Electrochemical Energy Storage
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Module - 07
Introduction to battery pack design
Lecture - 33
Introduction to Battery Management System: BMS Topologies, Hardware, Concept of Active and Passive Balancing, Other BMS Functionality, Software and Control

Welcome to my course Electrochemical Energy Storage and this is module number 7 where I am teaching Introduction to battery pack design and in earlier two lectures we briefly talked about the battery system and the failures of the lithium ion battery in last two lectures.

And this lecture it is lecture number 33 that is devoted to the Introduction of Battery Management System, where I will be talking about various types of BMS topologies, the hardware, concept mainly the hardwares and then the concept of active and passive balancing and what are the other functionality of BMS and software and control which is a pertinent part of the BMS itself.

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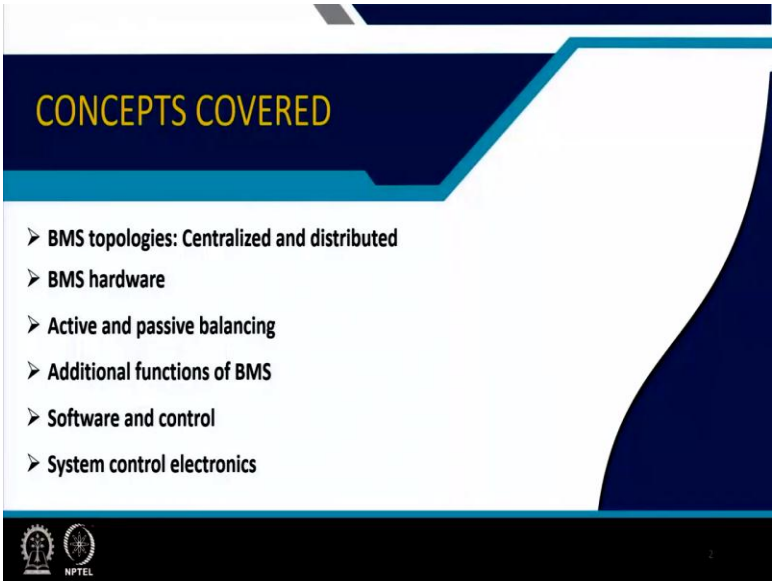

So, first I will talk about the centralized and centralized part as well as the distributed part of BMS topologies. And then we will talk about the hardware itself, then we will explain that what is active and passive balancing, then what are the other functions of

BMS and software and controls that are used for the BMS and then system control electronics what are the hardware that is used.

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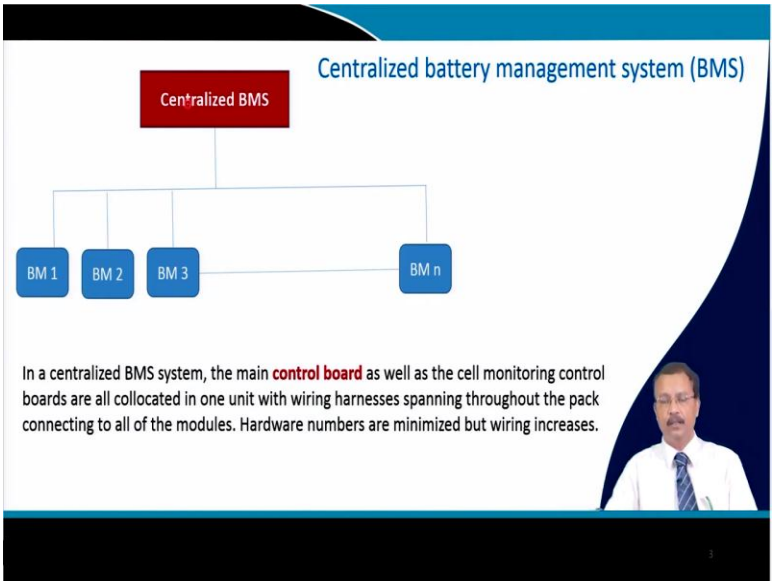

So, this is a topic of electrical engineering and we are material scientist. So, we are not going into the details, but what is the essential part of the battery management system that certainly you need to know. So, it you can consider it this is a brief overview without going into the details of the electrical engineering part, but you will get a thorough knowledge about the management system.

So, mainly there are two types of battery management system one is centralized battery management system. So, we call it is centralized BMS and as you can see there is a main control board here and the control board consists of the cell monitoring control all types of cell monitoring control including its voltage, state of charge, temperature everything is embedded here in and this is only one unit and then it controls all the battery module.

So, here you can have n number of battery modules and by this time you know that in each of the battery module there are number of cells which are connected in series and parallel combination. So, everything is controlled by this centralized BMS system and. So, there will be lot of wiring here as you can see that each is connected with this centralized board.

So, you will have to manage the wire wiring inside the whole battery pack and throughout the battery pack you have the wiring. So, jungle of wires you will have to manage this wires well. So, the advantage is the hardware numbers they are certainly minimized because everything is being controlled from one central unit, but the wiring is suddenly this is increased.

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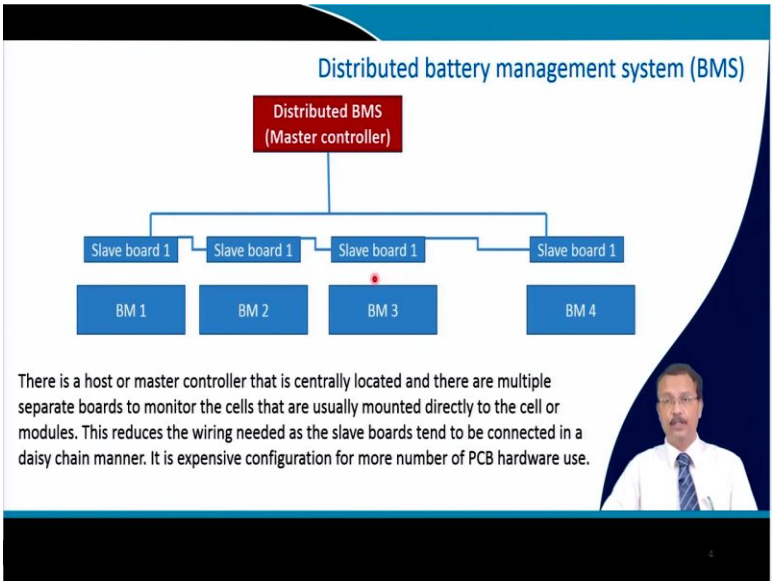

The second one is a distributed battery management system where there is a master controller which controls number of slave boards. So, the host or we call it a master controller that is basically centrally located and as I said there are multiple separate boards and this function of this boards they are different types of functions are there and each of them can control different types of functionality and these slave boards are connected the slave boards are basically they are connected to the battery individual battery modules.

So, you can have the hardware requirement that is quite distributed here. So, you have certain component in the master controller and the remaining say thermal temperature management, voltage management then the health monitoring they are all are there in this slave board. So, it is expensive because more number of PCB that you will be using for controlling this kind of for making this kind of distributed battery management system.

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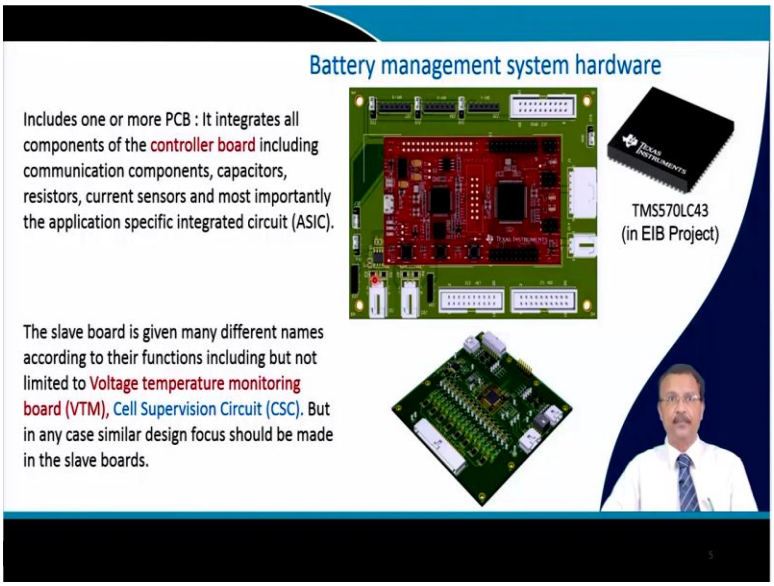

So, this photographs they were taken from our own work because we are also in a process as a part of my sponsored project we are making a 28 volt 16 ampere hour lithium ion battery pack for certain specific use and this is one typical PCB that you can see. So, this is the type of control board how it looks like. So, it basically integrates all components that is there in the controller board.

And this components could be communication components, several capacitors are there, registers, then current sensors and most important part is the application specific integrated circuit that is pertinent to the application of the battery and it is abbreviated as ASIC that is application specific integrated circuit.

So, usually we use the ASIC which is built by Texas instrument and this is we are using as a part of our project so, this kind of PCB board. And of course, electrical engineering students and faculty members they are involved in this particular work because lot of electrical engineering concepts are used.

And slave boards we use also the slave boards that is basically given various types of names according to their function. So, there could be voltage or temperature monitoring board both are integrated in one slave board we call is VTM abbreviated as VTM or Cell Supervision Circuit CSC. So, similar types of design architecture that is that PCB board design is done by the student and then they are fabricated and finally, this kind of design

should be more or less similar. So, the slave boards they all look quite similar and functionality is of course, they are different.

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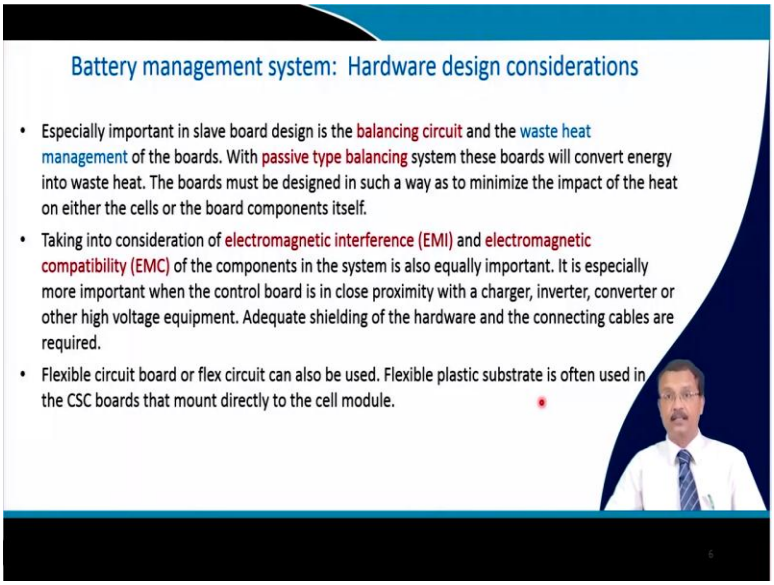

So, there are certain criteria for this hardware design part. So, especially for the slave board design one thing is very important that is known as balancing circuit and also the waste heat management of the board these two are important and sometimes they are integrated, sometimes due to the balancing lot of heat is generated and you need to have certain thing that I will talk about in my next lecture that how the thermal management is basically done. So, that will have to take care particularly for certain kind of balancing.

Now, this balancing is that not all the cells they have exact state of charge, some may be over charge, some may be under charge. So, specifically their charge imbalance could be there in individual cell by which you are making the module. So, you need to do the balancing to make the state of charge same at any instance so, that you can do by either active balancing or passive balancing.

So, that thing the passive balancing system that is quite useful that you have excess charge you just discharge it through a register and once you discharge it through a register then this charge will generate lot of heat because that charge that is getting discharged through a load register which is also part of this slave board and that will be converted to waste heat.

So, the board must be designed in such a way that to minimize the impact of heat on either the cells or the board component itself because it is not only the cells, but you are using lot of electronic components. So, let us save them from this heat so that is the primary consideration while someone is designing the slave boards or the battery management system this PCBs so, that is the first thing.

Second one is to take into consideration of this electromagnetic interference or electromagnetic compatibility abbreviated as EMI the first case and EMC the second one. So, that is for the components in the systems that is also equally important. So, you will have to shield it.

So, you may shielding is required and it is more important when the control board is in close proximity with the charger which charges the battery or the inverter, converter or other high voltage equipment, then adequate shielding is required of this particular hardwares and the connecting cables that is required.

So, you need to have a metal shielding EMI shielding sometimes flexible circuit board or they call it flex circuit that is also used. Flexible plastic substrate is often used in the CSC board that mount directly on the cell module. So, that is just to have more flexibility in the space inside the battery pack.

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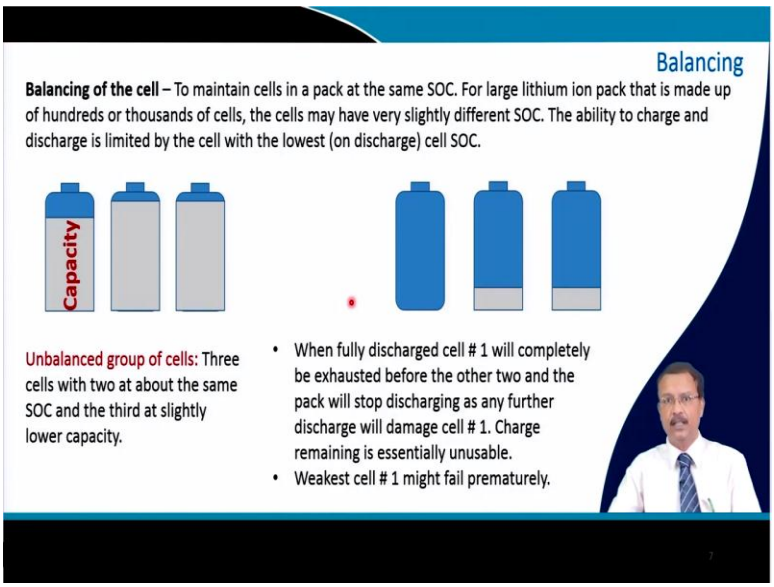

So, now, let us discuss about the balancing of the cell. So, that is extremely important and one of the important functions of the BMS. So, as I said to maintain the cells in a pack at the same state of charge that is the work of what we call the balancing. So, when large lithium ion pack that is made up of hundreds or thousands of cells that you know that either connected in series to increase the voltage or connected in parallel to increase the capacity of the cell. So, each individual cell they may have slightly different capacity the white part is the capacity.

So, as you can see this particular cell is slightly lower state of charge as compared to this two. So, this is not allowed. So, we call this is a unbalanced group of cells. So, two about the same SOC and the third one they are slightly of lower capacity. So, when you fully discharge this particular module then cell number 1 that is this one that will be completely exhausted. So, it will be exhausted completely before these two are completely exhausted.

So, you have little bit capacity always that will be there because you cannot discharge beyond a certain limit. So, this will not be completely discharge. So, sorry this will be completely discharged, but this one, this one and this one they will not be completely discharge.

So, this capacity is unusable and when you are charging back this battery then this will charge from here to here. So, it will be relatively faster to charge this as well as this cell and this will take little bit more time because it will have to go from here to here and again, it will be discharge fully right.

So, in principle what will happen that this cell will have to work more and therefore, this can prematurely fell and you can imagine there are number of cells in a module. So, if one particular cell you are exhausting it by over discharge, over discharging and then again full charge and again it may not be fully charged.

So, that will exhaust this cell and that will prematurely the cell can fail. Particularly the series connected cells one cell fails that is not good for the health of the whole battery system. So, something must be done for this and this is actually the balancing.

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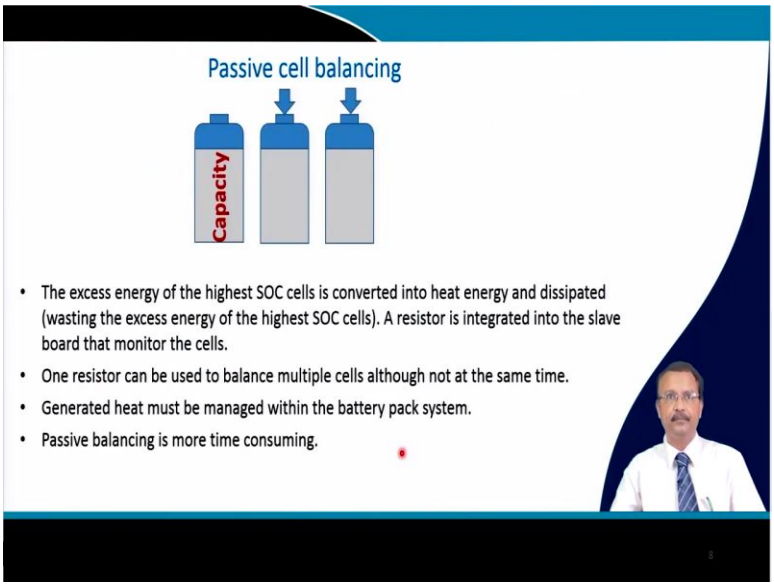

So, first we will talk about the passive cell balancing and this is quite straightforward, the excess energy of the highest SOC cell. So, this one was the highest and this one also was the highest. In fact, these two cell capacity was higher as compared to this one this is converted into heat energy and dissipated.

So, you are wasting the excess energy of the highest SOC cell and just to maintain the cell capacity similar to this one you will have to do a discharge of this cell and discharge of this cell. So, their capacity limit from say here it drops down to here and make it all the cell in the same level. So, usually a register is integrated into the slave board which is controlling that the passive cell balancing and this is one way of doing that.

So, one register they can be used to balance multiple cells of course, not at a single time not at the same time this is done. So, this is one way, it is not a good way because we are generating lot of heat. So, generated heat must be managed within the battery pack system. So, otherwise the not only the battery, but also the cell components they will get affected and of course, this is time consuming because one after another you will have to do it.

So, you have one this kind of board which is there. So, that particular board one at a time using the register you are doing passive cell balancing. So, it will take little bit more time. So, the each slave board has one register. So, it is a time consuming process.

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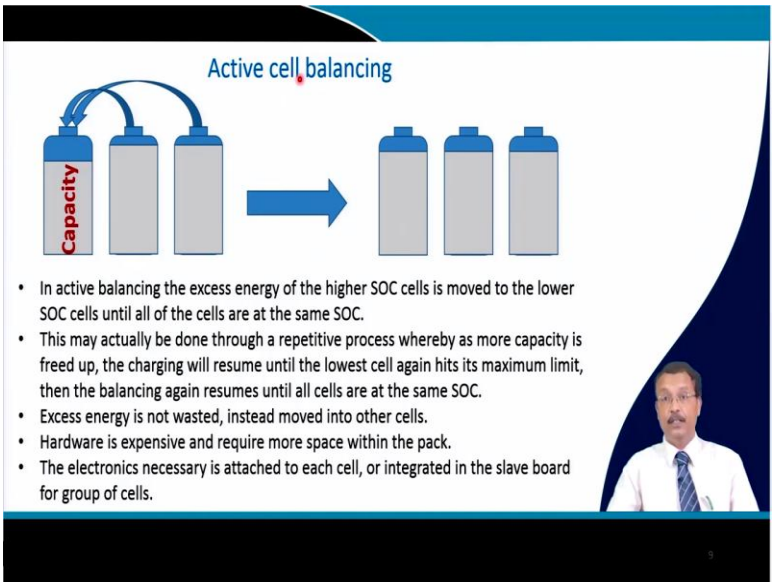

Second one which is although expensive and little bit more design aspects are required to do that is the active cell balancing for our case we are in the process of doing it, but this is done this is usually done for a good battery pack. And the active cell balancing the excess energy of the higher state of charge cells is move to the lower state of charge.

So, you have this kind of capacity for this two cells, then what you are doing you are using this excess charge to charge this battery more right. So, this is converted I mean this is transferred from this cell this is also capacity, excess capacity is transferred to this cell and as a whole this two capacities slightly fall down and this is raised little bit. So, that you have similar kind of capacity.

So, this actually may be done through a repetitive process whereby as more capacity is freed up, the charging will resume until the lowest cell that again hits the maximum limit so, then the balancing again resumes until all the cells are having same kind of SOC. So, the advantage of this is the energy is not wasted instead it is moved from one cell to other. So, it is not being wasted through a passive register in the slave board.

Hardware as I said they are expensive and require more space within the pack. So, the pack the battery module is a bit bulky. The electronics that is required for this to take place that is attached to each cells, or integrated into the slave board that is for a group of cells the latter is actually used. So, it is integrated in the slave board for a number of cells.

So, whenever it is detected that there is balancing required from high capacity site it will transfer the charge to the lower capacity cell and finally, the balancing is done.

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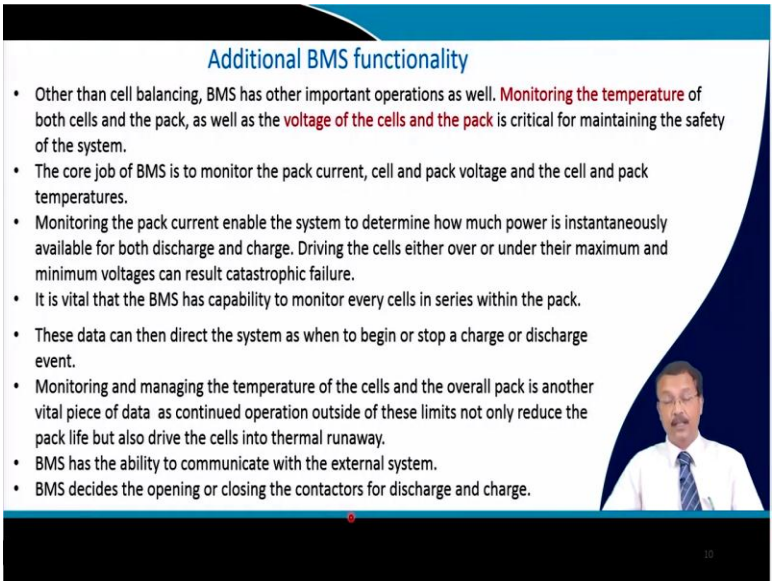

So, apart from this balancing there are additional BMS functionalities. So, they have one important operations that one can mention is monitoring the temperature of both the cells and the pack, together with that they monitor the voltage of the cells and the pack and these two are critical for maintaining the safety of the system, it may not be over charged temperature should not rise beyond a certain limit.

So, the core job of BMS is to monitor the pack current, cell and pack voltage and cell and pack temperatures. Monitoring the pack current enable the system to determine how much power that is instantaneously available for both discharge and charge which is quite obvious. And driving the cell either over or under the maximum or minimum voltage that can cause catastrophic failure, this I mentioned several times in my earlier lectures.

It is vital that BMS has capability to monitor every cells in series within the pack, parallel cells are not that much problematic, but in series connection which control the voltage you will have to monitor each and individual cells which are connected in series. The data can direct the system as when to begin or stop the charge or discharge event. So, continuous monitoring is required and accordingly the BMS can decide that whether

the charging of the whole battery pack is completed or whether the discharge should be stopped so that decision accordingly will be taken.

Monitoring and managing the temperature of the cells and overall pack is another vital piece of data as continued operation outside this limits that will reduce the pack life and also there could be in case of the temperature is raised beyond a certain limit that will lead to thermal runaway.

So, the BMS has ability to communicate with the external system. So, that is also another thing, through a data logger you can get back the data remotely, what is the voltage, what is the current of the pack individual cell, what is the state of charge state of health, whether the temperature at each part of the module not at each individual cell, but some part of the module if there is any thermal runway. So, these are all vital information that you can get.

So, there is a communication system which you can communicate externally through a computer or something like that and the data logger is there so that you can have a look. BMS decides the opening or closing of the contactors for discharge and charge which is quite obvious that whenever it sees something very unusual then it is important to close the whole battery pack. So, this is I mean usually does a remarkable job as far as the health of the battery operation is concerned.

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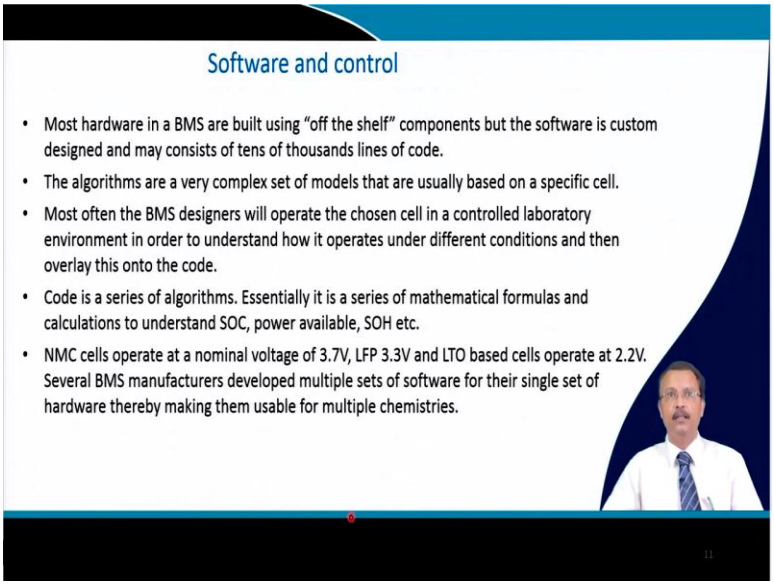

Software part is very important most of the hardware you know that although the design part is important for the PCB, for the controller, for the slave boards ASIC is already “off the shelf” one can purchase, most of the component in fact, one can purchase off the shelf, but the software is custom designed and may consist of thousands lines of code. So, that is another area which is important and we also take help of other scientists in this area to write this codes.

And sometimes these codes are very very complex and based on certain models for a specific type of cells. So, most often this BMS designer they will operate the chosen cell in a controlled laboratory environment in order to understand how it operates under different conditions and then they overlay the this into the code. So, for that the chemistry is important right.

So, if you are using different types of chemistry depending on that the characteristics will change you know the voltage profile will change. So, sometimes you will get a constant profile voltage sometimes you will get a sloping profile voltage. So, that kind of information you will have to put it into the code. So, essentially this codes are a series of mathematical formulas and calculations to understand the SOC power available what is the state of health etcetera.

So, depending on that the BMS price the part of the BMS price is mostly governed by this kind of custom design software. So, that is important and many of the cases they are patented the way they write the code. So, for example, you purchase one BMS for NMC cell nickel manganese cobalt cell that operate at this 3.7 volt if you use the cell which is lithium iron phosphate it operates around 3.2 2.2 to 3.3 volt. But once you use LTO as one of the negative electrodes then the cell operates typically at 2.2 volt.

So, it is important that this coding is for different types of cell not for a single type of cell and also their voltage profile is quite different. So, that is incorporated in the software. So, that you can change your battery chemist chemistry, but the same software that can run your BMS. So, this actually raise the price; raise the price of the whole system. So, it is a proprietary item as I told.

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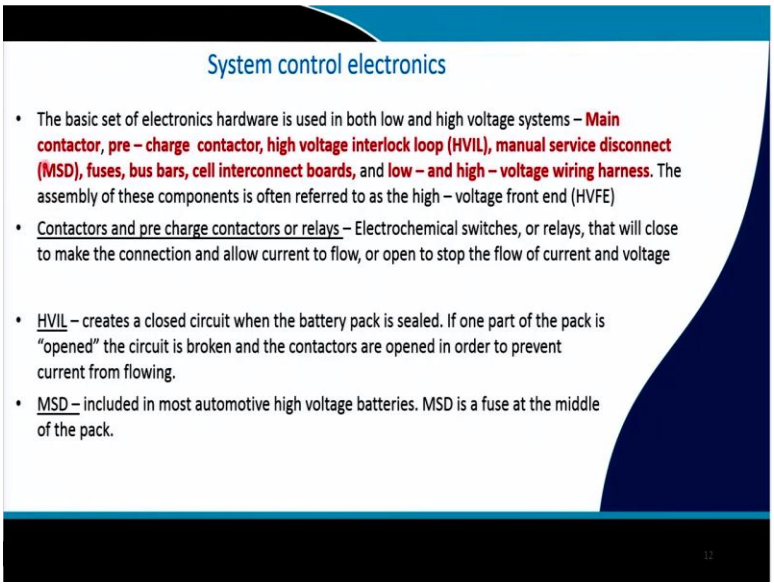

Now, while you design this BMS there are many system control electronics that is important. So, each of them has have their particular functions and I am not going into the details, but you should know exactly that what are the components that is used.

So, the basic electronic hardware that is used both for low as well as high voltage system, they are main contactor or pre charge contactor, then high voltage interlock loop which is abbreviated as HVIL, then manual service disconnect which we call this is one kind of fuse we call MSD.

So, that disconnect and apart from that also fuses, then bus bars to connect it, cell interconnect boards and low and high voltage varying this is important. So, these are the hardware that is used the assembly of all these components are often referred to as high voltage front end which is abbreviated as HVFE.

So, contactors and pre charge conductors or relays they are basically electrochemical switch or relays, that will close to make the connection and allow the current to flow or in open condition they will stop the flow of current and voltage. This high voltage interlock loop which is HVIL that creates a closed circuit when the battery pack is sealed. If one part of the pack is "opened" then the circuit is broken and the conductors are open in order to prevent the current from flowing. So, it is actually serving a very important task in the battery pack.

This MSD this is manual service disconnect that is included in most automotive battery the bigger batteries and this is basically a fuse at the middle of the pack for anything unusual that will operate this battery to shut down help the battery to shut down.

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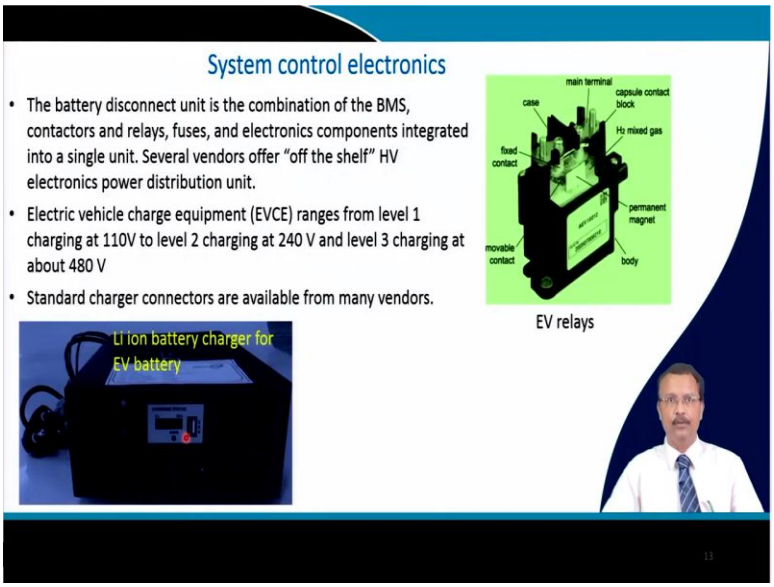

So, this battery disconnect unit is basically a combination of BMS then contactors and relays, fuses, electronic components integrated into a single unit. And several vendors they offer the "off shelf" so, HV electronics power distribution board. So, you can purchase it.

Now, apart from that you need a charger usually electric vehicles one of the examples you can see a typical charger of EV system usually they range from level 1 which charges 110 volt, level 2 240 volt, level 3 charging about 840 volts. So, different types of chargers are available and standard charger connectors are available from many vendors.

So, EV relay typically looks like this which is the contactors and the charging unit is something similar to that and remember this stays outside the battery pack and required when the charging is required you can charge the whole battery pack using this kind of charger.

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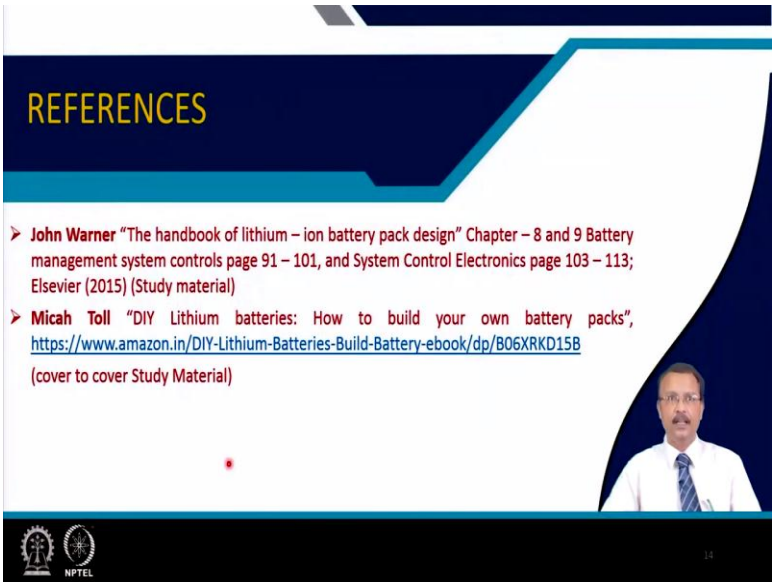

So, the reference for the study material is the book by John Warner and Chapter 8 that talks about the Battery management system controls and chapter 9 this is the System Control Electronics each individual part, the relay, the contactors, MSD whatever I talked about the details are given. So, this is one part and the second the book by Micah Toll that is do it yourself book and this is also gives a detailed view of how to connect and make a battery using this of the shelf components. So, both are important.

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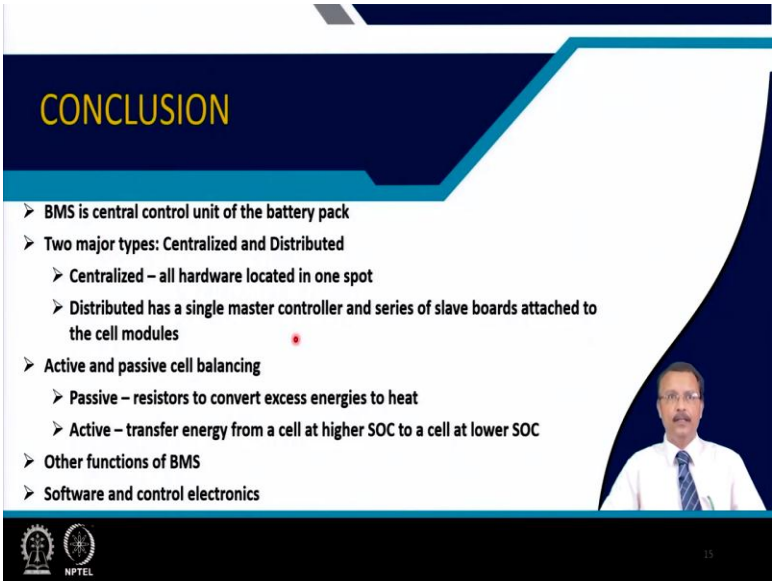

So, in this lecture we talked about BMS central control unit of a battery pack. So, that has two major types one is centralized and other one is distributed, the centralized one all hardware they are located in one spot, distributed as a single master controller and series of slave boards attached to the cell modules. Active and passive balancing you should understand by this time passive one is a register is used to convert the excess energy of an individual cell which is having relatively higher capacity as compared to the other cells.

And active balancing is the transfer of the energy from the cell which is having higher state of charge to a cell at relatively lower state of charge and other functions of BMS like monitoring the voltage, temperature etcetera that is introduced and finally, we talked about the importance of the software and control electronics.

Thank you for your attention.