Fundamentals of Electric Vehicles: Technology and Economics
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Lecture No. 27
Battery Pack Development - Part 1

That brings me to the next chapter, very important chapter, we will now move from cell to pack. Let us get into what is called battery pack development. So far we are talking about cells. Now, the pack behavior will be built on cell behavior. So, if I have, my cell has a maximum voltage of 4.2 volts and if I put 10 cells in series, I get 42 volts. Pack behavior will actually be the behavior of the cell plus some more constraints will get added. To make a battery pack, a very simple thing is done, cells are put in series or can be put into parallel.

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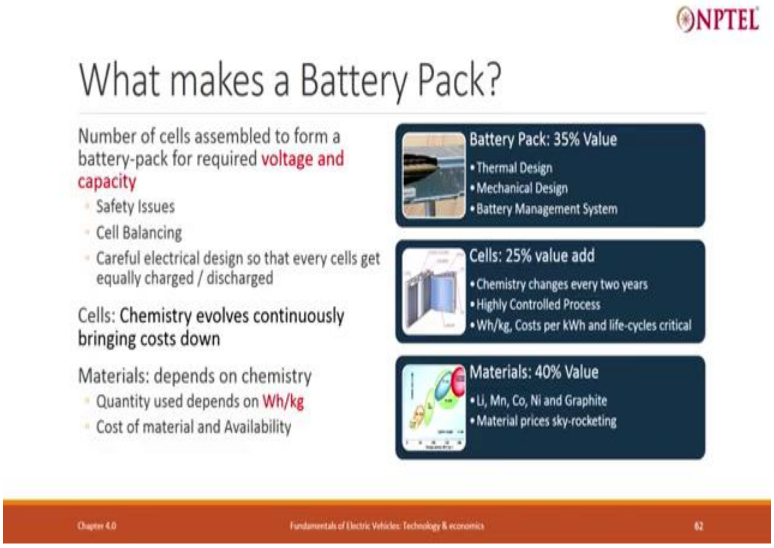

And there are several different methods of doing that. Before I do this, let me talk about what does a battery pack design means. Battery pack design is number of cells are assembled together to form a battery pack for required voltage and current. Voltage and currents are given for each cell. Now, you want this voltage and this current capacity, so you pack them together. The issues that you need to deal with is first safety issue. Now cell is cell it is given cell in itself is never used, it is a pack which is used. So, immediately look at the safety issue.

The second very important thing is what is called cell balancing. And I will come to the cell balancing in a short while. Because there may be two cells in parallel, but they may not be charged equally. If you are trying to charge two cells in parallel, will equal amount of current go in both of them, will equal amount of charging will take place? What if 5 percent more current goes into one and 5 percent less in another? The cells in parallel are considered to be imbalanced.

As we will go on, we will further look at it, imbalance cells hurt the cell life and battery life. As you start using battery, the cell if they are imbalanced, the imbalance will keep on increasing, after some time the cell the pack will become useless. So, important task that you need to do in battery pack is cell balancing. I will show you, you need to do a very careful electrical design, so that every cell is equally getting charged or discharged.

Cell balancing can correct for a small difference, cannot correct for large differences. So, pack itself has to design that actually this near same current will go. So, that is but in spite of that, if there is, because the interest changes of the cell, maybe there is imbalance and that correction can be done by cell balance. So, essentially, the battery pack design itself consists of 3 parts, one is the pack design, you take cell and you have the pack design. And that time besides these issues, the other thing that you need to worry about is the thermal design.

What happens when the pack is being used? Is it getting heated up and what is the impact of when it is getting heated up? Is the heat getting dissipated, thermal design will become very critical. Because if the pack temperature goes up, remember the cell temperature will go up, cell temperature can be even higher than the pack temperature. And remember that I talked about at 25 degrees centigrade cells behave very well, as you go to 35 it does not behave that well, at 45 it behaves much worse. So, thermal design becomes extremely critical.

The second design consideration is what is called mechanical design. When cells are packed together and connected together to even bus bars and put into a vehicle, the vehicle goes through all kinds of rough roads. As the vehicle goes through rough road, the pack vibrates. As the pack vibrates, it is possible that individual cells may vibrate. If individual cells vibrate, the gap between cells will increase or decrease.

One, it will impact the bus bar connection. Second, you will also find that because of the thermal issues, many of the cells tend to bulge and if they are bulging and they are vibrating, you can result into very serious problem. So, you need to design, the mechanical design of the cell pack has to be done such that, while it allows for some amount of increase, some amount of what is called the cell getting expanded, some amount, but not beyond a certain point.

It does not allow, it compresses, while it tend to bulge out, it will be get compressed and differential movements are minimized, this is a mechanical design. There is a total battery management system is very crucial, it will take care of safety issue and cell balancing. And finally, the electric design. What about cell in itself. I talked about cells earlier I am not going to talk too much about cells, but cells depends on the chemistry. And if it is a pouch cell or cylindrical cell or prismatic cells, it is a highly controlled process making the cells.

And if you remember what our per kg cost per kilowatt hour and life cycles are critical parameters. So, what is it, if I take a battery which costs 100 rupees about 35 rupees will come in the pack design 25 percent will come in actual cells and the remaining close to 35 to 40 percent is actual raw materials used. The raw materials used itself plays a very important role. Nickel, lithium, manganese, cobalt, nickel, so, I buy these raw material I will make sense, then from the cells I make pack and 40 rupees for raw materials, 25 rupees is actual making of cells, 35 rupees for battery pack.

This is approximate it varies from pack to pack, varies from cell to cell, but this gives you some idea. Materials depend on the chemistry, quantity of materials used. So, you again look at watt hour per kg. If you want to design a 10 kilowatt hour pack, you calculate how many how much kg of material you require. And therefore, how much kg of lithium, manganese, cobalt, nickel you require, that is how the cost is also determined.

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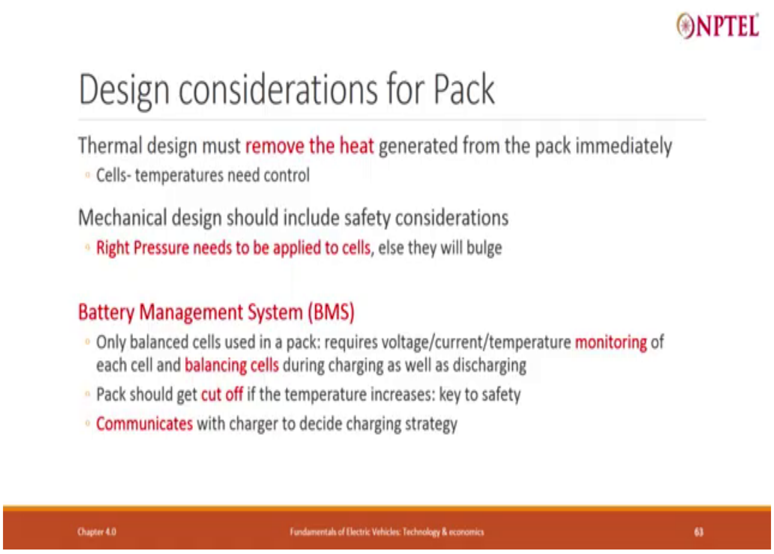

So, thermal design basic objective is to remove the heat generated from the pack immediately. Ideally, temperatures should remain constant, as close to 25 degrees centigrade.

Mechanical design so that cells do not budge and the right pressure is applied to the cells. And battery BMS will come only balance cells are used in a pack. So, when you select cells, you will like to use a balancer. And requires and after that, you monitor the voltage, current, temperature for each cell and then carry out the balancing during charging as well as discharging.

Now one of the most important thing is, something can go wrong and bad cells can get heated. As soon as cell goes above, any cell goes above a certain temperature, you immediately shut down the whole pack battery. It does not matter, let the vehicle stop. Because if you do not, you are carrying out the risk of blowing up the battery. If there is redundant battery, of course the alternate battery can take over.

So, if you ever use lithium ion cells or cells like this into a vehicle, in a aircraft, you have to worry because there can be a situation where you suddenly shut down. In a vehicle if you shut it down, well, the vehicle will stop. You will have to stop the vehicle on the road. You may create a jam, congestion but still you are safe. Aircraft, you will have a more serious problem. So, pack should get cut off, if the temperature increases, key to safety.

During charging time, the cells and the pack will continuously communicate with the charger and decide how the charging, should be done how much current should be put, do not put extra current, how much voltage should be used, remember constant current constant voltage I talked about.

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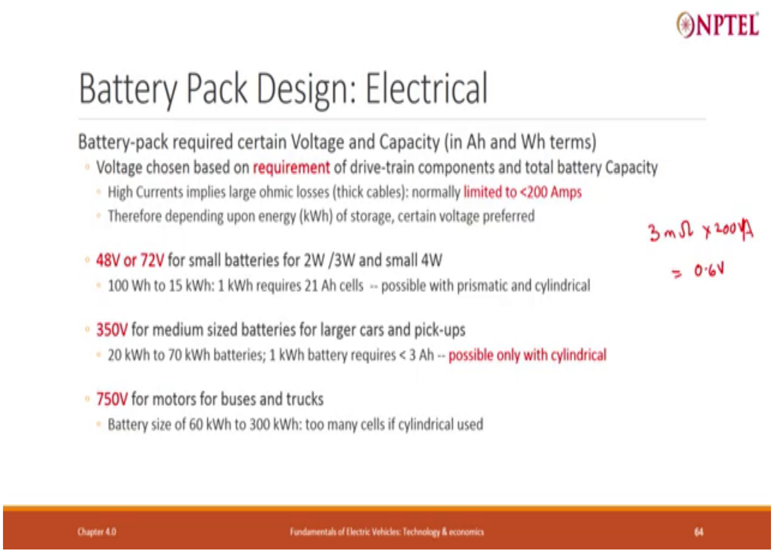

Battery pack design let us get to the electrical part of it. Battery pack designed to get a certain voltage and capacity in terms of watt hour or ampere hour, I want this is the capacity and this is the voltage. That is what a motor will require. It requires let us say, say I will motor says I want to, I can work at 350 volt or I will work between 325 and 375 volts. So, your battery pack has to design between 325 to 375, 325 when it is nearly empty, 375 when it is nearly full.

Remember one big problem is since you are talking about, suppose you are talking about a 48 volt battery and you are talking about a 5 kilowatt battery, you are talking about 100 ampere. So, if on the other hand, if it is a 48 volt battery, at times you may require 8 kilowatt peak or 9 kilowatt peak, you are almost going to push 200 amperes. Now, when you are pushing currents of this kind, there are multiple issues.

First of all resistance of every cable will make a difference. Earlier we assumed cables have 0 loss, 0 resistance, not so anymore. Between cell to cell the connection will make a difference. What kind of plating you are using, the resistance smallest milliohm resistance multiplied by 200 amperes is how many. Or if I take let us say a 5 milliohm or 3 milliohm resistance and multiplied by 200 volts, what I have 600 milliwatt, milliampere, milliohm into a have to do.

Student: (())(12:44).

Professor: Not I squared R, 200 amperes. Suppose I do 200 ampere, then the voltage is going to be 0.6 volts. Now, that can be the difference a 0.6 volts, I have a 4.2 to 3, volt 4.1 to 3 volt cell and my 0.6 is a drop in the connector itself, connection itself, in the cable itself. The voltage that I will get will be very very different in that case, I can get into serious trouble. So, and if I have two cable one giving you let us say 1 milliohm, another is giving you 4 milliohm, there is a 3 milliohm difference there is a 0.6 volt difference between two cells.

One is nearly full, one is nearly empty, so horrible thing that can happen. So, remember you are dealing with very high current, so you have to very very accurately carry out the electrical design. Of course it will also gives you I square R, losses I square into R that is a very very high losses also. So, depending on the kilowatt hour of storage, certain voltage is preferred. For example you do not want very high current. So if you want 5 kilowatt, 48 voltage is dust about okay, you want 10 kilowatt, just worry, 20 kilowatt, 48 volt cannot be used, then 350 volts is used.

48 or 72 volt is okay for two wheeler or 3 wheeler, 100 watt hour 15 kilo, 15 kilowatt hour itself is 300 amperes, already very high. Not good. So, this is something that you have to worry about. 1 kilowatt hour requires 21 Ah cells 21 Ah. Now 20 1Ah is not possible in those pencil cells, or cylindrical cells, of course, unless you put a number of them in series. So, it is possible only with prismatic and cylindrical cells. Because 1 kilowatt otherwise will require 21Ah and you cannot put too many of them in series and parallel, you will end up into trouble.

So, 100 to 15 kilowatt hour can become problem. 350 volt is commonly used for medium sized batteries for large cars and pickups. Now, here you can do a 20 kilowatt. 20 kilowatt divided by 350 volts, you have less than 100 ampere. 70 kilowatt hour will be 200 ampere but but there is something wrong in this, 1 kilowatt hour battery pack requires 3 amp, less than 3 ampere hour, well yeah. So, if you do a 1 kilowatt hour battery pack at 350 volt you require less than 3 ampere hour, now that is not possible except for cylindrical cells.

So, you can only make large packs, you cannot make small packs with 350 volts. Half a kilowatt hour is theoretically also not possible, you will require 0.5, 1.5 Ah. 750 volt is another voltage, here 60 kilowatt hour to 300 kilowatt hour is used. If you use cylindrical, too many cells will be used, we will get into this, but this is how the 3 voltages come and are used.

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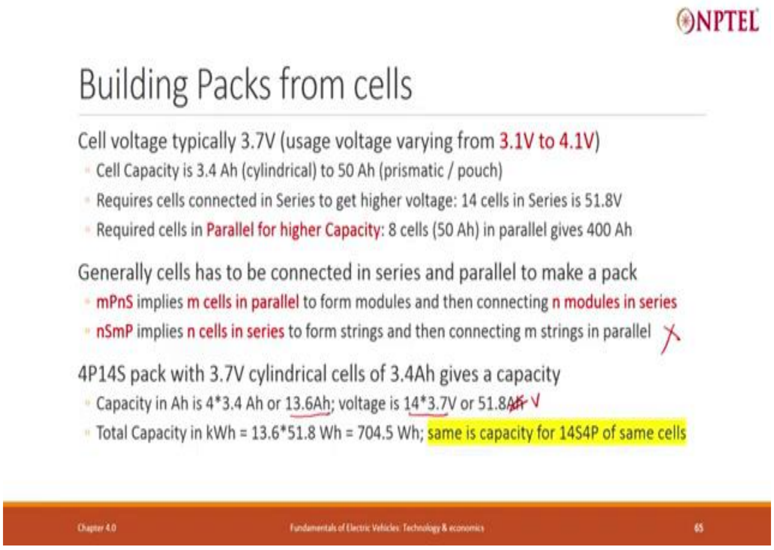

Let us look at how to build packs from cells. Typical cell capacity voltage is, typical voltage is 3.7 volt, from 3.1 to 4.1. Cell capacity is 3.4 Ah for cylindrical 50 Ah maybe even 60 Ah for prismatic cells. So, you have to require a number of cells in series, for example, if it is a 3.7 volts and if you want 48 volt, you need 14 cells in series, it will give you 51.8. If you want to go to 350 volts, the number of cells in series will become almost 6 times, about 7 times for 100 cells.

Because it is a 3.7 volts into 100 cells will give you 374. But, even if you get this in terms of voltage, what will be the current? A single cell depending on the cell that you use can only give you so much current. If you want more you have to put more number of cells in parallel. So, if you for example, put take 58 Ah cells, prismatic cells, and you take 8 of them in parallel, that will give you 400 ampere hour.

If you use cylindrical and you only 3.4 Ah and if you have to get 400 ampere hour how many are put in parallel? 125 cells. You can just imagine what will happen. Generally cells has to be connected in series and parallel and there are two mechanism what is called mPnS, m parallel and n serial. But what is also important, the order is also important, one is mPnS, another is nSmP. mP and nS basically means, you will take m cells first in parallel, that will form a module m cells in parallel and then you put n such modules in series.

Not so with nS mP, nS first you put the cells in series, n cells then you put in parallel and we look at both these designs mPnS and nSmP, you will see nSmP is not a good way to design and is not used. It is mP S that you will design and m and n can vary. So, 4 P14S, what does it mean? There are four parallel cells and 14 in series, 14 in series you can calculate, 14 in series will give you 14.3 into 3.7 or 51.8 volts, not ampere hour, 51.8 volts, this is a volt.

4 in parallel, now depends suppose I use cylindrical cell of 3.8 Ah, I get 13.6 Ah, this is a 13.6 Ah. So, total capacity in kilowatt hour is now this 13.6 multiplied by 15.8 volt. So the ampere hour multiplier 4 volt will give me watt hour, so this is a 705 watt hour with 4P14S. What if I did 14S first and then 4P? Then I will get the same capacity, capacity does not change, but you will see the other impact of it.

So, in a very simple way, you can see a 4 into 14, 56 multiplied by the capacity of a cylindrical cell, capacity the cell A in Ah multiplied by 3.7 volt that is the total capacity. But now let us go back to mPnS and nSmP.