Fundamentals of Electric Vehicles: Technology and Economics
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Lecture 13: BMS Design of Electric Vehicle - Part I

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So, in battery pack design what, what are the things we have covered till now, the introduction where we have talked about the system and subsystem of the battery pack, advantages, disadvantages, we have divided the design of battery pack into 4 sub-section mechanical design, thermal design, electrical design and the BMS. So, we have completed mechanical. We have completed thermal. We have completed also electrical design and now today we will start the BMS design.

Before BMS design we have completed the electrical design where we have talked a lot about resistance, equalization of resistance, equalization of current. And resistance become important because it keeps you the current, equal current if there is a division and that becomes very important in the case of BMS. Because BMS controls the current. So, if the current paths are not properly laid out, so there is a chance that you may get excess current somewhere and the less current somewhere and that would lead to the thermal degradation, thermal failures and all those thing.

So, that is a part which we have talked in electrical design. In BMS we will be talking a lot more, what is the functionality of BMS? What are the things it does? And how it is protects? So, BMS

is basically brain of a battery pack. And sometimes it also work as a heart because brains give signal, this is what has to be done and then it has also some parts which control the things like current. What is the important thing which comes out from a battery pack is current.

So, it is also controls the current that you should go or not, or you should come in or not. During discharge current has to go out during the charging current has to come in. So, it is controls that it should go out or not. In the case of a event like crash, it is also says that or ensure that the everything remains safe. So, with that introduction, let us move ahead, today we will finish this section, BMS designed for electric vehicle.

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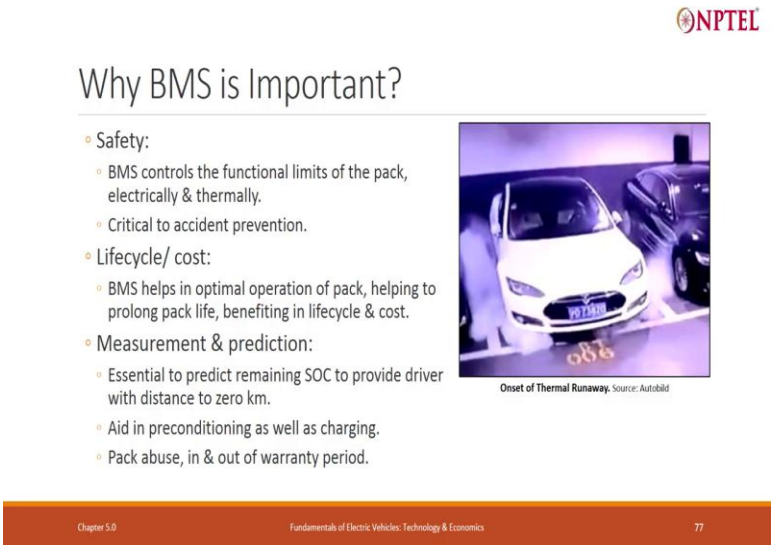

So, why BMS is important? The first and foremost reason is to have a BMS is safety. So, BMS controls a functional limits of the pack. Whatever functional limits within that pack will work safely, its controls like over-voltage. Over voltage may lead to the failure of the cell. Temperature if they exceeds some particular limit would again lead to the failure of the cell. It is not only failure of the cell. It may also trigger other events, which is harmful.

It is critical for accident prevention anything goes beyond the functional limit. It is stop current flowing outside or current coming inside. It also tries to reduce the damage to minimum. When we run the things in within the limit, within the limit which we have already know that it would be good for battery, it would be good for the life cycle, it would be good for the cost. So, it controls all those parameters which can enhance the battery life which can reduce the cost.

If we enhance the battery life what will happen cost will automatically get reduced. So, BMS helps in optimal operation of a pack helping for prolong pack life, benefiting in life cycle and cost. How can you prevent anything? How can you control anything? For that you have to do measurement. It is also measures voltage, current, temperature needed, if needed vibration and then based upon the measured value it takes preventive action or it controls the system.

Based upon measurement is also predict what is going to happen now. Based upon measurement it (also), it predicts, what would be the further kilo meter you can go with the, this pack. It predicts, what is health of your battery how many more cycle it can go before you discard the battery or before it indicates now you need, now it is a time to discard. It helps to know you what are the event has gone wrong in the past and what would be impact because of those events.

So, essential to predict remaining SoC, state of the charge to provide driver with a distance to 0 kilo meter. How much energy is left? How many more kilo meters you can go? Preconditioning sometime if you have active thermal management system and your ambient temperature is 45 degree or 48 degree. However, you knows, you know that battery can work well around 25 degree centigrade.

So, you start the thermal management system or BMS start the thermal management system to maintain the temperature at 25 degree centigrade before you enter into the car. It can also allow the vehicle thermal management system to take some power and pre-cool the cabin so that when you come inside the vehicle you feel comfort. You do not, you will not get, your time will not get wasted to pre, means to cool the cabin first and then to drive.

Or you will not get sub, you will not be suffocated because of the high cabin temperature. Pack abuse, if somebody try to take out, the current beyond the limit, it will register it will log, or somebody has thrown pack somewhere or it has hit and if we have sensors which can measure, so it can lock those function. So, by this way, it can also say that this event happened on the battery pack, which is not supposed to be done.

So, like temperature you specify some temperature that packs would run between that. And due to some reason that temperature has exceeded and you are, you are still using, so the life cycle will come, or it may trigger to a safety concern. So, in those cases the warranty claim can also be

taken based upon the event. Now, we have put a battery that it should run between 20 to 30 degree centigrade.

Location based like I am running a vehicle in Chandigarh. The temperature would be generally 22 to 35. Now, somebody takes that vehicle to, to Rajasthan and run that in six months there in the high ambient condition 48, I can see easily, see our condition was this at this location, but you have violated that location, so you cannot claim the warranty. Or if there are real issues it can log those event and can say no, your pack is in warranty, it should be replaced because there would be some, there was, there was problem because of the internal architecture.

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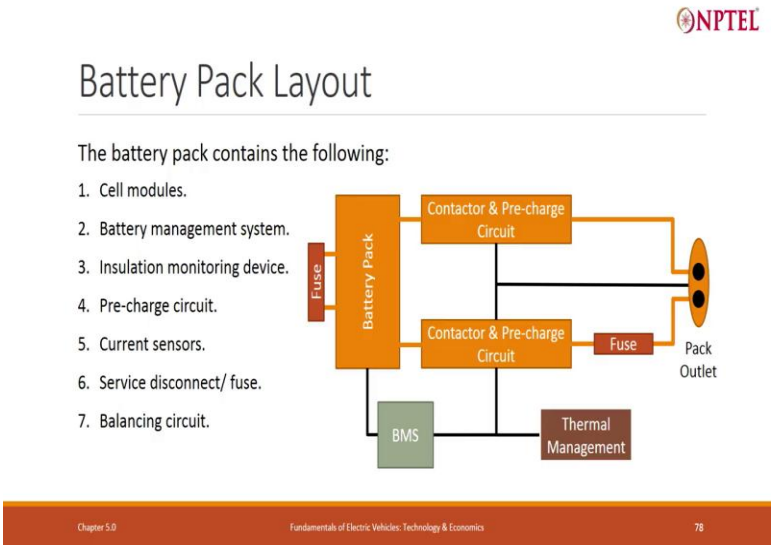

Now, I will show you the battery pack layout how, which we have already shown earlier also, but again, I want to show in other way, how does it looks like. So, you have a battery pack and then inside the battery pack or outside the battery pack depending upon the battery. It is a fixed one or big one or a small one you have a BMS and then you have live lines, where you have contactors, or relays, or MOSFETs that means switching device. Then it would be connected to the outside either through motor, motor, motor or motor controller mostly for the vehicle application.

And then there is a signals, communication signals that can go to vehicle control unit or vehicle management unit. Then there is a pre-charge circuit in built with the contactor or in your BMS. For safety reason you can have fuse in line, in series or external, in external cables or at both

places. And then you have also thermal management system, which is being controlled by BMS. So, cell modules inside the battery pack, battery management system.

Insulation monitoring device, if it is high voltage system then to separate out high voltage line and low voltage line, and that one should not interfere with other, we provide also a safety feature either in BMS or controlled by BMS is known as IMD, insulation monitoring device. So as soon as it detects there is a high voltage and it is leaking, this IMD, insulation monitoring device sends signals to BMS and BMS cut-offs the current flowing. Pre-charge circuit, pre-charge circuit here. Why we require pre-charge circuit, we will discuss later.

Current sensors, current going in or going out has to be measured accurately then only you would know you can calculate or microchip (can) calculate the charge, state of charge. And if it is accurate then only you can predict the state of health. Service disconnects fuse. So if I disconnect this fuse and if it is at positive terminal, so you do, even though BMS is not functioning but still you can isolate the system. And then cell balancing circuit these are the major part of a BMS battery pack.

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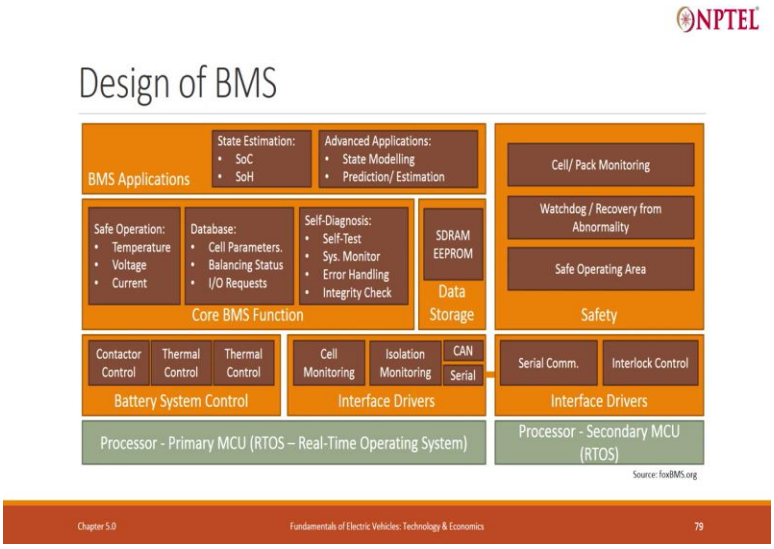

Now, we will go to design of BMS. What are the things in BMS is there? So, the core BMS function. What is the core BMS function? Safe operation. What are the things needed for safe operation? You need to know the temperature, voltage and current and everything should be

within the specified limit. Then you also need to measure and store different other parameters like cell parameters.

Again in cell parameters could be Ah, OCV versus SoC curve and all those things. Then balancing status, self-balancing status. And input-output request, if motor is requesting current and my contactor are open, current cannot go, so it has to honour by closing down the contactor, so that current can flow. Then self-diagnostics, like self-test all my functions are working or not. My temperature limits are within the specified limit or not.

My temperatures are within the specified limits or not. My cell voltages are within the specified limits or not. In the past event does any error occurred, which may be harmful, or can we ignore that before going to the service, various types of error handling, during the last tribe some error has come, but now that error is no more. So I will just, BMS will just log that as a event and then allow the, if it is, if it is sees that, that is not a safety issue, it will allow the battery pack to draw the current or take the current. Integrity check, my all function are working or not.

My, all sensors are working or not. My all hardware is working or not. And how it is being done, there is a particular codes written for that, particular modules written for that one. So, that is what is the core BMS function, what else? Application, what are the application? State estimation, what is the state of charge now? And what is the state of health of the battery now? Advance applications, if you have sufficient sensors, which costs you can measure SoC, SoH, however, it is difficult to always measure.

So, sometimes you predict or calculate based upon the derived quantity based upon the current output and current out and coming in. So, that is what is known as state modelling SoC and SoH we model based upon the past experience, based upon the calculations, based upon the theory, based upon the correlations, empirical correlation, based upon the correlations. So, that we say state modelling. What is, what would be the SoC? What would be the SoH? How many cycles more my battery pack will function satisfactorily that is important.

Then it is also predict and estimates. At this moment my cell temperature is 35 degree. If my vehicle is running, what would be the temperature after 5 minutes? It can predict, it can predict how many more kilo meters now my vehicle can go based upon the past experience or model, that is estimation. Next, where does this all data get stored? So, we have a data storage on the

vehicle, either it can be a flash memory or a external memory card. Where all the datas get written. So, that you can retrieve calculate or BMS can retrieve calculate, estimate.

Now, battery system controls, contactor controls, contractor is open or closed or it should be open or closed or my current like MOSFETs should be open or closed. Switching devices, it can control, it has to control the switching devices. Then thermal control thermal management. If my temperature is exceeding some particular limit, my flow rate has to be increase or the thermal system has to be switched on. Or my fan, which is generally at condenser in active thermal management system, need to be switched on.

Interface drivers there are severals hardwares in a, in a BMS, ICs, MCUs, CAN, serial communication so those (interface) interface drivers has to be present as a hardware form, as well as has to be controlled by software. Then and all these things will happen when you have a real time operating system. Because everything is working at that instant itself. When your vehicle is running it at that instant all the things has to be to retrieved, calculated, estimated and given back, decision has to be given back. And that is being done by real time operating system.

This primary MCU, generally a BMS will have for redundancy either masters, or master slave, or primary and secondary MCU, that type of configuration. The secondary MCU will monitor cell and pack voltage, current, temperature. It will act as a watchdog because sometime this may hang. In that case, it should be able to take minimum safety decision that is okay. Let us contact, let us make contactor open. So, that current should not flow because I am not getting any advice or any signal from the master control unit, to maintain the safe operating area.

Then communication, serial communication, my contactor is closed. Now, it (have) it can be opened either through MCU if a request comes, or the secondary MCU, or there would be a, generally there would be a stopper, emergency stop. So either control has gone from my primary MCU, or from the secondary MCU, or from the emergency stop contactor will open. So that what we say interlock. And if I put, if I put emergency stop that means even MCU is saying no you should be closed primary or secondary, still it will make it open because that priority is very high for, priority is absolute for emergency stop.

So it, this all three is interlocked. However, if I put emergency stop it is absolute, nothing can override it. The contactor has to be opened because it is a safety concern. So, most of the time

this can be clubbed together can be separated out. However, safety is always given the highest priority and sometimes absolute priority. Like in the case of interlock or emergency stop. It has absolute priority, nothing can override that.

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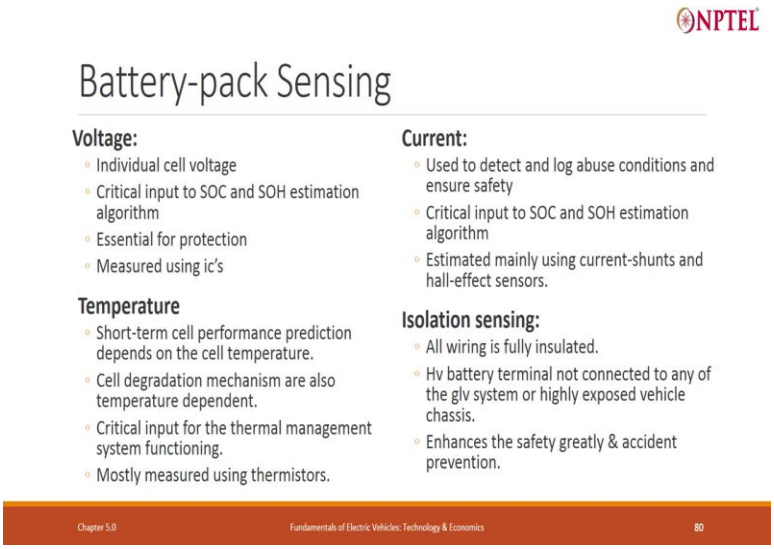

Now, next how do we do all the things unless we sense or measure BMS cannot decide anything. To decide anything it had to sense or measure. Voltage, what we do, we measure individual cell voltage. When I say individual cell voltage, mostly it is parallel cells, whatever cells in parallel is considered as one cell. So, we measure that cell voltage. For redundancy purpose we can measure at two different points or two different sensors.

But when we say cell voltage measurement that means all parallel cells together one set of parallel cell together, that is forms individual cells, that is what we say individual cell. To reduce the number of sensors, this is very critical input to SoC and SoH estimation then in MCU management control unit or master control unit. Because algorithm is running inside the MCU with the parameters, by taking the cell voltage it will estimate, what is SoC left over, or what is SoC has already consumed, and what is the state of charge right now, how many more kilo meters it can go.

It is essential for protection because over-voltage and under-voltage both are, both are dangerous. Over voltage may lead to the complete failure of cell. May, since now it has excess energy what it can store, it can open up, or the next it can burst. And how it is being done,

generally being done by IC, integrated circuit. Temperature short, term as well as long term. Cell performance prediction depends upon the cell temperature.

So, unless we do not measure, we cannot predict the performance. Now, my cell I have limited between 25 to 35. Now, my cell temperature is around 34, will it, what it indicates, you should not draw lot of current now because what will happen, the temperature will further increase rapidly. So, it will say limit the current or close the current while charging as well as discharging. Both the cases. If I know the cell temperature, if BMS knows the cell temperature then only it will say to the thermal system increase the flow to cool down, or decrease the flow, because I am in at comfortable temperature limit.

Cell degradation mechanisms are, is also dependent on temperature. So, unless I do not have a temperature history, history means measurement. We cannot predict cell digression, degradation. And if we cannot predict cell degradation, we cannot predict SoH accurately, SoH is state of health. It is critical input for thermal management functioning, higher the temperature, I may have to increase the flow, either it, if it is air cooled, I have to increase the air flow, if it is liquid cooled I have to increase the flow of liquid.

If the temperature is less, it has to reduce. If it is within the limit, it may tell thermal system to shut down till my temperature is going beyond a limit. This all are energy saving options because thermal management take energy again from the same battery. There are several ways of measuring the temperature. Mostly we use thermistor because of its low cost and the reliability, high reliability. However, there are sensors available like thermocouple, there are non-contact measurements like optical sensors.

However thermistor is widely used for temperature measurement, what else current. So, what are the things, measurement, voltage, temperature and then current. The most important measurement is current measurement. Because unless we do not measure the current accurately we cannot calculate SoC, SoH. It is also used if I measure current accurately, I can say or it can log abuse conditions. If I am saying point 5 C my discharge rate, I consider it is a uniformly distributed.

But half of the time a person takes the full maximum current and half of the time it is idle. So, it is abuse condition. What I am saying is the average, sometime for few seconds you can go for

full current or maybe slightly above the, that also. The typical example I can say you. Let suppose I design a battery pack where you can take extra current required for 3 seconds or 5 seconds. Now, what you do, you increase the throttle you got the overcurrent whatever is required, whatever is limited, you reduce up throttle and suddenly again you increase.

So you do more than required cycles. So, that is becomes abused condition or during the charging if it is recommended for point 5 C and you are charging at 1 C. So, if you have a proper current measurement, you can find out that excess current beyond the limit or even in the limit, it has always been taken at the higher side. How it is being measured, mostly by current shunts or by hall-effect sensors.

The another things what you require to measure is isolation sensing. My circuits would be, my, since it is high voltage, high current DC, for low-voltage you may not have to worry that much, but for high voltage, anything beyond 100 20 volt DC you have to worry about isolation circuit. Your all wirings are covered properly or not. If it is not covered, what will happen, there could be a chance of short circuit for low voltage, high voltage also.

And other than that short circuit, you can go, you can also get shocked. Your wires should not be exposed to the vehicle chassis or any metallic part. Then your whole vehicle would be at high voltage. In such cases unless you do not measure you cannot make contactor or MOSFET or any other switching devices like relays open. So, this enhances safety greatly and prevent the accidents.

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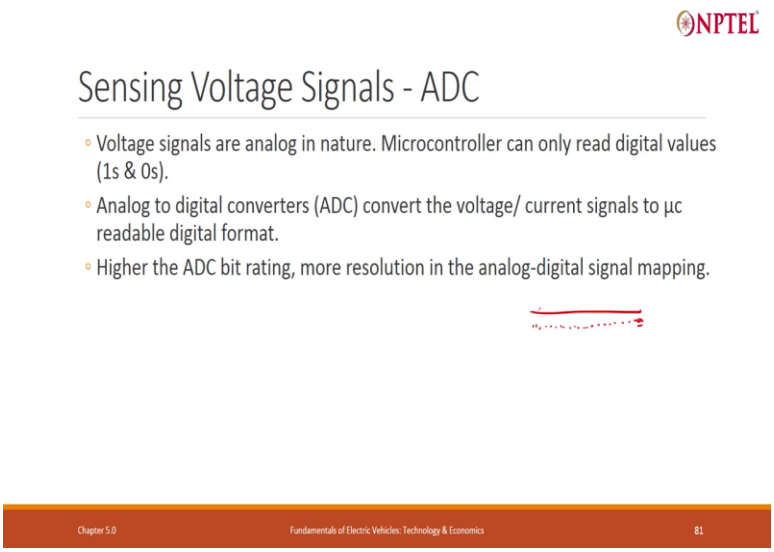

How do you sense a voltage signal? Generally all the signals what we are measuring here is analog signal. However, a microprocessor, what it reads is a digital signal. So, what do we use? So, we use something known as ADC, analog to digital converter. So, voltage signals not only voltage even current, temperature are generally analog in nature.

And microcontroller can read only either 1s or 0s binary system. So, analog to digital converter with which, which we say ADC converts the voltage current or any analog signal to microcontroller readable format. Either is 1s or 0s or in that way. Higher the ADC bit rating, you can find more resolution. Analog is what, continuous digital discrete, discrete means how much discrete.

If I say the current is 1 ampere for 1 second and I see point 1 second 1 ampere another what happens in digital form point 1 second 1 ampere, point 2 second 1 ampere and in between that information got missed. However in analog it is continuous 1 ampere. However in digital point 1 second, point 2 second, point 3 second, point 4 second because it has to be discrete. So, how many points, what is the line? Line is a collection of points correct. Now, you increase number of points, your resolution increases.

You see it is more like a line. See, now, this one is line, how can I do that one? I can also put like this. So, what you see, this is also a line. If I increase number of dots, what happened, now it has, it is representing almost a line. So, you number of dots in a line, you increase, you are increasing

the resolution. Otherwise, why it is in discrete form. That is what means resolution. So, higher the ADC bit rating, more the resolution.