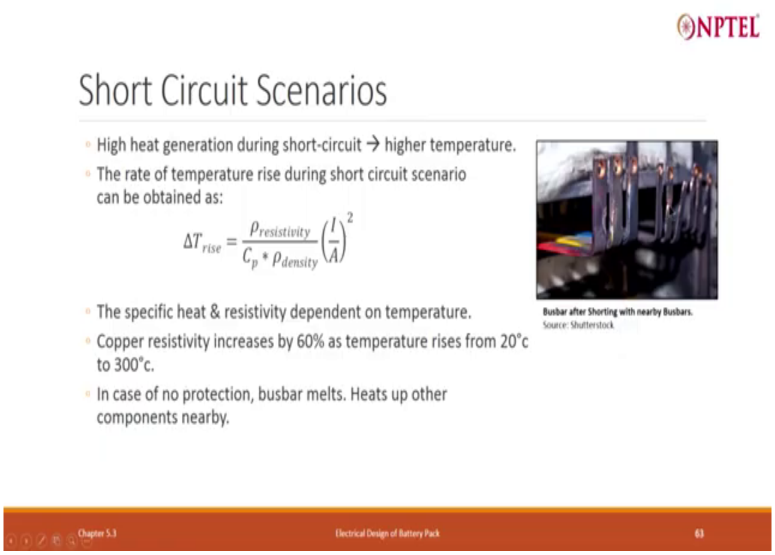

Now, what will happen in short circuit scenario. That is a next, now you have done for regular thing, regular design, now the next important part becomes short circuit scenario. What will happen, high heat gets generated during the short circuit, very high temperature. The rate of temperature rise during short circuit scenario can be obtained from the formula, the delta T rise is equal to resistivity divided by heat capacity of the material into the density and then multiplied with the current density square.

Current density becomes very high during the short circuit scenario. Now, somehow you can consider a specific heat is independent of temperature, however it is also dependent on temperature but resistivity highly dependent upon temperature, your temperature keeps on rising, your resistivity will keep on rising.

A example, the copper resistivity increases by 60 percent as temperature rises from 20 degrees centigrade to 300 degrees centigrade. So, your resistivity is increasing continuously as temperature is rising, so it is creating further more and more heat till the time it’s finally melts. So, if you do not have any protection what will happen, finally bus bar will melt. Now, it is not only melts, it is also heats up near by component, my battery, my cell safe operation could be 60, 65 degree or 70 degree.

Now, it has, it is going to 200 degree, 250 degree, 300 degree centigrade. What will happen, it may cause the thermal runaway or it may melt a portion of cells also. Now, your whole battery pack is not usable. So, what we do in such situation, we have some protection circuit. So as soon as it detects the current surge, it will try to disconnect the current path.

But if it is happening externally, the same thing can happen internally also, within the pack also. So, we should also worry about if it is happening inside can we put something known as thermal fuse within the bus bar. So, what will happen, it will get disconnected quickly there. Thermal fuse is, it melt also but the melting point is much, much lower than the bus bar material melting point temperature, could be 60 degree or 70 degree or 100 degree.

Now, you see here in this picture, if 2 bus bar get sorted, what happens, you see this region get melted completely, this region got melted completely. So, very thick, so still structural integrity is there but you see the melted portion. If you see in this exactly, almost 75 percent portion is melted.

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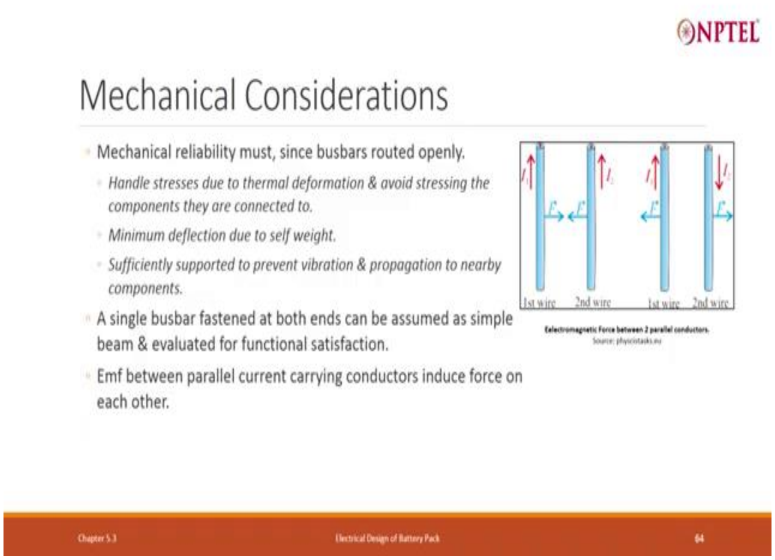

Now, mechanical consideration. The mechanical reliability must because otherwise what will happen it may break; it may break and touch with other things can create short circuit scenario.

Your current flow will stop continuously, permanently. It had to handle because now you have limited the temperature some 5 degree, 10 degree, or 20 degree based upon that.

So, within that if there is any thermal stress develop the bus bar materials should be able to accommodate that thermal stress means, it should not fail, it should have minimum deflection, because of the self-weight, generally self-weights are very low unless you are using very high, very thick cables or thick but bars. It should be sufficiently protected from the vibration by providing the proper anchoring points or proper support.

So, during the vibration, during the running of the vehicle it should not break, so that stress also, it has to take care. At elevated temperature, at your design temperature that is important. A single bus bar fastened at both the end can be considered or assumed as a simple beam and you can evaluate all the mechanical consideration by applying the beam formula.

Now, another thing generally there is a negative terminal, there is a positive terminal, there is a parallel connection, there is a series connection, there is a parallel and series connection. So, there are two bus bars running in parallel generally, when the DC current flows in the same direction it is tend to attract each other because there is a magnetic force generated there.

We say it EMF again here, but it is something different than EMF what you study in motor chapter, we say Electro Motive Force here. So, it attract, if the current is in opposite direction it repels. Now, if your current is very high what will happen, the high amount of attractive force or repulsive force will act. So, while designing, constraining, supporting the bus bar you also need to worry about this force, which would not be there if there is no DC current.

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Now, conductor insulation, what conductor insulation does, why it is important. First of all, if you touch by mistake you do not get exposed to the high potential difference. It also helps in heat dissipation by increasing the surface area, because you put some thickness over that one. It also helps to mitigate the thermal accidents by absorbing the sub-heat or by acting as a insulation material, so that heat would not get escaped outside quickly.

So, the operating voltage, whatever operating voltage generally for low 120 volt DC and low we do we consider it is safe for human, you do not have to worry too much there, but as soon as you go 350 volts, 680 volt, 800 volts, you have to start worrying about dielectric strength. Dielectric strength is that it will resist the current here, it will not allow the potential your exposure directly to the high potential.

Operating temperature, because everything has some melting point, so whatever the operating temperature it should be firm and rigid. if I am saying my operating temperature is minus 42 plus 70, in that case it should be firm and rigid, it should not lose its property. It should be able to help the environmental condition, means if my bus bar is covered with the insulation or conductor insulation material it should not allow the dust or humidity to corrode or to form a metal oxide, have a property, that even some moisture is there.

It should not fail; it should not allow the moisture increase to the conductor. The common insulation materials what we use here is nomex, tedler, mylar, kapton, epoxy glass, heat shrink tubing it is a very common, and a lot of time we do powder epoxy coating also, epoxy powder coating.

Now, what should be the thickness of insulation, higher thickness less dielectric strength. Decreased bus bar capacitance, now what will happen if there is a less dielectric strength and then there is a decrease bus bar capacitance. At higher capacitance generally there is a lower impedance, if you have higher capacitance, C, L and R C is denoted, capacitance is denoted by C, impedance by L, and resistance by R. These three terminology, these are common in electrical engineering.

So, higher the capacitance, then you will have lower impedance. And what lower impedance does, electromagnetic interference, it reduces. If you have lower input impedance, you have low EMI and we always want to have low EMI depending upon the situation. This thickness also plays an important role in thermal stability, if your thickness is very high you get very higher, high surface area, so you release the heat quickly. And at higher volume the peaks get reduced, however your cost increases. So, there is always a critical thickness of insulation that you want to keep, again that is considered by resistance as well as the thermal consideration.

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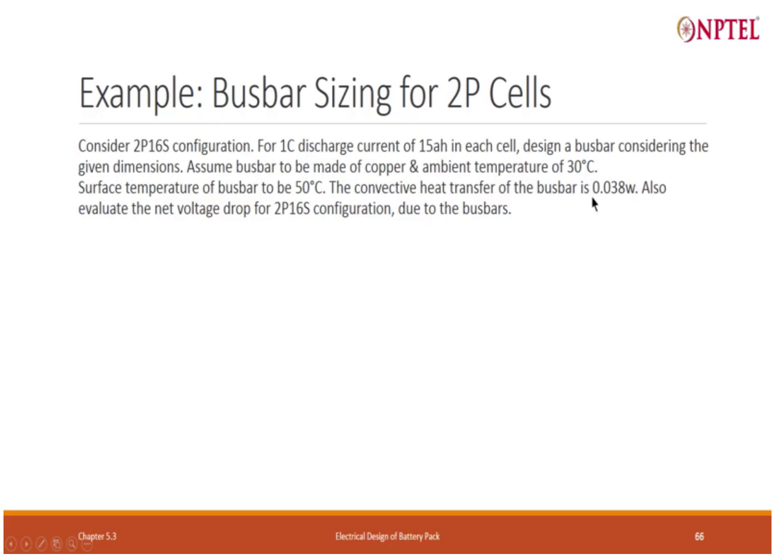

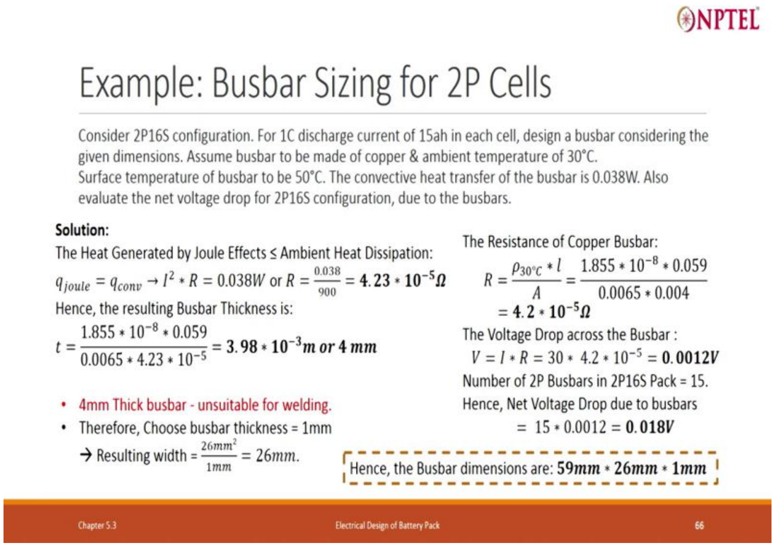

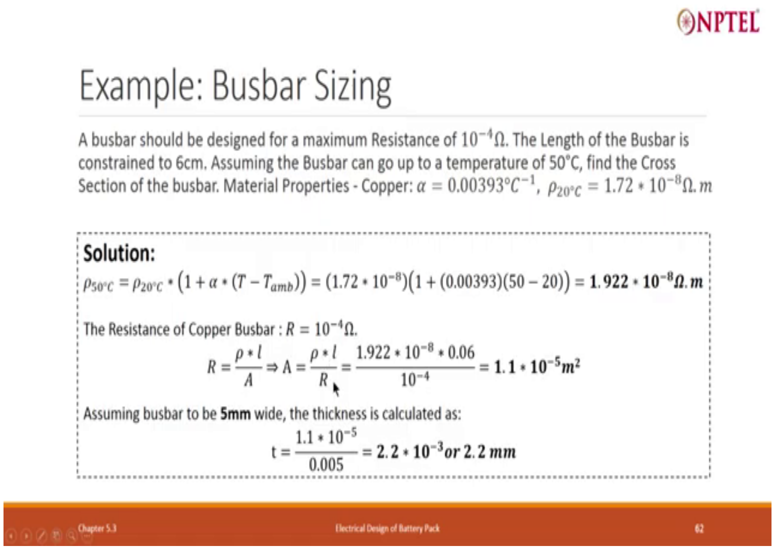

Now, another example. What we have taken here is 2P16S configuration, what we have done in thermal as well as in mechanical design. For 1C discharge the cell capacity is 15 ah, material selected is copper, ambient temperature of 30 degrees C. The surface temperature of bar has to be 50 degree C, h of the bus bar is 0.03 watt. The convective heat transfer, the total q, q is 0.038 watt, no it is not convective heat transfer coefficient, it is total heat transfer.

This is total heat transfer not the convective heat transfer coefficient, total convective heat transfer it is, so that is ha delta T, its unit is Watt, Watt should be written always in capital because it is a name of a scientist. Also evaluate the net voltage drop for 2P16S configuration due to the bus bar. Now the solution, heat generated by joule effects should always be less than the ambient heat dissipation, what the heat we can dissipate.

And from there you get the resistance value equal to 4.23 into 10 to the power minus 5 Ohm. So, the resulting bus bar thickness becomes around 4 mm, we get area of cross section, we get the width and then from that we find out what is the thickness of the bus bar and that's comes around 4 mm. Now, 4mm thick bus bar is unsuitable for welding, so what is the suitability of welding, for us it is 1 mm. This 1 mm also is has been taken by considering all other mechanical aspect, mechanical consideration has already been taken care here to reach to the 1 mm.

And then we are also saying that, this 1 mm thickness will also help us in bus bar welding. Now, what would be the resulting width in that case, the resulting width of the bus bar would be 26 mm. Can we accommodate that 26 mm, if yes will go ahead with that, if no, then we have to increase the bus bar thickness from the area of cross section, that area of cross section will come from this what we have done in the last slide, rho into l by R, which has not been done explicitly there since we have done this thing earlier itself. So, here area of cross section comes is 26 mm square.

Now, resistance of copper bus bar, same 4.2 into 10 to the power minus 5 Ohm after taking this thing. The voltage drop across the bus bar, so V is nothing but R we know, I we know, so 30 ampere into 4.2 into 2, so 0.0012 Volt or I can say 1.2 millivolt. Now, how many bus bars we have, 15 in the case of 2P16S, last time I said 17 where I have taken the first and last also, but if you see the same size bus bar, which connect 2 plus 2 cells, 4 cells together would be 15.

But if you consider the last 2 cells, first 2 cells and last 2 cells, so you will have a 17 bus bars in that case, that side. But that would be half of the 4 cells bus bar. So, you have total voltage drop across the bus, across the bus bar in whole pack is 18 millivolt and the 18 millivolt is significant drop. So, either we can keep this by knowing that now we have 18 millivolt, voltage drop because of the bus bar or we can reduce further by increasing the thickness or by increasing the width, to reduce the resistance. Any question till now?

Student: (())(22:51)

Professor: 60 volt.

Student: Six zero?

Professor: Six zero.

Student: (())(22:57)

Professor: Yeah, but it is a significant, when we talk about the balancing of the cells and all those things, so my first to last, we should not go for more than 10 millivolt, my first cell to last cell so not have a difference for more than 10 or 12 or 15 it is again design consideration. Or this also says that, okay 18 millivolt is acceptable for us, but may not have 50 millivolt, so if I still reduce the width my resistance goes up, my temperature consideration goes up, my voltage drop goes up.

Student: (())(23:40)

Professor: No, ambient is not in your control, correct, ambient is what it is, ambient is not in your control. So whatever heat is getting dissipated is not not much in your control other than the temperature differential or delta T, whatever you select I can go for 10 degree plus ambient that is what is in your hand, but other things in ambient is not in your hand. Neither ambient temperature, nor heat transfer coefficient, these things are not in your hand. However, resistance is in your hand, you can change the thickness and width to that level.

Student: (())(24:19)

Professor: Number of bus bar is basically the number of parallels and series based upon that you select the bus bar. If I have, so the question is that how many we require, so now if my all the cells are in parallel, so I require 1 bus bar on the negative terminal, 1 bus bar on the positive terminal. But if my cells are in series, so as many series that many bus bars will come plus 1, plus 1 it will come.

If my 16 cells, 2 parallels in is now acting as 1 cell, so 16 cells, so my total bus bar would be 17, however the first and last bus bar would be connecting only 2 cells, in the sense 2 parallel cells. Other bus bars is correcting 4 cells, 2 parallel plus another 2 parallel. So, what we have decided my bus bar dimension has come 59 mm in length, 26 mm in width, and 1 mm is thickness.