Fundamentals of Electric Vehicles
Technology and Economics
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Lecture 32
Fundamentals of Battery Pack

Welcome back. So now we are going to start Fundamentals of Battery Pack. Before entering in this chapter I would like to recap what professor Ashok has already taught you. In the first chapter, he has talked about a comparison between IC engine vehicle and electric vehicle and what are the difference and what are the similarity. In fact, most of the things of IC engine vehicle can be adopted, what are the changes?

There are two major changes, one of them is that instead of engine we need to move for motor and controller as a prime mover and instead of a gas tank or petrol tank or fuel tank we need to move as a energy storage for like lithium ion cells, lithium ion battery pack for providing the energy to the motor and controller. There are other auxiliary systems that also need energy and that has to be migrated to electrical based platforms.

In this chapter 2 he has talked about regal dynamic, what would be the energy consumption because of the different forces on the vehicle? Aerodynamics, the force due to inclination that is also known as gradient force, rolling resistance and then what else. Basically these are the forces which need to be overcome by the motor. And then in chapter 3, he has talked about EV subsystem like auxiliary system. Like steering system, air-conditioning, brake booster, pumps etc.

In chapter 4 he has talked about electrical vehicle storage, where he has talked about different cells, cell chemistry, how to make a pack, basics of electrical design and then finally he has moved to the economics. Now, we are going to start how to make a battery pack, what are the fundamentals of the battery pack. So, I will give some introduction what are the things needed for a battery pack and then we will move today on mechanical design.

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What does a battery pack needs? You can see right side there is a picture of a car which is under fire. How come this happen? If there is a short circuit which is most common cause of electrical fire. So, a careful electrical design must be there inside a battery pack. What do you mean by electrical design that how the cells are connected in series and parallel. The mechanical member which connects the cell is bus-bar. It should be designed properly so that it can carry the required current.

The second most important thing which a battery pack needs is thermal design, a careful thermal design. We have seen during the last chapter that temperature impacts cell life significantly. For a optimum life of a cell the temperature should be something between 15 to 35 degree centigrade.

However let us consider India, if you go to Leh and Ladakh the temperature goes to minus 20 degree, you go to the part of Jaisalmer or Rajasthan, Jaisalmer is a place in Rajasthan, the temperature during the summer goes 250-253 degree centigrade.

So, this is environmental factor at the same time there is a if you go to Assam heavy rain so moisture, if you go again to Leh and Ladakh the moisture content is very low because of the low temperature. So, proper thermal design ensures that your battery pack is always running at optimum temperature to enhance your cell life or pack life. Since battery pack is a very heavy capital cost compared to IC engine vehicle.

So, we want to get the maximum out of it, cycle life as well as calendar life other than the energy. Life of a battery pack is very important, if my cell is able to run for 8 years or 5

years, I should provide sufficient protection for that so that it should run for that, that means my battery pack should not corrode, should not break away, my cell should not move. As well as the material what we select there should be of a quality which can sustain our required life.

Durability, a vehicle runs in different terms again I will take example of Leh and Ladakh it is completely a hilly area even most of the places roads are not build. In Chennai and just outskirt of the Chennai every second you have to do braking and what braking results it results in jerk force, jerk which you cannot immediately measure.

So, the nature of force is not properly known then you just go to highway you can run to 90 kmph and suddenly you got suddenly you get a path pole. So, the battery pack should sustain all this vibrations, all this running condition that for your entire life whatever life we decide 5 years or 7 years or 2 years or 1 year, it should run for that particular life.

Now the performance becomes very important, if I do not use proper material what will have? We will have different type of resistances that will reduce the current output at the same time it will waste that energy as a form of heat now if we have to remove the heat again we need energy, to run a system which can remove the heat.

So, a proper material, proper design is required for a required performance. Safety, it becomes very important, reason up if current is not controlled properly, what will happen? Cell will keep on getting heated up. A cell has a particular temperature range where it can work safely. I am talking different thing then performance. Sometime we may allow the cell to go beyond even 35 degree, 45 degree, 55 degree because we know we can run but after 55 or 60 degree we may not allow the cell to go because it could lead to the fire hazard like something like known as thermal run away.

Or if there is a short circuit how quickly we can cut off the energy flow so that the fire should not spread away or if there is a adverse environment outside like it is raining heavily, so water should not go inside because water is a conductor it can lead to the short circuit. So, all those precautions we have to take inside a battery pack are in a battery pack.

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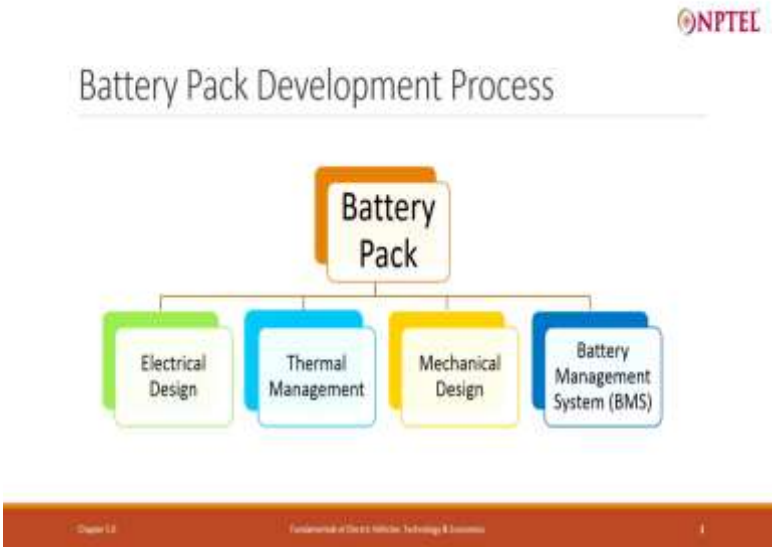

So, next we are moving to battery pack development process how do we do battery pack development? So, basically a battery pack I can divide into 4 sub-domains. First one is electrical design. In the electrical design basically we look upon all the contractors bus-bar, cell terminals, wiring harness required for energy flow in and out and also the signals which should go to our controller right now I am talking controller I will define the name later.

It should also be able to control the flow based upon current flow or voltage based upon the requirement. Now next one is the thermal management. As I discussed, the thermal management is required for a longer life of the battery pack to get maximum out of it what we paid for because again our temperature requirement is again 15 to 35 maximum this is what a optimum temperature range.

Below 15 there is a problem, beyond 35 there is a problem. Mechanical design; mechanical design is required for all safety, durability, performance to mitigate the external environment my cell should not move constraints all the constraints for that mechanical design is required. And finally the battery management system; the battery management system is heart of a battery.

It controls everything from current flow during charge as well as discharge cycle it communicates to the subsystems like motor if they demands this much of current I should allow. It communicate with the charger that this much current I require for my charging or this much time I require, it communicates with outside world that my range is this much, it communicate with the driver this is my range available to me now.

I can go for next 50 kilometre, I can go for next 30 kilometre it controlees all the events what is happening inside a battery. If my cell temperature is going beyond a certain limit which I have already fixed, it will cut up the complete energy flow so that there should not be a further damage. If anything is not working to its intended use, it will lock those things for service in for future service.

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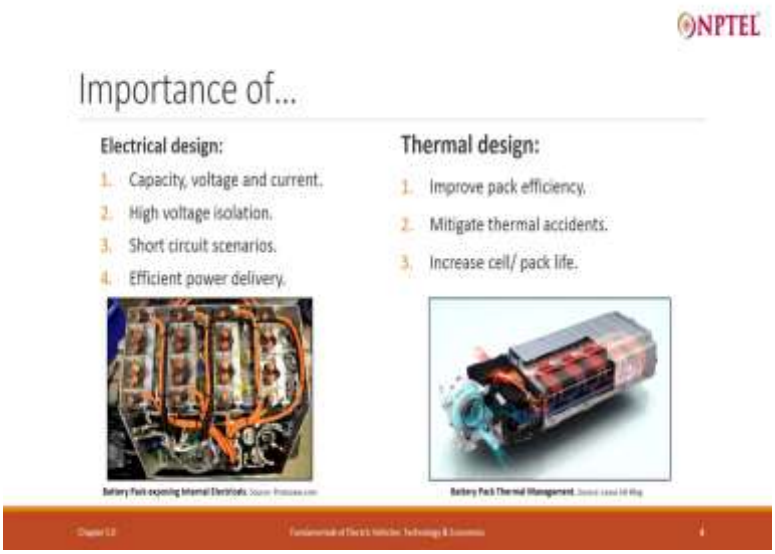

So, next these 4 things what we have talked, what is the importance of those 4 things? Electrical deign deal with capacity, voltage and current. If I have to make a 2 kilowatt battery pack, so I need to put cell in series and parallel combination or parallel and series combination. This also tell us what supposed to be the voltage and if there is a voltage requirement for the motor or auxiliary system drive, this tells us what would be the again, parallel and series combination of cell.

So, remember in chapter 4, mpns theory, parallel make Ah increase. Series makes voltage increase, high voltage isolation. Nowadays for higher capacity battery pack like 10 kilowatt hour battery pack or 15 kilowatt hour battery pack or 50 kilowatt hour battery pack or 100 kilo watt hour battery pack, we go for higher voltage range like 350, 750, 800. The DC voltage is safe for human till 60-65 maximum you can take up to 100 volt.

Beyond that, it is not like easy you touch and it will throw you out. (())(14:33) it will give you a chance. Here, that situation does not happen. At higher voltage, you would always be if you touch it in bare hand, you would be in problem. So, if there is any leakage or any anything because of that my high voltage tunnel is touching to the ground or my body part of the vehicle I need to isolate that and that again comes from the electrical design.

Otherwise, the passenger in the vehicle would be in problem, it could be a life threatening problem. Short circuit scenarios, if short circuits happens what should be done or how should I design that short circuit should not happen. A short circuit is nothing but a touching of positive and negative terminal. And because of that what happen? The energy gets very energy gets converted into heat which melts that particular location. And finally the efficient power delivery.

Efficient power delivery means my resistances or any losses which has should be minimized during the electrical design. Next thermal deign; what does thermal design do? It improves the pack efficiency because you are running within the certain temperature limit. Whatever the heat is getting generated, you are removing efficiently. And if you have maintained the temperature particularly your life also increases.

For electronics, it is a known fact, every 10 degree increase in temperature would bring a life to half that means, if 50 degree centigrade my let suppose some resistor life is 1000 hours, at 60 degree, the life would be 500 hours only. And the increases cell pack life by maintaining the optimum range of the temperature for running it.

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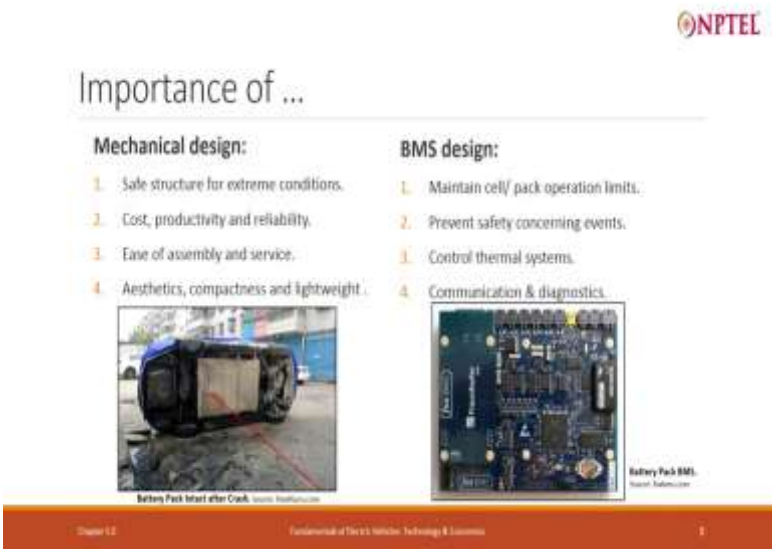

Mechanical design; you can see in the picture a car is toppled and it happen frequently, everywhere it happen. If battery pack is also getting broken during that time, what will happen? Now you do not have any control there, it could be a muddy water, it could be a mud, it could be a water logged area, fumes can come, short circuit can happen and because of the impact itself, the cell may degenerate, can lead to the fire.

So, what we need to take care in mechanical design? Even in extreme conditions, my battery pack integrity should be maintained. And that is what is safe structure for extreme conditions. The cost, we should select a material which can help in safe structure for extreme conditions but the cost should be minimum. We can assemble and dissemble battery pack for service or for recycling quickly that is what productive means.

And reliability, it should the fail without giving any warning. So, when we are talking about a life or durability or reliability, if I know it will fail only after 5 years, after these many cycles, it should fail only after that. Because we know, we can replace at that time or we can repair. Mechanical design should ensure ease of assembly during manufacturing as well as if there something goes wrong, the service should be much easy because this all involves cost.

Manufacturing involve cost as well as service also involve cost. It should look good, anything looks good have more appealing power to buy. Compact; I should take mechanical design should take minimum volume and provide the maximum energy. If that would be the case, we can come closer to the petrol or IC engine driven vehicle because we can increase watt hour per kg as well as watt hour per litre.

If we increase that one, we can come closer to the petrol energy petrol energy level. It should be light weight. You would have seen in chapter 2, if we increase the mass, our energy demands increases. Can we make minimum possible edition because cell is not in our control, the other parts like bus-bar, casing, cell holder can we use a material which can give all other things as well as it is light weight?

Now next move to BMS design; the importance of BMS design is maintain cell and pack operational limits, operational limits can be over voltage, under voltage, excess current, temperatures. It should prevent any safety concerning events like one of the example I can give you, if my, if motor is demanding a current of let us suppose 100 ampere, some cases it can happen even though you have put 60 amperes limit.

So and if I have put 60 (ampe) you mean my pack cannot given more than 60 ampere, so anytime beyond 60 ampere demand, it should cut off. It should control the thermal system so that my temperature remains become optimum limit. Communication, it should communicate with all other subsystems inside as well as to the externals worlds. It should also, it should be able to log if there is any critical event has happened which is not threatening at that moment but could be.

Like if my pack temperature is continuously coming, if I have put a limit 50 degree and it is coming continuously 45 plus that means something is going wrong. It should keep on logging those events so that during the service I should know what are the things has happened inside the pack and I should be able to take appropriate action for that.

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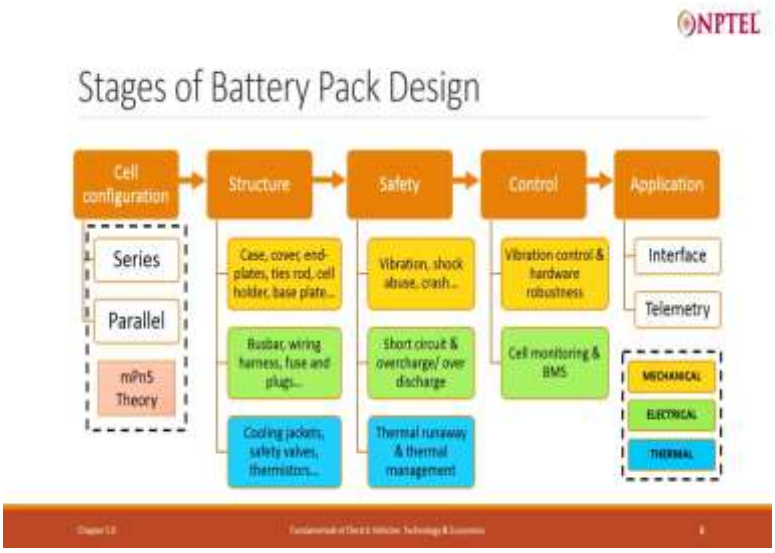

Stages of battery pack design. What I was talking about is importance, why those 4 electrical design, mechanical design, thermal design and the BMS design is important. Now I will talk how to make a battery pack. So, what are the stages involved in battery pack? The first one is cell configuration. To achieve required voltage, current and capacity we have to put the cells in series-parallel and what we have understood in chapter 4, parallel first series second and that is why mPnS.

So, Ah will get by putting the cell in parallel, first parallel and then required voltage by putting the cells that each parallel group in series. Now second one is structure. What a structure covers? You see right side there is a 3 colour codes, mechanical, electrical and thermal. It is a basic division. So, when I am talking about case cover, end-plates, ties rod, cell holder, base plate, these all become a part of mechanical design.

Even though this is a structure but it is a part of mechanical design. When I talk about bus-bar, wiring, harness, fuels and plugs these all are parts but a part of electrical design. Now for thermal design, what are the things we required? Cooling jackets, safety valves, thermistors. Next we move to safety. At some places because of some reasons battery pack does not has a movable parts but let us suppose because of the any reason my motor start vibrating, because of any reason and that vibration is not in control, what should it do?

It should cut-off my battery pack should cut off the current flow or energy flow. We discuss a picture where the vehicle is toppled that is case of like crash or shock abuse. While manufacturing the battery pack if somehow its fell down or if even if it is packed in the vehicle and because of the any reason because of rusting of the nuts and bolts which has fixed it to vehicle fails and battery pack fall down, that is the case of shock abuse. It should maintain its integrity or my BMS should be able to cut of the energy flow at that moment.

Short circuits; very high current flow which could lead to the melting of the bus bars can lead to the welding of P charge circuit so that means my circuit is always open, (sorry) close that means current is continuously flowing. Over-charge and over-discharge, C rate, if my cells are designed for C-rate of 1 during discharge and 0.5 C during the charge that should not exceed even if externally it is applied or externally if somebody is demanding or something he is demanding. That is the part of electrical design.

Now for the thermal design, thermal runway, thermal runaway is a phenomenon where all the energy of the cell as well as the chemical energy stored in the battery comes as a heat. It is a quite high, the nature of 1 mega joule and (())(27:03) and its various short duration event, you cannot control. So, before it reaches to thermal runaway condition I should be able to safe my battery and the thermal management which allows not to reach any condition beyond the limitation of the pack.

Next one is controls which I talked just now. If vibration even vibration do we can we have some sensors which after detecting some abnormal behaviour in vibration or the shock or in the case of crash can shut down my battery and that comes a part of control. Again, it can be mechanical, you can have something some spring loaded system where beyond a certain vibration, it disconnects or you can have electrical mechanism, some sensors or some actuators.

After sensing a particular vibration beyond particular vibration limit, it will open the path so that no energy flow further go and it can also take a preventive measures like if there is a energy stored in the cell, how to dissipate that energy so my energy content of the battery pack come down during the condition of like crash. Cell monitoring and BMS; it is a continuous process which we need to keep on doing so that nothing over suits neither current nor voltage, vibrations, temperatures.

The next is applications; applications basically two things, interface with the different subsystem, drivers, displace and the telemetry. It also tell let us suppose there is a fleet, it

should also tell fleet owner this is what your (vehicle) this is where your vehicle is and this is now it has only 70 more kilometre to go.

If there is any event critical event has happened that it can tell that this time cell temperature has exceeded even if I have put some T2 temperature and I have put a quotient at T1 temperature it has exerted my temperature quotient temperature of T1. So, pack is still working but one need to worry when it when to do the service. So, these are the stages of battery pack, cell configuration, structures, safety, control and application.