Fundamentals of Electric Vehicles: Technology and Economics
Professor Kaushal Kumar Jha
Centre for Battery Engineering and Electric Vehicles
Indian Institute of Technology, Madras
Lecture 15: BMS Design of Electric Vehicle - Part 3

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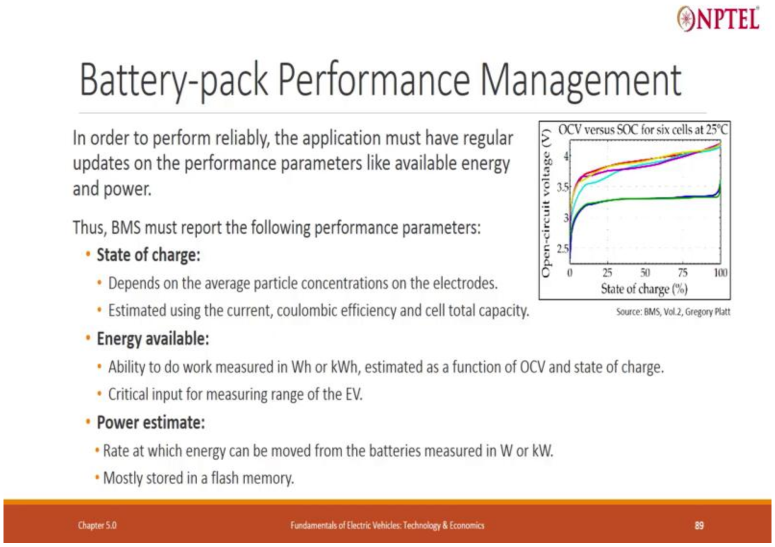

The next function of a BMS comes is battery pack performance management. What that means performance management? What is your SOC norm, what is your SOH? How much power is you can draw? So, these all are performance of a battery. To manage this performance BMS software as well as hardware, like if I need 30 ampere current and my contactor can give only up to 20 ampere, and if I need 30 ampere current, but my software says no you can take more than 20 ampere. So, my performance become limited to 20 ampere only, either through hardware or through software.

That is one part, this is basically in design part. The second part is BMS through hardware and software whatever is its limitation, what we have set should give you that. If I have set, I can my, my battery pack can give you 40 ampere current, so my hardware should be robust enough to give you 40 ampere current and software should allow it to go up to 40 ampere current. So, for that what has to be done, the BMS must report the following performance parameters.

What are that? State of charge, depends upon the average particle concentration on the electrodes, which you cannot do, but what you can do, you can measure the current, you can measure the charge coming in and going out, you can do the coulomb count, how many, how much coulomb is coming inside, how much coulomb is going outside. So, based upon that, again there are several algorithm, how to do the coulomb counting, but that is what the charge is coming in or going out.

And that finally depends upon what is the average particle concentration on the electrode, that is a chemical process, that chemical process when get converted into electrical energy, so coulomb charge comes in and goes out that has to be counted. And how it has been done? It has, it is being done, or it is estimated by measuring the current, then coulombic efficiency of the cell and the total capacity of the cell.

Energy available, how much energy is available now, how many more kilometers my vehicle can go and how does it do that? One of the simplest way of doing that is the function of OCV, OCV is open circuit voltage of a cell and that gives very fair idea, how much energy it has now. And how, and OCV curve is not linear. The (impo), and it also depends, it is all, it is also dependent upon temperature. So, you do all the measurement in the lab, test lab and then feed these as a tabular form.

So, that microprocessor can read, if this is a volt it can measure the voltage and then it compares with the tabular, with the table which is present there. And then it says okay now this is the SOC now. It is very important to find out the range, available or whatever is leftover and how much it is consumed. Then power estimate, how much power motor can take from the battery, it required 1C discharge, or it required 2C discharge, or if it is required beyond 1C discharge for how much time, or for 2C discharge, how much time. When I add how much time that becomes energy, when I say intently then it become power.

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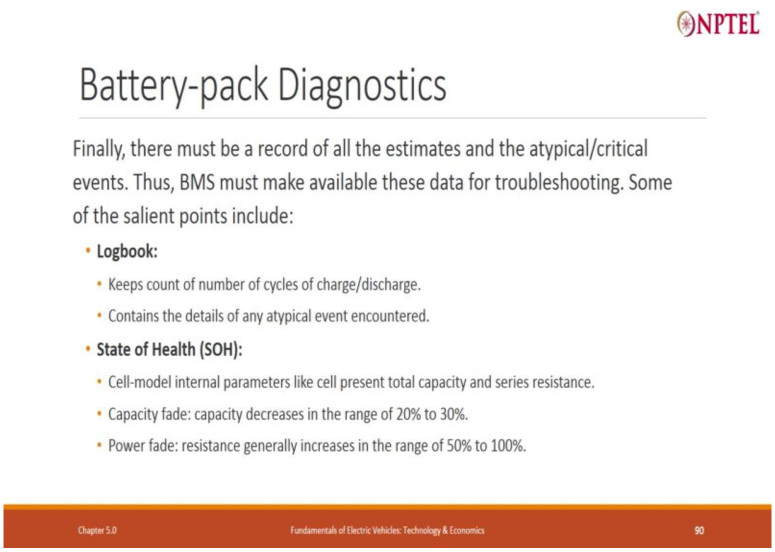

Diagnostics, so finally, there must be a record of all the estimates atypical critical events. Thus BMS must make available these data for troubleshooting. Now, my contactor got opened at this, this moment and it is not closing, I must know what was the reason for contactor getting open. Otherwise, you will keep, there could be thousands of reason and then you keep on checking one by one all thousands of reasons. But if it has logged that event, you will know that because of this this happened, so rectify this thing only. And that is what is known as diagnostics.

And where does it write down all the events in logbook, keeps counter of number, keep count of number of cycles of charge, discharge, contains the details of all atypical or safety events. And this helps to determine the state of health. You have already made a model and then based upon that model, you are feeding all these values, all these atypical events, temperature conditions, voltage condition, usage condition and then finally, you estimate SOH. Capacity fade, if my range has come down to 20 percent or 30 percent, now I cannot use that cell anymore, because my range has come down, so I need to replace.

Power fade, I cannot take 100 percent of the initial power now, it has also reduced because of the changes in the chemical composition inside the cell, because of the increase in internal resistance. It can be used for some other application but it no more useful for the electric vehicle application now. It could be used for energy storage application, secondary use. So, these all the parts comes as a diagnostic and how it has been done, again by done by, again done by BMS.

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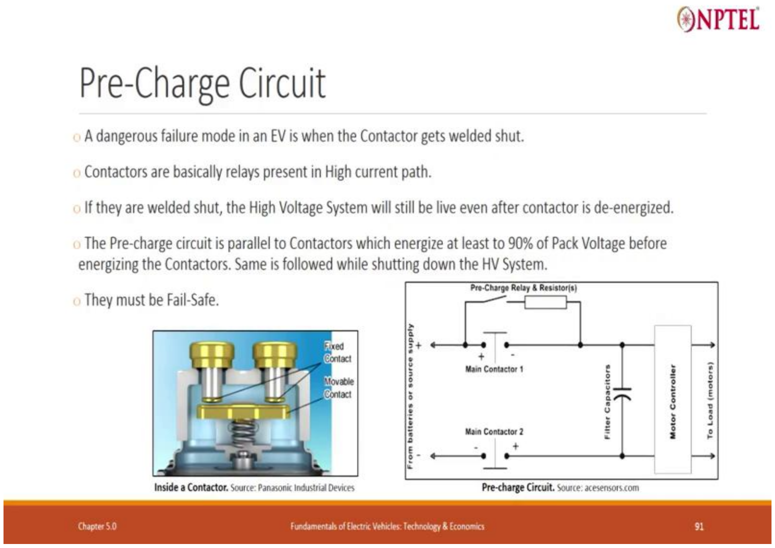

Now, another thing we would look upon in the BMS hardware especially, there is something known as pre-charge circuit. What will happen if my volt is, now if I connect a path, so it is at some potential, it is also at some potentials. If this potential is low, (what) high amount of current will rush. Now when high amount of current will rush, what will happen? Think, in one side what is the heat generation?

Student: (())(8:37).

Professor: I square R. Now my I is very high, so the heat generation would be very high, what will happen?

Student: (())(8:50).

Professor: It can melt. Melting can lead to the welding. So, a dangerous failure mode in a EV is when a contactor gets welded shut. If you are using MOSFET, the MOSFET will burn out. Now, it is very important here, now if your contactor get welded shut, what will happen? Even your BMS is saying my contactor is open, but still the voltage level is very high, if it is HV application, high voltage application, your path is still close.

So, what is being done for that, that you (pass), you allow a small current, let voltage to build up some percentage of your original potential difference. Generally, it is considered as 90 percent. Now, you have a very small potential difference the current rush would be small because the current is again a flow depends upon the potential difference. Now, your potential difference is almost only 10 percent of your original value, you can go for 95 percent, 85 percent depending upon the application.

And such circuit we see as a pre-charge circuit. And as soon as your 90 percent potential difference has reached or 95 percent then you allow the main contactor to be open. So, the current rush is not high and once main contactor is open, then you can close the pre-charge circuit. Because pre-charge circuit is only mean to reduce a potential difference between two connecting path, to reduce the current rush which can lead to the failures, can be welded shut or MOSFET can burn out, MOSFET is nothing but a switch like contactor because of high current.

So, contactors are basically represent in high current path, so how do we, how do we do. If they are welded shut, high voltage system will be still live even after contactor is de-energize, means, you say it is open up, open, but it is not. So, how do we do? Parallel path, we use parallel path with the, with the resistor and another switch, so that my potential difference between here at this point and this point is only 90 percent if this would not have been there.

Now, let us suppose here it is 5 volt or let us suppose it is a 100 volt here. Now, if this pre-charge is not there, so pre-charge circuit is not there, as soon as I switch on the connector, this is 100 volt, this is at 0 volt. So, what is your potential difference here? 100 volt. Accordingly, if you know the resistance of this path, obviously wire will have some resistance. So, what will happen?

Based upon that resistance the high current will flow through this and that can, now if your high current is flowing here, what will happen this contactor get welded out. If it is MOSFET here, this MOSFET will burn because again the heat comes as I square R, internal resistance, junction, junction resistance. So, before you open a main contactor you allow a percentage, very small fraction of the current to go through this path and how do we, how do we control that current, through the resistor here.

Now, what will happen, now initially it was 100 volt here, 0 volt here, now on this path, now it is 100 volt here, 90 volt here. Now, you close this contactor, now potential difference is how much, only 10 volt. So what would be the current rush here? 1 by 10th of, if my pre-charge circuit would not be there. So that is why pre-charge circuit is important, to reduce the failure, to reduce the safety events.

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Next management controller unit, MCU or you can otherwise also say microcontroller. The MCU is basically brain of again BMS, in BMS is a brain of battery pack and the brain of BMS is MCU, basically a microcontroller. What it takes care of? It take care of state determination, which state battery pack is, what is SOC, SOH and all those things, all communications are happening properly or not, data monitoring, logging, measuring, communication all the things it control.

Pack control, electrical more current, less current, high voltage, low voltage, high temperature, low temperature, over voltage, under voltage, everything, either at cell level or pack level or both is being controlled by MCU. Safety protection, almost all the safety protection is being taken care by MCU, there are independent or redundancy safety protections also available. Like I said thermal fuse, electrical fuse, IMD, can work independently also and can work with, along with MCU also. Emergency switch, interlock operations, all are a part of safety protection.

Communications, communication between different nodes, between microcontroller to ICs which measures voltage current, temperature sensing devices, all the calculations, modeling, is a part of MCU, we say it management control unit and other word it is basically a microprocessor. Who are the manufacturer of microprocessor commonly used for heavy application? ST, TI. Who else?

A BMS usually contains a master and slave MCU, primary and secondary MCU for redundancy purpose not necessarily, but generally the new microcontroller or MCUs or management control unit can perform wide range of activities, sensing, prediction, control in sync, all the things, it can do all the things together because of the advancement of computing power of microprocessor.

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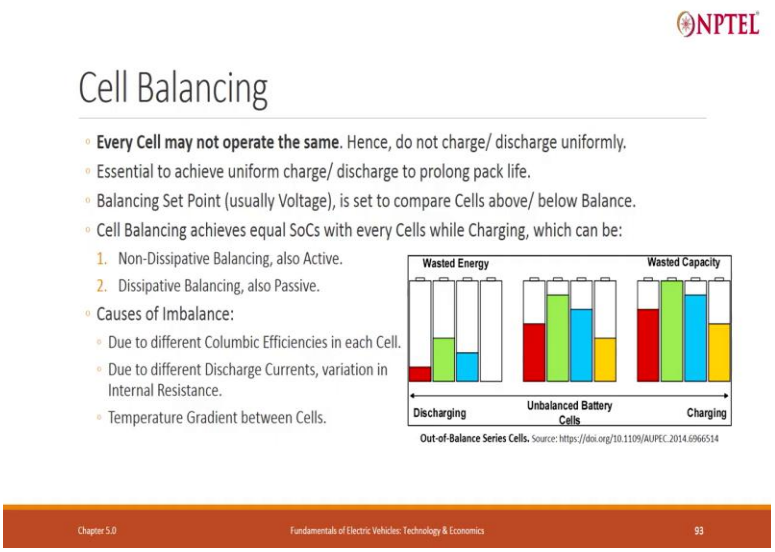

Now, another important aspect of a BMS is cell balancing, what happens if cell balancing will not be done? The most important thing is that, it will degrade fast or you will not be able to use the, the proper energy what it has. So, every cell may not operate the same, hence do not charge or discharge uniformly. However, it is essential to achieve uniform charge or discharge to prolong the life of a battery pack, and if you increase the life of battery pack, what will happen, your cost will come down, you will be able to take more energy per unit or per rupees per unit of cost.

You see here the nice representation, while these all are unbalanced cells, poor cells in parallel, not all the cells are at the same energy level while discharging. Now your 1 cell has been discharged even though other cells have same energy but you cannot utilize it. Because BMS has already detected 1 cell under voltage. So it cannot move further now, so it will stop, or open the contactor so that no current can go outside.

However, you still have energy left here, if you consider this if you can distribute equally all those energy available in all 4 cells, you still have maybe some 20 percent energy left here, but since one cell has already discharged, this rest of the energy get wasted. Similarly, while charging this second cell had charged very fast it has taken the required energy to cover it up. However, other cell can still take a charge but since this cell has gone in over voltage stage, now I am fully charged, the charging gets suspended.

So, you are not able to fill the energy, complete energy what it can take up. So, you are losing the performance, charging as well as in discharging you are not able to take the benefit the 100 percent benefit of the cell energy. Balancing set point, usually a voltage it is set to compare cell above or below balance, we set up, we set a set point. Now, for an MC chemistry what would be the cell voltage? Peak cell voltage is 4 point 2 volt or 4 point 3 volt. So, I will set up a point 4 point 2 volt.

Now, some cells could be below, some cells could be slightly above. So, I will try to bring back all other cells to the 4 point 2 level, 2 volt level. How it is being done, there are two ways, active balancing and passive balancing. So non-dissipative balancing is known as active balancing. And the dissipative balancing is known as passive balancing. If I am using this cell energy for charging this, this and this cell till all the cells become at the same level, so I am not wasting the energy. So we say it is as a active balancing.

Now, what one is the lowest one here? If I had to balance in other way, in passive balancing what I will do, whatever extra energy is here than the lower level of cell, I will drain it out through resistor and that is dissipative balancing and we say it is a passive balancing. So there we lose the energy. However, generally it is being done while the charging. So you have cheap energy available. And it will not happen in this way. It would be hardly in 1 percent level or point 5 percent level all the cell.

What are the causes of imbalance? Different coulombic efficiencies of cell, different discharge current violation in internal resistance, sorry variation in internal resistance. Also now if this 4 is connected with a bus bar, now you are providing a source here what will happen? This two will be at higher voltage and this two would be at lower voltage. Why? Because of the resistance here, unequal resistance.

So what we studied in electrical design, current equalization. And how it was happening, basically because of the resistance, not resistivity, I am talking about resistance, which is a product of L1 by A1, proportional to L1 by A1. So if we maintain the same resistance then that can reduce the cell imbalance, then it only depends upon coulombic efficiency. But temperature gradient at the cell, what will happen here, if this is a pack, what will happen? These two cells, has a very less surface area to move out the thermal energy. However, other two cells has more area. So, temperature gradient in cell also creates imbalance.

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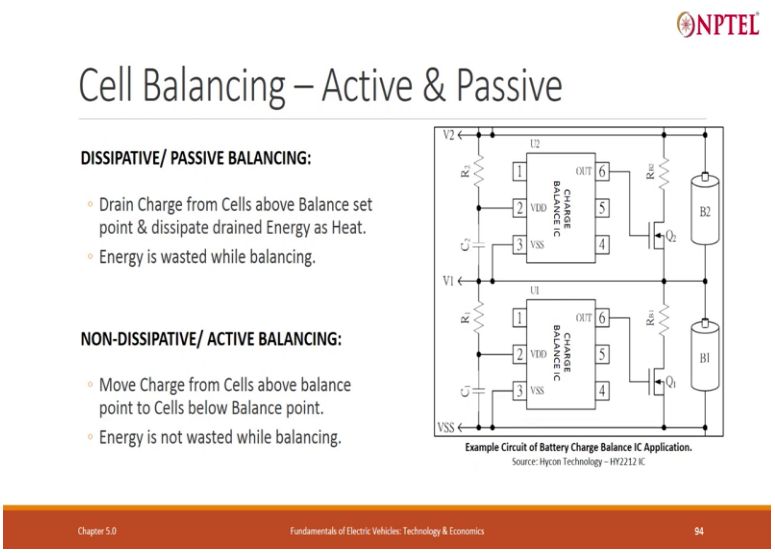

Now, we will, I have already talked about active and passive balancing. Here in passive balancing what we do, we put a resistors in a parallel path and try to reduce the energy to the set point to the state level by dissipating the heat. However, in active balancing, what we do, we try to use the energy to charge other cells, so that it, that lower charge cell can reach to the level of charged cells.

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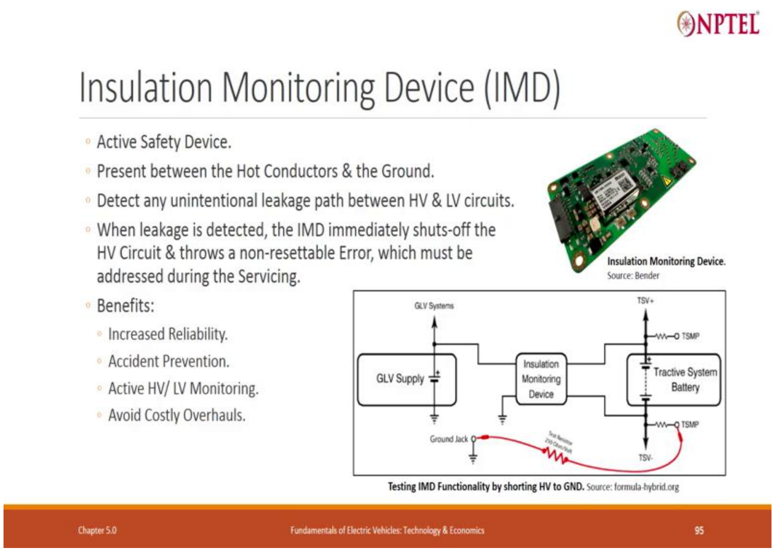

Insulation monitoring device, it is a active safety device which we have talked several times. It is present between hot conductor that means positive terminal and the ground. Detect any unintentional leakage of current between high voltage path and low voltage path. As soon as it happens, if there is, if it sees any leakage (unint) intentional leakage or unintentional leakage, what it does, its open the contactor. So, that the high voltage path can be isolated, it will not create any problem or safety concern to the people working around, will not allow to go for short circuit mode.

What are the benefits your system reliability would be increased, Accident prevention, active high voltage and low voltage monitoring, you can monitor also, if there is any current leakage, you can check it out, BMS can take action. And if such things happen, what happen? Your battery pack will get damaged, your vehicle will get damaged, the person working or a passenger may get health issue.

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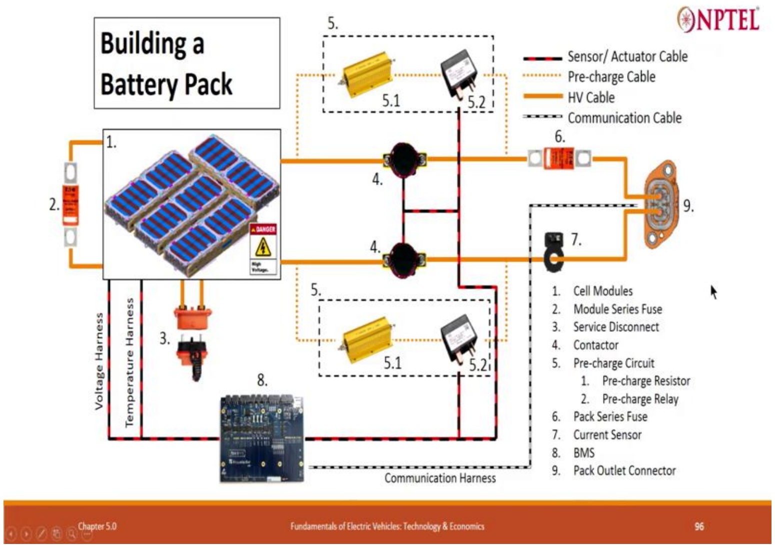

How do we build a battery pack? So, we clubbed together all the cells through MNS, M parallel M, MPNS theory. We connect for a series fuse, we connect with contactor through BMS, the energy outlet, pre-charge circuit either in connector and if you are using MOSFET as a switching device, then in the BMS, then you have different sensors which communicates with a BMS and then you have high voltage cables. So, cell module, module series fuse, service disconnect if you want to disconnect this part here, contactors here, pre-charge circuit here, your pre-charge resistors, pre-charge relay, pack series fuse here, current sensors, BMS and pack outlet connectors.

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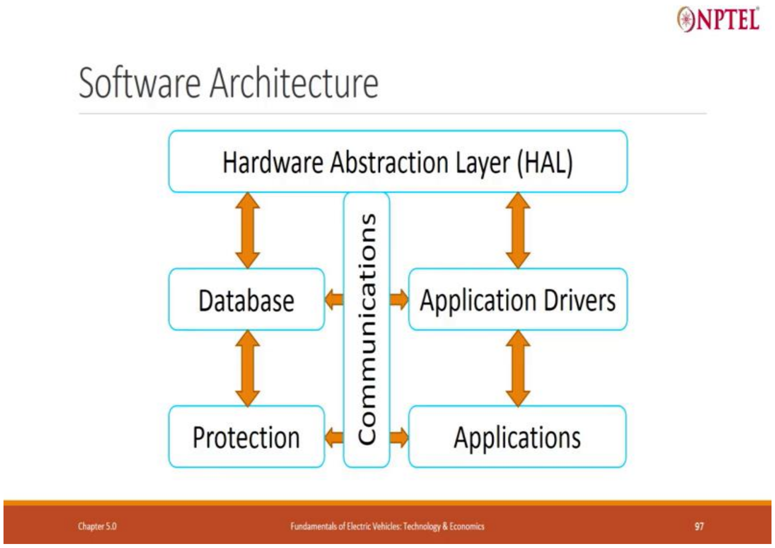

So, what we have talked till now is mostly BMS hardware and what softwares can do. What are the softwares, how it architecture? So, it has basically a hardware abstraction layer HAL which is nothing but the drivers related to microprocessors ICs and all those things. Then what it has, database, flash memory or EP ROM, then the protection modules. Database, EP ROM, flash memory, it has to be written, but how? It has to be a coded module, so that it can say these are the data coming up and these are the data has to be written up in flash memory.

Then protection, there is a hardware based protection what we have talked about fuse and all those things and then there is a software based protect. As soon as current is going abnormal, cut off. So, how it is being detected? It is being detected by the software. Now current has come more. So, let us cut off the, it gives us, it sends a command to open up the contactor.

Application, SOH, SOC, SOH, this all the modeling as well as writing up the data, logging the events, communications, all the parts, software parts comes as a application part. And when application will have, will have its drivers and how it is (com), it is communicating with HAL, database, protection, application drivers, applications and all those things, these all are software modules, everything is communicating with each other. And generally, most of the time it is written in embedded C.

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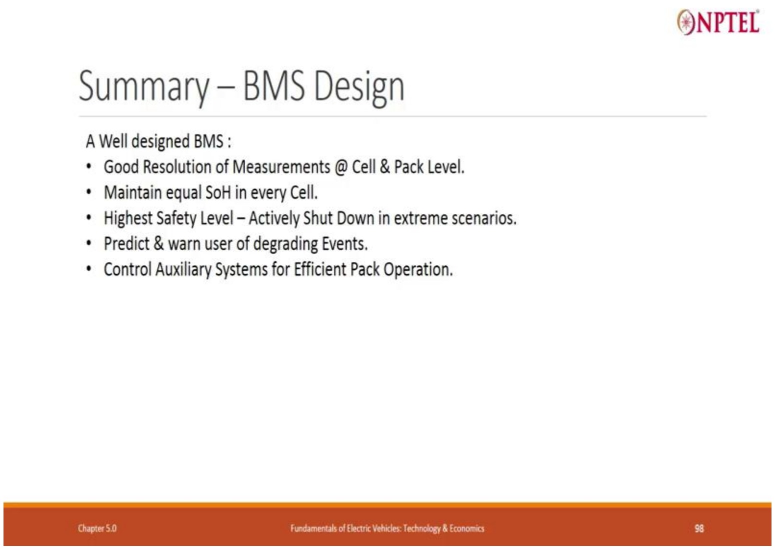

So with this I am summarizing BMS design, a well-designed BMS should have a good resolution of measurements at the cell and pack level. Higher bit of ADC always helps. Maintain equal SOH in every cells, state of health. Highest safety level, in case of any threatening event, unwanted event it should shutdown, it should not shutdown, it should shutdown other peripherals like current going outside, if temperature is shooting, thermal management system has to work harder, all those things.

Predict and warn user of degrading events, now battery pack capacity is this much only. Control auxiliary system for efficient pack operation and how it is being done, with the combination of hardware and the software. So, with that, I am completing my fourth section and overall battery pack design. So, what we have done here in this battery pack design? We have converted battery pack design into the 4 sections, mechanical design of a battery pack, thermal design, electrical design and BMS.

In mechanical design, what are the things we have studied, we have studied the base plate design, end plate, side strips and then we also tried to understood, what are the vibrations mode my battery pack can go. We have also studied what are the vibration standards we use in India. Then we have moved to thermal design, where we have looked upon various aspects of the thermal management system, how the cells get heated up, how the cells cool down, internal resistance concept, heat transfer coefficient, use of heat transfer coefficient to select a thermal management system.

The range of operation through, range of temperatures in which our thermal system our battery pack will be most efficient. Then we have come to the electrical design. In electrical design, what are the things we have covered? It is mostly bus bar, cables. We have also done a bits of thermal and mechanical design to improve the bus bar. We have also seen the different ways of joining the bus bar or electrical paths.

Then we moved to the BMS design. In the BMS design we have understood different hardware software combination and its functionality. So, with this today is the last class for battery pack design. In the next chapter motor and controller design would be taken care of by Professor Kernel, he will start from this point onward. Thank you, thank you very much.

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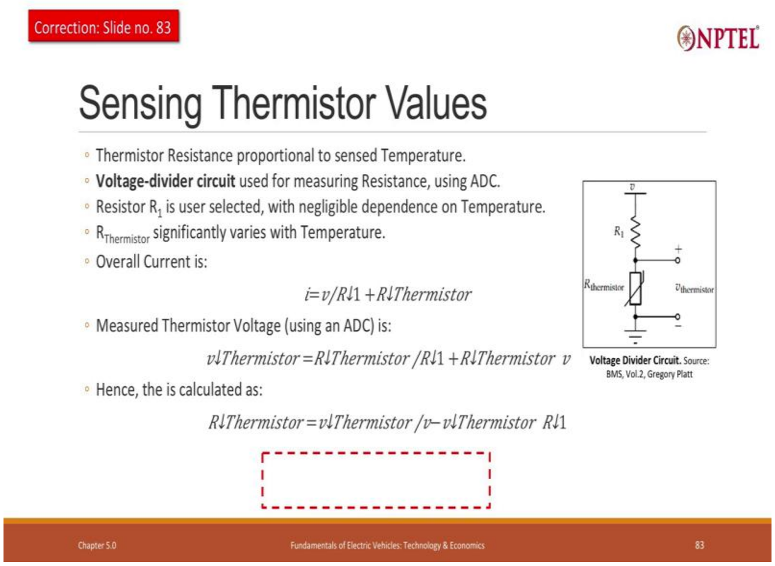


Correction: Slide No. 84

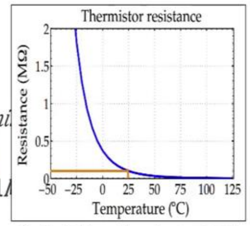
Example: Measuring Thermistor Temperature

If the Thermistor is placed in lower leg of Voltage Divider Circuit of 5V Source & R_1 = 100kΩ. The voltage across Thermistor is 2.5V. Using the plot show, find the Temperature sensed by Thermistor.

Solution:

$$R\downarrow Thermistor = v\downarrow Thermistor / v - v\downarrow Thermi \quad R\downarrow 1$$

$$R\downarrow Thermistor = 2.5/5 - 2.5 * 100 * 1000 = 0.1 /$$



Thermistor Resistance vs Temperature. Source: BMS, Vol. 2, Gregory Platt

From the Plot, we roughly estimate the Temperature to be **25°C**.