Fundamentals of Electric Vehicles Technology & Economics
Professor. Ashok Jhunjhunwala
Indian Institute of Technology, Madras
Lecture No. 28
Introduction

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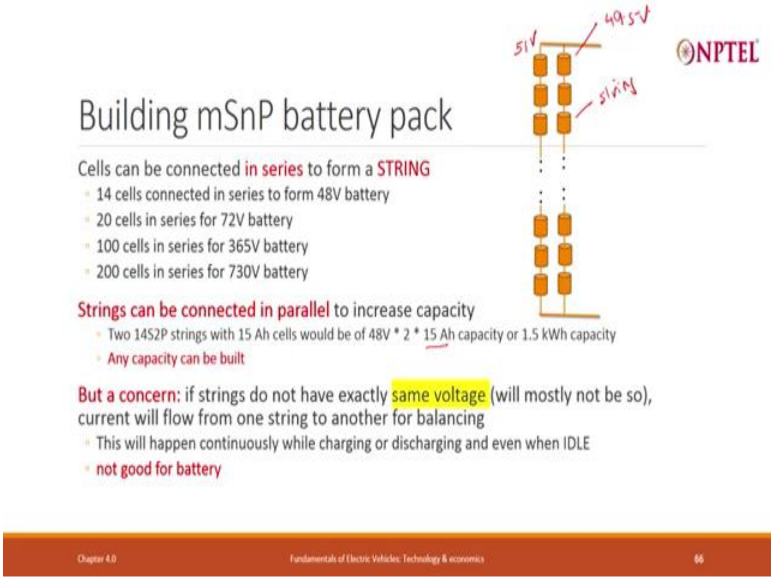

First, let me look at mSnP, m in series first and then n in parallel. As I told you this configuration is not preferred configuration, this is what it shows you first put 14 or what m cells in series, you put another m cell in series and this you call it a string, each one of them is a string and then you put multiple strings in parallel and that gives you the n strings in parallel, it will give you mSnP. 14 cells if you connect it in series will give you 48 volt so it becomes 48 volts, if you put 20 cells in series it will give you close to 72 volts. So, that is how the battery packs are designed.

Of course, as I told you this is not the best way, we will come to that in a few minutes. 100 cells in series will you 365 volt, 200 cells in series will give you 730 volts. Strings can be connected in parallel to increase capacity. So, if I use 14S into 2P of 15 cell, I get 48 volt, this 14 series means 48 volt into 2 in parallel each is 15 Ah capacity so I get you multiply this 96 into 15 ampere hours is 1.5 kilowatt hour capacity, any capacity can be built.

Any voltage, any current can be built using something like that, but there is a concern. I put 14 of them in series, let us say cells have slightly different voltage at any time at any time during charge or discharge. Suppose, the voltage of this together works out to be at any time 50, 51 volt, and for this it works to 49.5 volt. What will happen? String voltage of the two strings are different and you connect them in parallel, immediately a current will start flowing like this because the voltage has to be same, this is internal current, not external, this is called balancing. And every time we charge or discharge the voltages of number of cells in series will not be same.

So, a lot of balancing required, a lot of this balancing actually hurts, you are actually discharging and charging the cells, the cell life goes down unless cells are exactly the same voltage. Even if you take the cells at the time of manufacturing measure, if they are exactly the same after some usage as SOH becomes from 100 percent to 99 percent, the voltage will not remain same. And the current will keep on for flowing from one string to another. This will happen continuously while charging and discharging, even when idle you will keep on trying to balance and not good for battery so this mechanism mSnP is not used.

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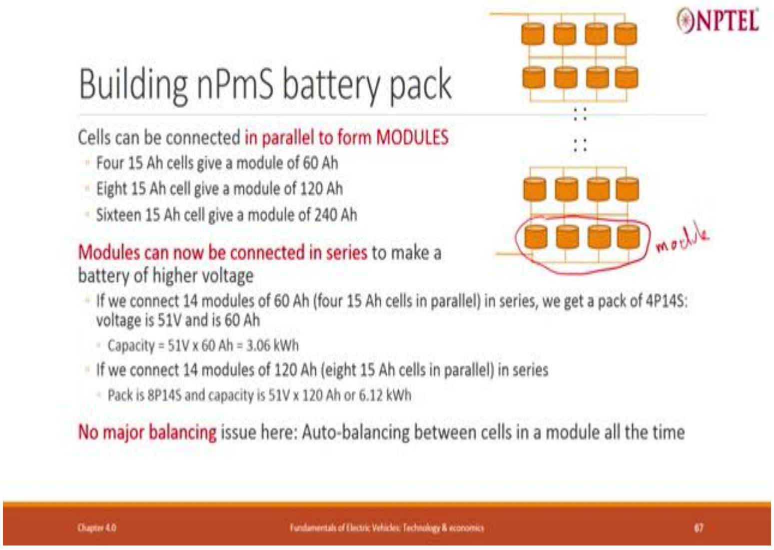

What is used is something like this. You first create a module, this is a module, put n series cells in parallel and then you connect them. So, this is a module, first you connect the module and then you put module into series, you put four cells in parallel of 15 Ah, you get 60 Ah. 8 will give you 120Ah, 16 will give you 240Ah, so you get a module of different Ah. Now you connect them in series to make battery fire voltage.

You put 14 modules of 60 Ah you will get 4P14S 51 volt 60 ampere hour, capacity is 3.06. If we connect 14 modules of 120 ampere hour in series you will get 8P14S or 6.12 kilowatt, this is the way nPmS and this the only way the right way of designing it. No major balancing issue, of course, you can say here the within a module there may balancing. What if the cells are of not same voltage? Well, this is the reason the cells in parallel has to be carefully chosen, they are exactly similar kind.

And while charging-discharging you have to make sure that different current does not flow through, that is the reason you actually connect them like this, you have to make sure that the resistance is not difference, if the resistance is different, you know, different current will flow, do not worry about it. If internal resistance is different, you apply the same voltage different current will flow. So, you have to worry about each and every of this, there is a self balancing and at time you can enable some more balancing which is okay otherwise land up in trouble.

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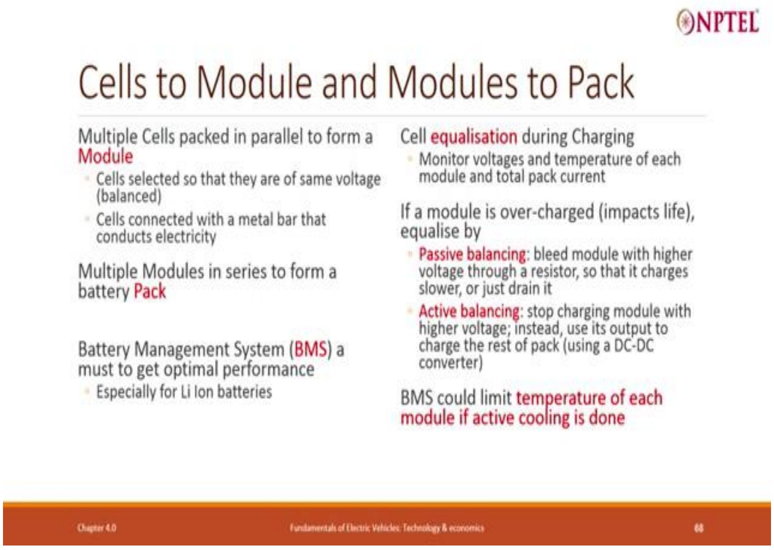

So, basically cells to module and module to pack, so multiple cells packed in parallel to form module, cell selected so, that they are same voltage balanced cells connected with a metal bar that conducts electricity. So, the cells are put on a metal bar so that it does not give too much of resistance, it is conducted very easily. Multiple modules hooked into a series to form a pack and then there is a battery management system which will monitor the voltage of every module, the current of every module and temperature of every module.

And for lithium ion batteries, it will then try to work to get optimal performance. During charging if unequal current flows between multiple batteries, you will try to do what is called equalization, it monitors voltages and temperature of each module. If a module is not getting sufficiently charged, you bypass another module or you let more current flow into that module. If temperature of any module is going up, slow down, do not let it charge. If a module is overcharged as opposed to another, it impacts life.

And there is a two methods of balancing. I think probably Kaushal will cover that more. One is a passive balancing and another is active balancing. Passive balancing basically means bleed one module with higher voltage through a resistor so that some current flows into the next module. Active balancing stop charging a module of higher voltage and instead charge the other module at lower voltage. And then BMS has to worry all the time about temperature.

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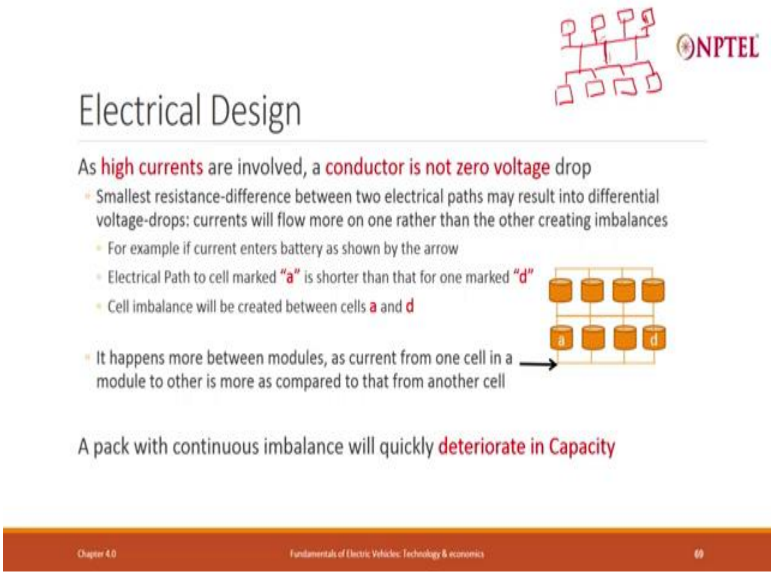

A very important component of electrical design, as high currents are involved a conductor is not a 0 voltage drop, that is the point that I am making. Smallest resistance different between two electrical paths may result into differential voltage drops, current will flow from one rather than or another rather than the other creating imbalance. So, a lot of imbalancing take place because electrical design is poor.

In fact a very interesting thing that I had come across there are let us say there is a metal plate to which all the cells are connected. This is then connected in series to another metal plate where four more cells are connected. And these two metal plates can even be same, it does not matter. You will think you have done it right, you have thick metal plate which you have connected, but look at here, this path from here to here is shorter path as opposed to here to here.

Shorter will have a smaller resistance, longer path will have a longer resistance because there is only single connection between these two, you have problem. So, the way to correct is that you will have multiple connections, you cannot have a single connection, then more or less same amount of current will flow, same thing I am showing here, if a current enters here and supposed to be going here, the same thing the current is entering, if it goes through a it encounters resistance, it goes through d if your let us say inlet comes from one side inlet also has to come from a way by which all 4 gets equal.

And this is the kind of problem that you will get into it happens more between modules as current from one cell module to another is more as compared from one other cells more cells. A continuous imbalance deteriorates capacity, some of that can be corrected but a continuous imbalance deteriorates capacity.

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So, electrical design has to carefully done. I want to point out two more things and stop here. What if there are failures, what kind of failures happen? Suppose you have modules nPmS, n cells in parallel m in series and one of the n parallel cells become open circuit, what is open circuit? Suppose there are 4 of them now only 3 cells are in parallel, one of them is not there.

So, suddenly he this is happening only in one module, other modules have full capacity, but this one module capacity has gone by 3 by 4 of the original one, overall pack capacity will go down by 3 by 4 because when the current flows, the current if you try to flow more, if all of them are getting charged by 1 C, this will start getting charged by 1.33 C, that will destroy the pack completely. Overall capacity itself goes down, because though other cells have capacity, capacity will not be utilized. So, open circuit basically immediately means, in any module one cell is all.

Supposed there is a short circuit one of them parallel cells, all the cells in parallel will get short circuit. So, you see the voltage will go down by 3.7 volt, which basically means, the voltage has gone down, your motor etc everything has been designed to operate at certain voltage, now they will get differential voltage. But still short circuit is better than open circuit, open circuit hearts you much more. So, drive train will get poor performance, but one can do that and these are to be monitored, the BMS has to monitor if anything like this has happened.

Now replacement will involve taking out the module, and these are all module which are welded together, very difficult to take out the modules. So, replacement of module may be sometime possible, replacement of cell is not possible. Now, when you do the design itself, you have to worry about what will I do if I have to replace? How difficult will it be? You cannot think about it later.

So in the design time, you can sort of say these things I will only connect through screws, so that they can be taken out, I will connect even even the bus bar that I will connect through screws, so I can open up and take this out. If a serial connection between module fails, battery fails, it does not go through. But it is generally easier to repair, it may require some bus bar replacement.

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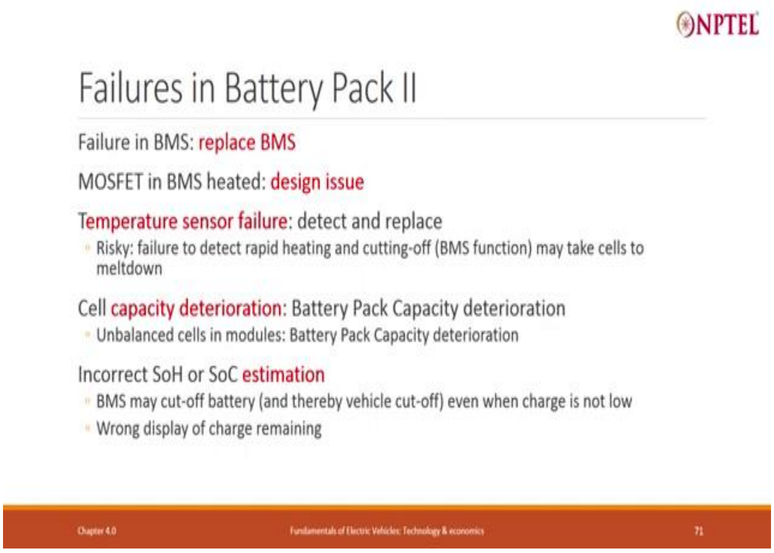

What happens if a BMS fails, that is more easy to detect and it does fail, BMS fails more often, but easy, just to replace BMS recalibrate everything you are worried about again SOC and all those things. But the other problem that you often find that you have to switch in current, switch off current, and for that use MOSFETs. And MOSFET is a heat dissipating device and if a MOSFET is getting and you are supposed to remove that, if a MOSFET is getting overheated, you will see the temperature, it is a design issue, if one MOSFET is getting heated compared to the others, you have to worry about it, you have to shut down that MOSFET otherwise, the MOSFET is likely to fail.

Temperature sensor failure, there are lots of temperature sensors, every module temperature is going to be sensed, every MOSFET temperature is going to sense and you find some time these temperature sensors not well not very good quality, in which case, they will give you all kinds of results and you will end up doing something totally different from what you were supposed to do. Sometime the sensor will fail, some time sensor will give you a wrong temperature and you have to detect it otherwise, these are dangerous because it can result in too many down.

You think that there is nothing wrong in the sensor but it is getting heated up is one of the most risky thing. Cell capacity deterioration that is another thing that happens and largely it is unbalanced cell in modules, battery pack capacity deteriorates. Incorrect SoC and SoH estimation. What are the important thing, we had a battery with incorrect and the drivers will complain saying, sir it was showing 40 percent SoC and suddenly my vehicle got cut off.

For a long time we thought something was wrong in vehicle. Something was wrong in display, actually we found out later on it was SoC, SoH estimation mistake, it can result into a problem.

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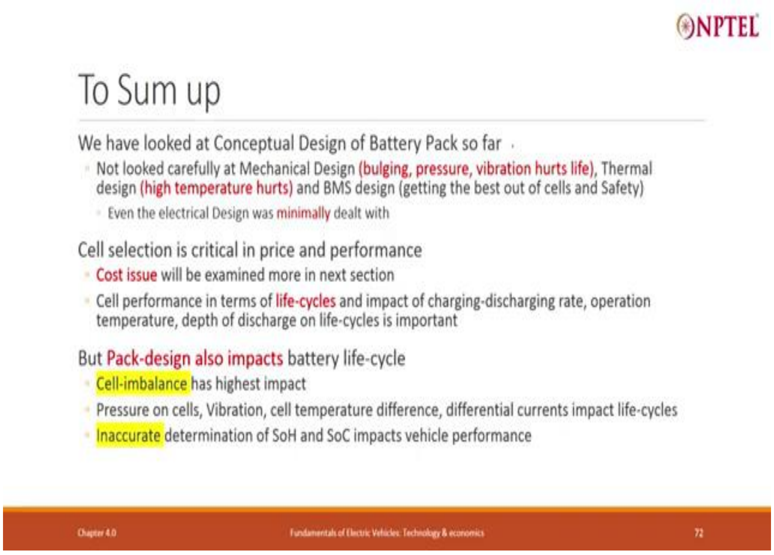

So, to sum up, we have looked at a conceptual design of a battery pack so far. Not so carefully at what will be the mechanical design which will stop the bulging, the pressure, how will vibration be tackled, not a thermal design, they are basically done electrical design and you have not done the BMS design. This is what Doctor. Kaushal will actually do in his set of lectures, get into a depth of each of these things. This is what a battery pack design will be. The simple configuration of putting them in series and parallel is fairly easy, everybody can do it.

Electrical design is somewhat tough, but because you do not understand 200 amperes, if it was 1 ampere the problem would not be so serious. A milli ohm resistors will only give you a millivolt difference. So, electrical design we dealt with minimally you may deal a little bit, but more carefully as mechanical, thermal and BMS design you look at. Cell selection itself is critical in price and performance, cost issue will be actually looked at very carefully in the next section, cell performance and life cycles and impact of charging, discharging rate.

Operation temperature, depth of discharge all of these will have impact on life cycles. All of this will have impact on cells that is the next section we will look at what is the battery cost, usage cost that I have been talking about right from there. The pack design also impacts the battery life, cell imbalance has highest impact on battery life, pressure on cells, vibration, cell temperature differences, differential currents impact life cycles of the battery.

Inaccurate determination of SoC and SoH of course hurts the bad vehicle performance, after some time starts hurting the battery performance. So, this is what we have to summarize this and what we will do next, is there some questions fairly simple questions.

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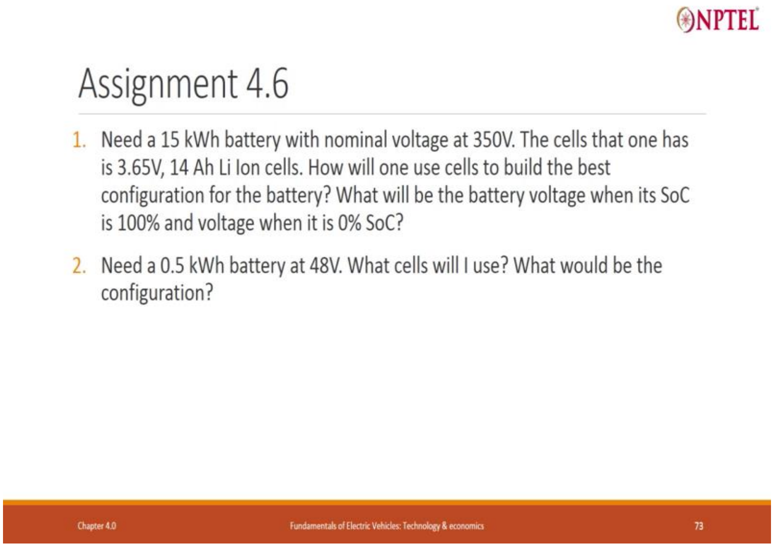

I will not go through the questions well, let me quickly look at it. Battery pack of 15 kilowatt hour with a nominal voltage of 350 volt, your cells are 3.65, 14 Ah configure what will be the battery voltage at 0 percent and at 100 percent. Need a 0.5 kilowatt hour battery of 48 volt, what is cells that are used? What would be the configuration?

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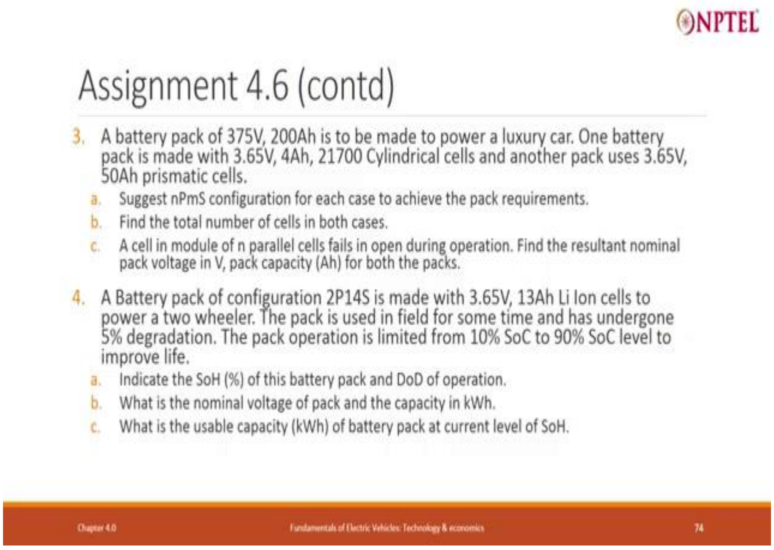

A battery pack of 375 volt, 200 ampere hour is to emit to power a luxury car. One battery pack is made with 3.65 volt, 4 Ah, 21700 single cell, and other with prismatic cell. Suggest nPmS configuration for each case, find the total number of cells in each cases. A cell involved module of n parallel cell fails, find the resultant nominal pack voltage in V and ampere hour for both the packs. You will find some interesting results.

A battery pack of 2PN14Sn is made using 13 Ah lithium ion cell to power a two wheeler, the pack is used in the field for some time and has undergone 5 percent degradation. So, SoH is 95 percent. The pack operation is limited between 10 percent to 90 percent SoC. Indicate the SoH percentage of this battery pack and DoD of operation, I have already given you the answer. What is the nominal voltage of the pack and the capacity in kilowatt hour? What is the usable capacity of the battery pack at the current level of SoH?

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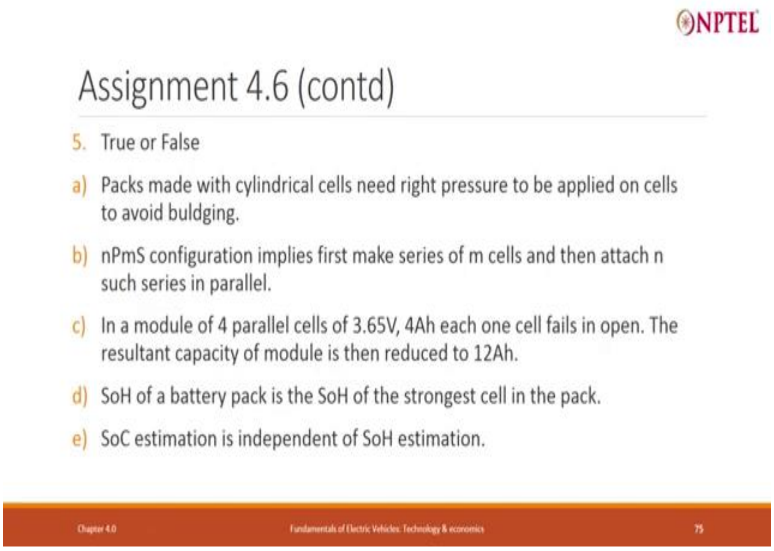

And there are various true and false please answer that and you will then come to the next section, which I will do next class.