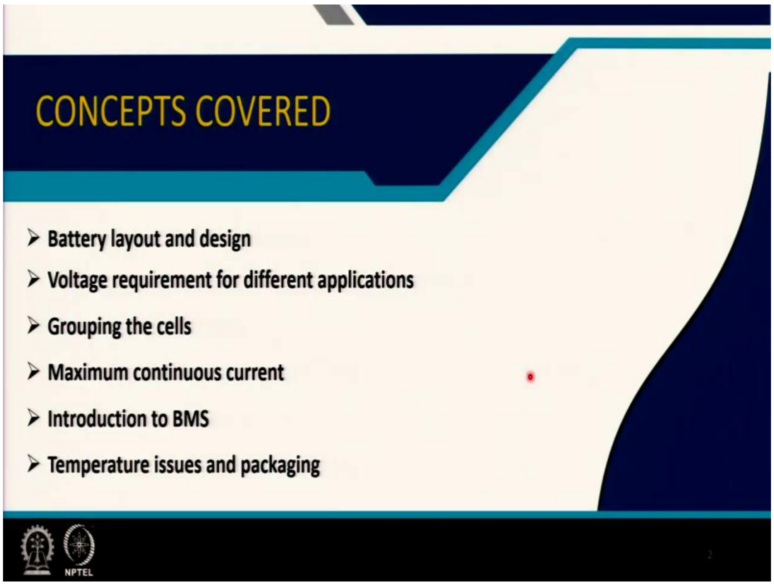
Electrochemical Energy Storage
Prof. Subhasish Basu Majumder
Department of Materials Science Centre
Indian Institute of Technology, Kharagpur

Module - 07
Introduction to battery pack design
Lecture - 31
Introduction to Battery Module, BMS, Thermal Management and Pack Design

Welcome to my course, Electrochemical Energy Storage and this is module number 7, where I will introduce the basic concepts of battery pack design. And, in this particular lecture we will be talking about the battery module connection of the cell in series and parallel connections, the need of battery management system, the need of thermal management system and how to pack this battery module inside an enclosure. So, that will be described.

(Refer Slide Time: 01:03)



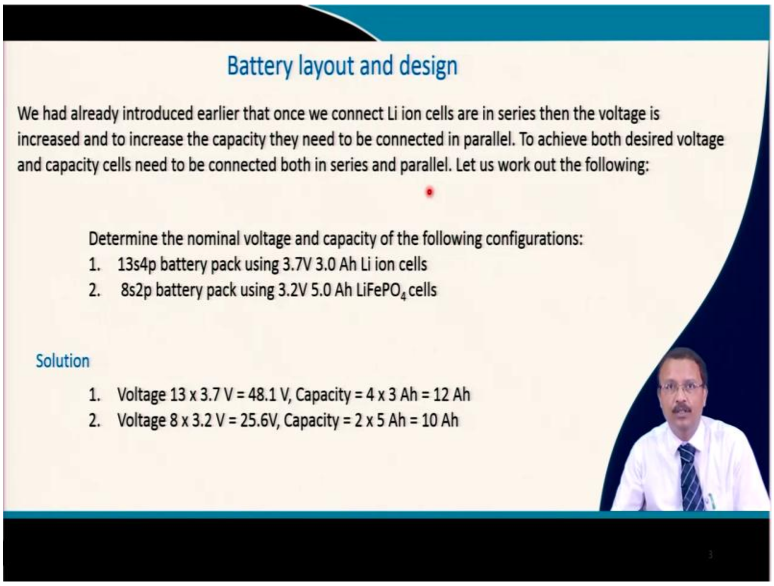
So, the concept that you will learn through this lecture is how to do the battery layout and how to design the battery. At the end of the lecture I will be giving one reference book and that you should read. People who are interested to work on the battery, for the manufacturing and understanding how to built the battery pack they must read this book from front cover to the end cover.

So, the whole book should be read and it is excellent book as far as the illustration is concerned, and part of it I have used in my lecture and you should read it if you are really into this game. Voltage requirement for different applications, just to give you some kind of idea, what are the genesis of this voltage requirement and how to group these cells to increase both the voltage and the capacity.

Then, what is continuous current requirement, the maximum continuous current how you can estimate from a battery pack. Then we will talk about the introduction of battery management system, exactly what for it is needed. Why almost all big battery packs they need it, but smaller batteries two three batteries you can omit that.

So, that although the BMS I will cover in more details in the next lecture. So, I will introduce this and similarly, the temperature issues and packaging issues of the battery that also will be covered.

(Refer Slide Time: 02:48)



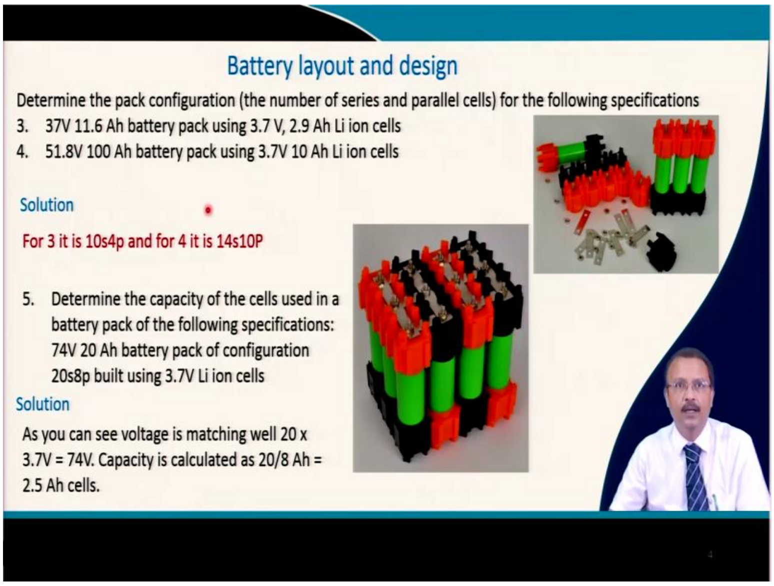
So, earlier we have already talked about, that once we connect this lithium ion cells they are in series then the voltage is increased and to increase the capacity they are needed to be connected in parallel. To achieve both desired voltage and capacity cells need to be connected both in series and parallel. So, you should have a matrix, you should have cells connected in a series; that means, the positive is connected to negative and also in parallel where positive and negative connections are same.

Let us cite you some example, say the you are required to determine the nominal voltage as well as capacity some configuration 13s means 13 lithium cell is connected in series and 4 are in parallel and it is given that the cell is having a nominal voltage of 3.7 volt and capacity 3.0 ampere hour.

And the next one is 8s2p battery pack using a 3.2 volt. So, it is lower than this, but the capacity is higher. So, you will have to determine the nominal voltage. The voltage is straightforward 13 into 3.7, so that gives you 48.1 volt and capacity is 4 into 3, because you have 4 cells connected in parallel, so 4 into 3 is 12 ampere hour.

And, you can also know the energy once you know the voltage and capacity. The second example you are getting a 25.6 volt that is the voltage you are getting out of this battery pack and capacity is 10 ampere hour. So, it is a straight forward calculation.

(Refer Slide Time: 04:51)



So, again if you are required to determine the pack configuration, that is the number of the cell which are connected in series and parallel. If you are asked to build a 37 volt 11.6 ampere hour battery pack using 3.7 volt 2.9 ampere hour lithium ion cells, you can work it out that for this one the configuration is 10s4p that will give you this kind of values. And, for the next one it is 14s10P that will give you 51.8 volt 100 ampere hour battery.

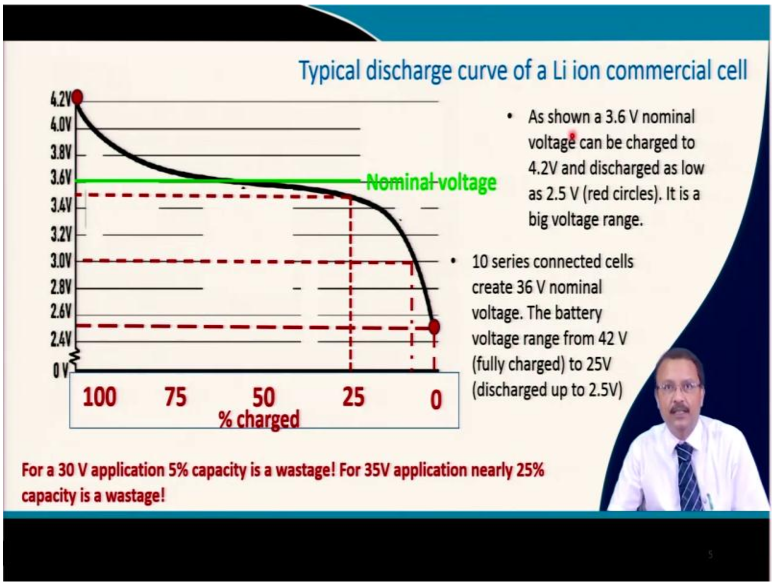
So, you will have to connect the cells in series and parallel type of connection. So, also you should determine the capacity of the cell using in a battery pack of the following specifications. So, it is given 74 volt and 20 ampere hour battery pack of configuration 20s and 8p built using 3.7 volt lithium ions, so you need to determine the capacity.

The voltage is matching well because 20 into 3.7 that is giving 74 volt and capacity is calculated as 20 divided by 8 ampere hour. So you need 2.5 ampere hour cells. So, this kind of calculation you should familiarize yourself. Now, the connection of the cell, you need to connect the positive terminal, negative terminal and connect in series and parallel. Usually, this kind of caps they are available we personally we have used it and this is actually bolted with nickel bolt for a very strong compact connection.

Because, if there is a loose connection; then that creates lots of problem. So, this is the easiest type, because if you just do the tap welding here then if for example, this cell is bad, then to take it out is a really difficult task. Because you will have to take this one out, to take this one out, this and this also you will have to open and this may be connected with this one.

So, if you go for this kind of holder then you put the battery like this then you have a top cap here and then you can with this with the help of this screw which is part of this holder, you can connect it with this tabs and then screw tight it. So, this is a much better configuration what I feel. So, these are available in the market, in Alibaba or in Amazon you can easily find this.

(Refer Slide Time: 07:51)



Now, there is an interesting part as far as the voltage profile is concerned and I would like to draw your attention. This is a typical curve for a lithium ion battery discharge. So, it is being discharged from 4.2 volt down to say 2.5 volt, so that is the range. So, you can calculate the nominal voltage which is somewhere in between these two. So, that nominal voltage is 3.6 volt which is actually written on the battery cap.

So, you can charge this to 4.2 volt and they are from there you can discharge it down to 2.5 volt. So, these two are marked by this two red circles. So, it is a reasonably good voltage range. Now, if you have a 10 series connected cells, so that will create as far as that nominal voltage, it will create 36 volt. So, the battery voltage basically, this is the nominal voltage of the battery that you have made.

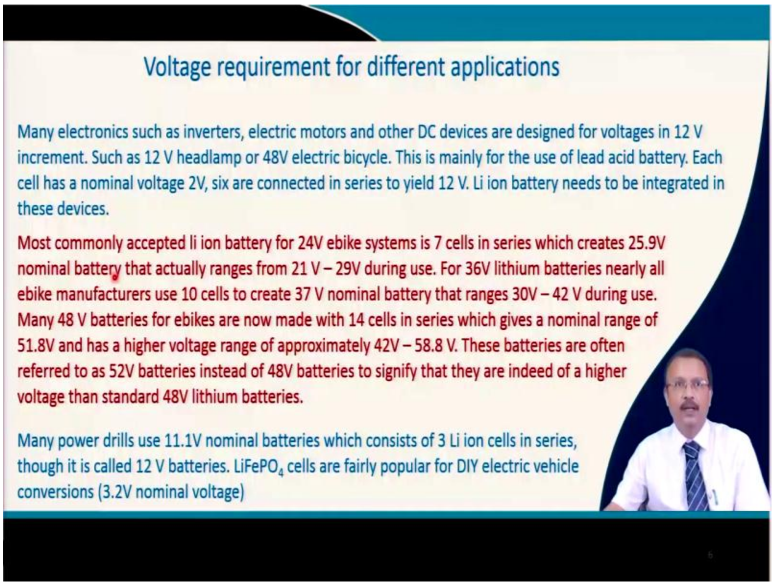
But the battery voltage that ranges from 42 volt in fully charged condition down to 25 volt right, so this is the total range of the battery during operation you can operate 42 volt to 25 volt according to this curve. Now say, if you have a particular application which require 30 volt, 30 volt is required. So, once you require a 30 volt and you have a range of 42 volt to 25 volts, so exactly 5 percent of your capacity will be wastage, because we will stop here.

30 volt is here, so we will just stop it. So, this much capacity we will be losing. So, 5 percent capacity will be lost. But, if you need a application an application which requires

35 volt, so 35 volt is here. So you cannot go below 35 volt range, so you will have to stop it here.

So; that means, all the cell will be discharged at 3.5 volt and in that case 25 percent of the capacity is a wastage. So, whenever you have a specific application in mind, you will have to select the cell in such a way so that this loss are minimum. Otherwise, this capacity will never be used that may not be that bad for the battery, but you might put in a little bit larger cost in getting this cells or making this cells. So, you should keep it in mind.

(Refer Slide Time: 10:48)



So, a voltage requirements varies depending on the application that you have in mind. Many electronics such as inverters, electric motors and other DC devices, they are designed to work in a voltage in 12 volt increment. And there is a historic reason for it. You know the lead acid battery which is the last module I will be teaching. Lead acid battery came first and each of the cell will give 2 volts. If you connect 6 of such cells in series, you will get 12 volt.

So, it is easy for you to make in 12 volt. So, 12 volt, 24 volt, 36 volt, 48 volts, so in multiplication with 12, so that is the reason. So, 12 volt headlamp or 48 volt electric bicycles, they are very common using lead acid battery. So, each cell as I told is having a nominal voltage of 2 volt and they are connected to in series to get 12 volt.

And, lithium ion battery now you need to integrate with this kind of application, because you are trying to replace lead acid battery which is much heavier much bulky with the lighter lithium ion battery. So, that also should get a 12 volt increments. So, if you have the most commonly accepted lithium ion battery for 24 volt, which is used for electric bicycle, 7 cells connected in series each which create about 25.9 volts nominal battery.

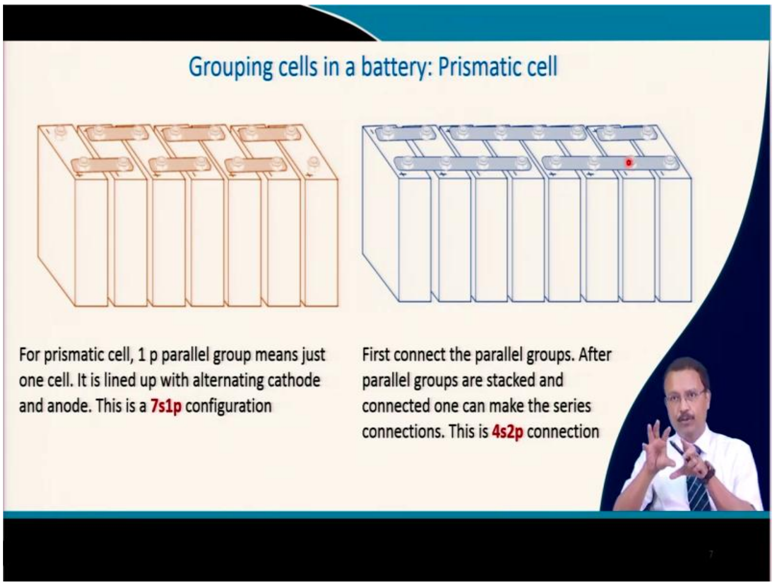
So, actual range is 21 to 29 volt during use, the one that I showed you, the top of the charge and bottom of the discharge. So, for 36 lithium ion battery all ebike manufacturers they use 10 cells, which create 37 volt nominal battery and that goes to 42 to 30. So, 42 to 30 and that is used and 37 volt nominal battery use and your requirement is 36 volt. So therefore, the wastage is marginal.

Now, many 48 batteries for ebikes they are actually made for 14 cells in series, which basically gives a nominal range of 51 8 51.8 volt and has a higher voltage range from 42 to 58.8 volt. So, this kind of battery because of this wide range they are often referred as 52 volt battery instead of 48 volt battery.

Just to signify that they are indeed having a higher voltage than standard 48 volt lithium batteries. Many power drills that we use is having a 11.1 volt nominal battery which consists just 3 lithium ion cells in series. So, the size of this is pretty small nowadays, and if you have seen the bigger power tool battery you will have to connect it to the power source is a very bulky now very small powerful power tools are available.

So, in this case, still it is called 12 volt battery. And usually for this purpose, lithium iron phosphate cells are fairly popular and this is one of the do yourself do it yourself project for electric vehicle conversion 3.2 volt nominal range to make this small sports car you know. So, that is the general battery lithium ion battery that people are using.

(Refer Slide Time: 14:53)



Now, if it is a prismatic cell like this, then you can connect it something like this for a 7 cell series and 1 parallel kind of configuration, which is pretty straightforward you have this is positive it is to be connected with negative. Negative to positive and positive to negative.

So, these are all 7 are connected in series each and one cell is there only. That itself is a oneself with one negative terminal and this one is the positive terminal. So, this is pretty straightforward, in case of this series and parallel configuration, for example, 4s2p, this kind of thing.

First, you will have to connect the parallel in groups. So, we will have to identify the parallel cells and then connect this and then you have a bigger battery, so then positive to one of this battery will have to be connected to the negative of this and vice versa, to get this 4s and 2p connections.

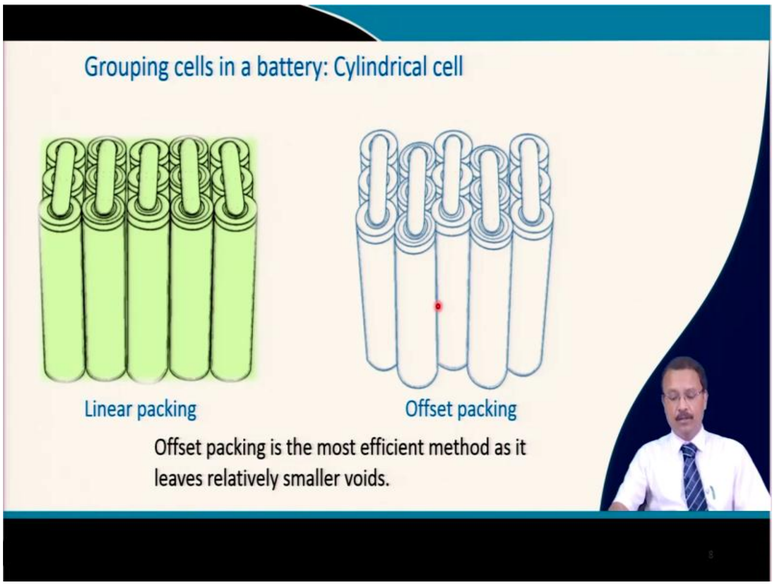
So, please work out and try to understand what I try to convey, that how basically, if you have this kind of pouch cell, you know the positive and negative terminals are marked and you know that how they are made. This is basically you can consider just like a pouch cell which is packed in a rectangular box.

So, this positive and negative we are having, so, in order to get 4s2p, this is the kind of configuration that you need to use. So, two like this, then two in reverse, then two like, this and two in reverse, something like this and then you connect it such that two cells they are in parallel. So they are individually one cell, so these two you can connect as one dash, if you consider 1, 2, 3, 4, 5, 6, 7, 8, because total the matrix will give you 8 cells.

So, you have total 8 cells, then first two is 1 dash, second is 2 dash, 3 dash and 4 dash then positive of this two will have to be connected with negative of this one and negative of this one with positive of this one. So, from this connection you can easily make out how to make the cell connection. This is important for bigger cell and you will have to be a bit careful how to make the design.

The book that I have referred they have given several examples of this kind of simple connection, or if you wanted to connect in a triangular shape for a bicycle. How to connect this pictographically, it is very well illustrated.

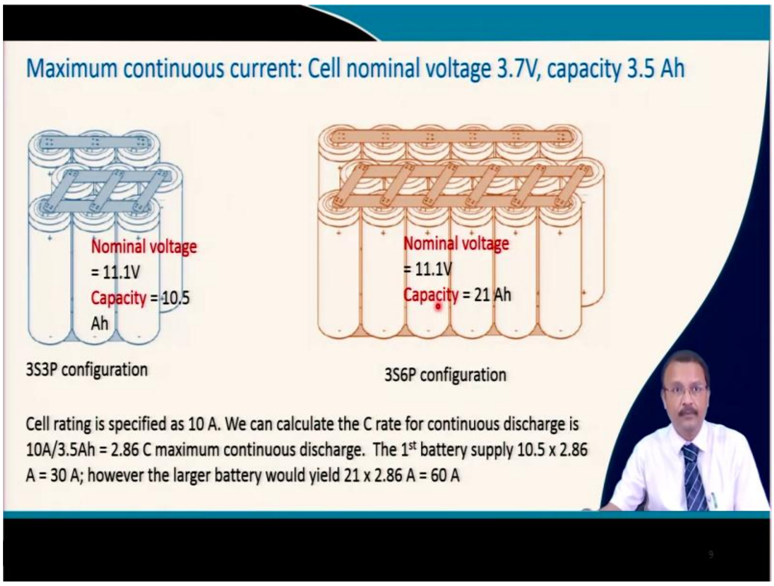
(Refer Slide Time: 17:44)



So, similar kind of connection can be done for cylindrical cell as well. In case of pouch cell you are little bit flexible as far as the space is concerned, but in case of the solid cylindrical cell or the prismatic cell, actually those much space is gone alright. So, you will have to pack it properly. So, if you have the cell connection something like this, so this is known as linear packing.

So, in linear packing the void space of course, is little bit more, so we are consuming more space. And, this is known as offset packing, where you can see that this is slightly offset. So, that this gap is minimized. So, it is more packed up as compared to this one. So, this is one of the most efficient method to leave relatively smaller void between the cell, because space particularly for the mobile application is of your concern.

(Refer Slide Time: 18:49)



Now, maximum continuous current that you need to estimate, if you know the cell nominal voltage is 3.7 volt and capacity is 3.5 ampere hour. Then this is a typical 3S6P kind of configuration. 3 cells they are connected in series, and 3 cell in parallel. So, that is the configuration for that and this one is the configuration for 3S and 6P.

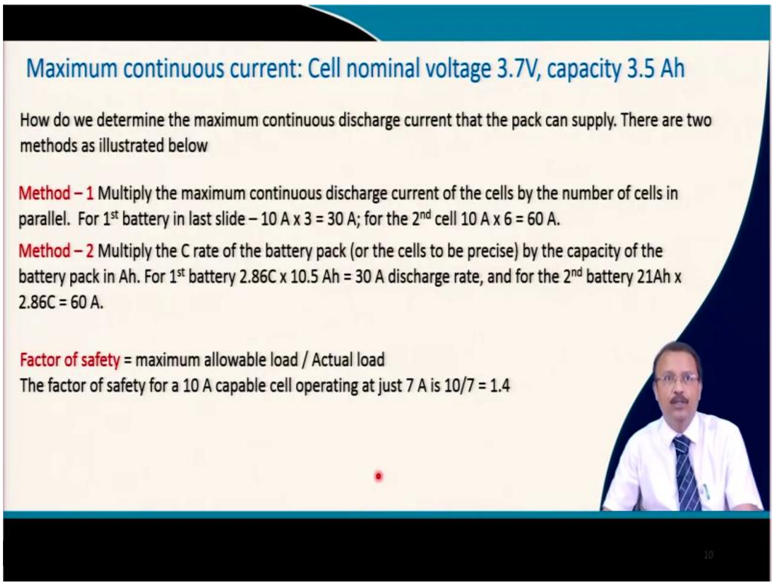
So, nominal voltage you can calculate here at 11.1 volt, because 3 are in series, 3 are in parallel, so capacity is 10.5 ampere hour. In this case, the voltage remains same, because still it is three cell in series. So, the nominal voltage is still 11.1 volt, but the capacity is higher because number of cell in parallel is large.

So, capacity is 21 ampere hour. Now, the cell rating that is specified as 10 ampere and that cell rating specified by the manufacturer. So, we can calculate the C rate for continuous discharge is 10 ampere divided by its capacity 3.5 ampere hour.

So, that will give you the C rate, because you know the C rate is in one hour the discharge capacity. So, you know one hour the discharge capacity is 3.5 amperes. So, in order to get 10 ampere, 2.86 is the C rate. So, that is the maximum continuous discharge. Now, if you consider this battery, the first one, they will supply 10.5, which is the capacity into the C rate. So that means, totally you will get 30 ampere hour. For this one you will get 21 ampere hour and this is the actual C rate. So, it will get 60 ampere.

So, this battery is 11 volt, this battery is also 11 volt, but due to the capacity it is higher than this. Continuous maximum current you can drain 30 ampere for this and 60 ampere for this.

(Refer Slide Time: 21:18)

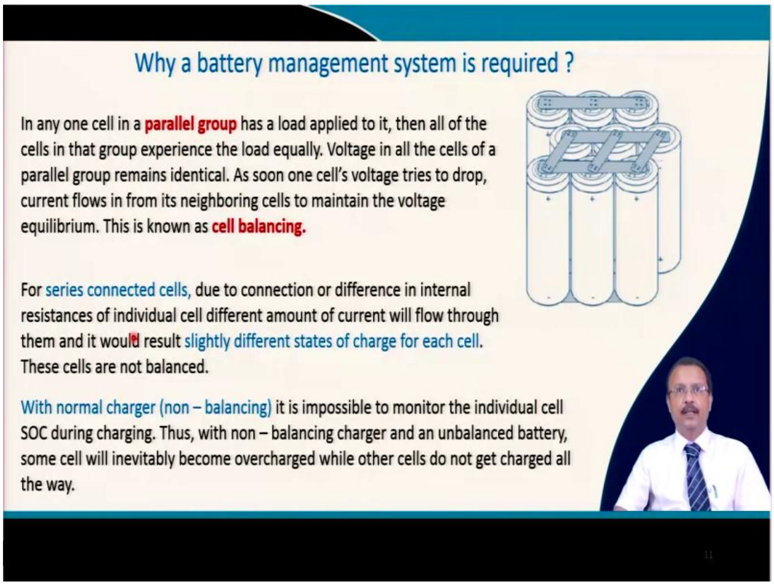


So, how do we exactly determine the maximum continuous discharge current that the pack can supply? This is one of the important criteria. So, two thumb rule methods are there; first method tells multiply the maximum continuous discharge current of the cell by the number of cells in parallel.

So you know, that the rated discharge current is 10 ampere and 3 are in parallel, so it will give you 30 amperes and second one is 10 ampere, still the same cell you are using that will 6 are there in parallel, so we will get 60 ampere.

Second method is multiply the C rate of the battery pack of the cell to be precise by the capacity of the battery pack in ampere hour, just I worked out for the first battery is 2.86 into 10.5 ampere hour, that is 30 ampere per hour which I showed earlier and second battery, it is 60 ampere. Now, we will have to consider a factor of safety that the maximum allowed load divided by the actual load. So, the factor of safety for a 10 ampere capacity cell operating just at 7 ampere is 1.4. So this factor of safety should be maintained so that the battery is not abused.

(Refer Slide Time: 22:46)



Now, why exactly a battery management system is required? So, once the cell is in a parallel group it has a load applied to it, then all the cells in this group experience the load equally. So, if in one cell the voltage drops down then from the other it is compensated. As soon as the cells voltage tries to drop, current flows from the neighboring cell to maintain the voltage in equilibrium. So, parallel cell is not a problem and this phenomena called cell balancing.

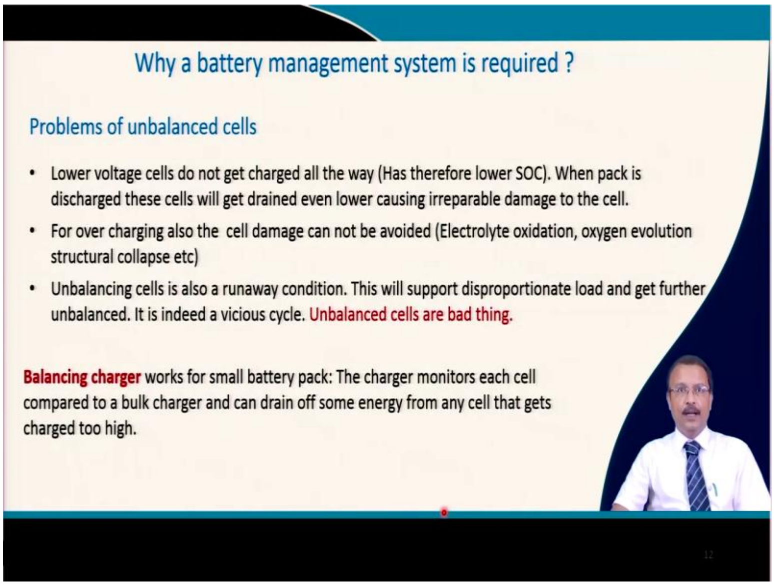
Now, in case of a series connected cell, the situation is slightly different, because of this connections and also the internal resistance of the cell, you have slight different internal resistance of each individual cell. And, this is due to this fact current that is flowing through the cell is little bit different.

So, all the cells, they are in slightly different state of charge and these cells are not balanced, even if you are using a same quality of cells; that means, they have same nominal voltage same capacity, but the internal resistance need not necessary they are all identical.

So, this series connected cells are usually not balanced. Now, when you have a number of cells are relatively less then this unbalancing is not a major problem. And, with a normal charger which is non balancing, you cannot basically monitor the individual cell. Only you are applying the voltage across the pack. So, small connected cells in series, it is not a major problem, but for larger battery pack it creates a problem, because the state of charge is different.

So, with that normal charger, which is non balancing and a unbalanced battery where the cell capacity is different. Some of these cells will inevitably become overcharged and other will not get charged all the way. So, overcharged cell is problematic and if the cells are not fully charged that is also problematic.

(Refer Slide Time: 25:29)

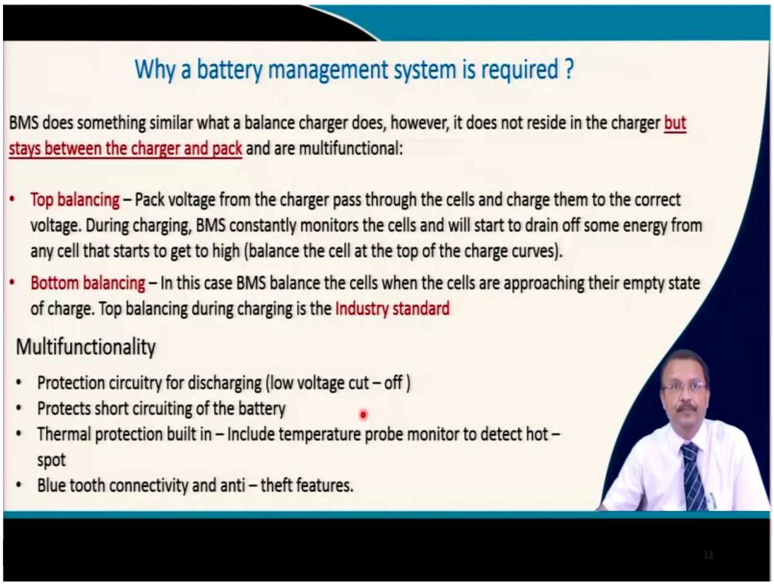


So, the problem, if I summarize for the unbalanced cell, there are three major problems. Lower voltage cells do not get charged all the way, so their state of charge is low. When a pack is discharged this cells will get drained even lower causing a irreparable damage of the cell, because they are not fully charged.

The cells which are overcharged, that also can do the cell damage, because you know the overcharging can lead to electrolyte oxidation, oxygen evolution, structural collapse and many other factors which already I have described in my earlier classes. And, unbalancing cell that can also is having a runaway condition. This will support disproportionate load and get further unbalance, so it is a vicious circle.

So, due to this vicious circle, unbalanced cell will be more unbalanced if you continue like this. So, that is a bad thing unbalanced thing. Unbalanced cells are bad things. So, balance charger that works well for the small battery. This charger monitors each cell compared to the bulk charger and can drain off some of the energies from any cell that gets charged too high. So, it works more or less well for limited number of series cells.

(Refer Slide Time: 27:05)



So, when we are talking about BMS, which I will elaborate in details in my next class. In this module, so they does something similar to this balance charger, but BMS actually it does not reside in the charger. Like normal charger and balance charger if you see that you cannot differentiate, but the balance charger they sell balancing capability is there, but in case of BMS proper BMS that stays in between this charger and the pack.

And they are actually multifunctional. Not only this cell balancing, but they do a lot of other functions, which are beneficial for the battery pack. The first it does is stop balancing that pack voltage from the charger pass through the cells and charge them to correct the voltage.

Each during charging BMS continuously monitor the cells and they will start to drain off some of the energy for the cell which gets overcharged. Bottom balancing also is possible. In that case BMS balance the cell where the cell approaching their empty state that is towards discharge.

Now, usually they stop balancing is the industry standard. So, most of the BM,S they do the top balancing. I will give you a details of this active and passive balancing in my other lectures, in this particular module. Now, what are the multi functionality? Number one is there is a protection circuit for discharging. So, that we call low voltage cut off. It will not allow you to overcharge as well as over discharge the battery.

So both are important. You cannot over discharge the battery in your mobile phone, there is no BMS of course. So, they have a smart charger, so they actually do the thing, but in a bigger battery you have a protection circuit. It protects the short circuiting of the battery. Particularly, in the series connection if one is short circuit, then the whole battery is gone.

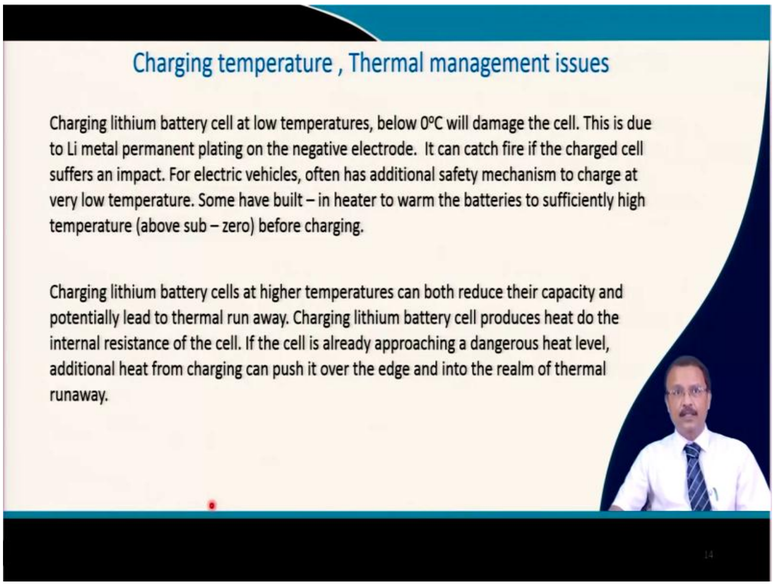
So, BMS take care of it replace, it bypass that short circuited cell and still the battery can run, because you have a range of top of the charge and bottom of the discharge as I mentioned. So, if you have an application of 30 volt you have basically 42 to 25 volt range, so you can manage that.

Thermal protection is built in, that include temperature probe monitor to detect the hot spot. So, if there is any hot spot and that leads to the thermal runaway condition, BMS take care of it. BMS they have Bluetooth connectivity, so you can and with a data logger, so the battery all electro chemical characteristics that that is there on the display.

What is their voltage, what is their charge, what is the state of charge, what is the state of health, what is the temperature inside the cell, that can be displayed and there is a data logger.

So for remote application always you can have a look, that how it performed. And it also we can have a anti theft feature. So, you take the battery out, but you cannot run it, because unless it receives a signal it will not start to discharge or you cannot charge it even. So, all these facilities if they are incorporated in the BMS, then the BMS is of course will be expensive.

(Refer Slide Time: 30:58)

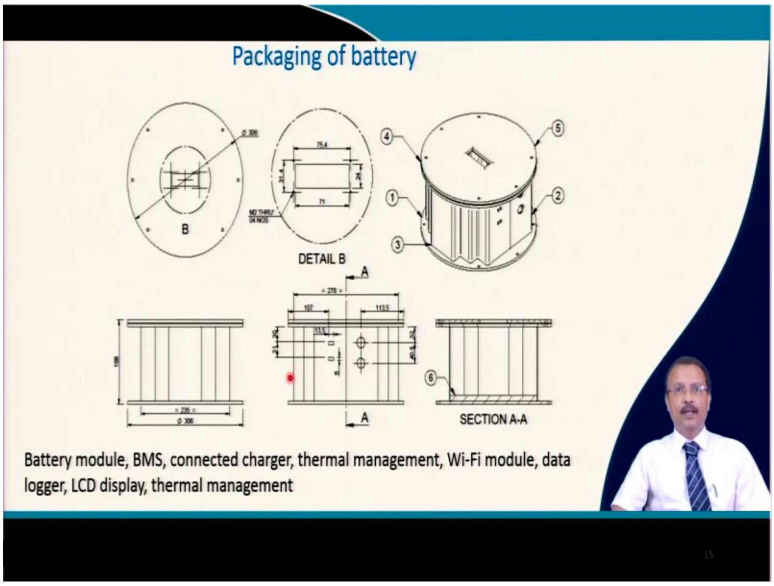


Charging temperature is important and thermal management issues; these two are all important. The first one is quite interesting. Charging lithium battery at low temperature, below 0 degree with damage the cell, because what will happen, that when you charge it then lithium instead of going for intercalation because of the very low energy, it will electroplate on the graphite surface. And, therefore, electroplating you know the dendrite will form and that will pierce the separator and there will be internal short circuit.

So, for certain E V, therefore, there is a heater circuit there. So, it raises the temperature from sub zero to up to a level so that you can safely charge it. And, charging lithium battery cells at higher temperature can both reduce its capacity and potentially lead to thermal runaway. So, charging lithium battery cell produces heat that you know, because of the internal resistance of the cell.

If the cell is already approaching, a dangerous level of fit then additional heat from charging can push it over. So already it is hot and then you are charging on top of it then that will lead to thermal runaway. So, you need to have a good thermal management system to get rid of this heat. There is a separate lecture where I will discuss that how exactly it is done.

(Refer Slide Time: 32:40)

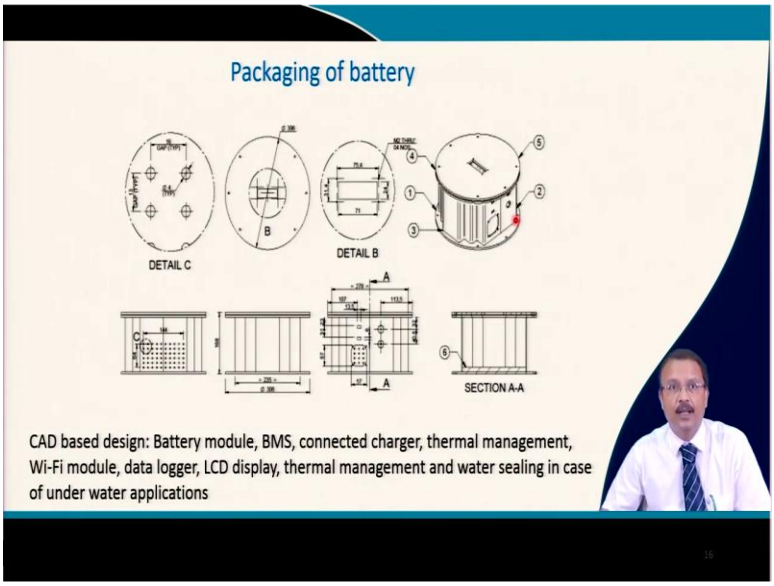


Now, you will have to put everything together inside a casing. So, this case actually CAD design and this is basically taken from one of our own project. I am not going into the details, what is what. But, this kind of case is not only it can hold all your battery module, then BMS, then you are able to connect the charger, there are thermal management in terms of you can put a small fan. So, that the fan sucks and there is a continuous flow of air.

Even use a phase change material, just it will take the heat and then it will melt itself and save the battery. So, lot of ways that you can adopt. And also, this battery is in a water shield condition so you can use it under water. So, there will be no water leakage it is connected of course, for this kind of application where the battery is working somewhere else and you are monitoring from some other remote place.

So, some kind of connectivity is required and for smaller distance Bluetooth connectivity is also incorporated. And there is a display here. Display can actually show you all the characteristics of the battery over charge as well as discharge.

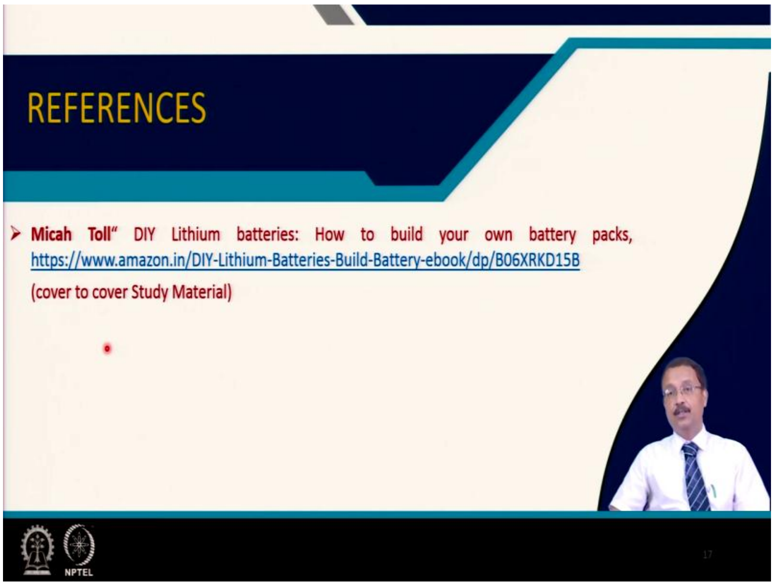
(Refer Slide Time: 34:08)



There are various types of design that we could think of and accordingly make this pack design where all this cylindrical or pouch cell battery module along with the battery management system and thermal management system, they are all packed together. So, it is a CAD based design and as I said, battery module, BMS, connected charger, thermal management, Wi-Fi module, data logger, LCD display, thermal management, water sealing so it is a complete set of battery.

So, that is we call the packaging of the battery. So, each individual part I will explain it in more details, how the BMS works, how the thermal management works, how to do a good packaging and this is just the introduction that why exactly we need it to make a battery module for a particular application.

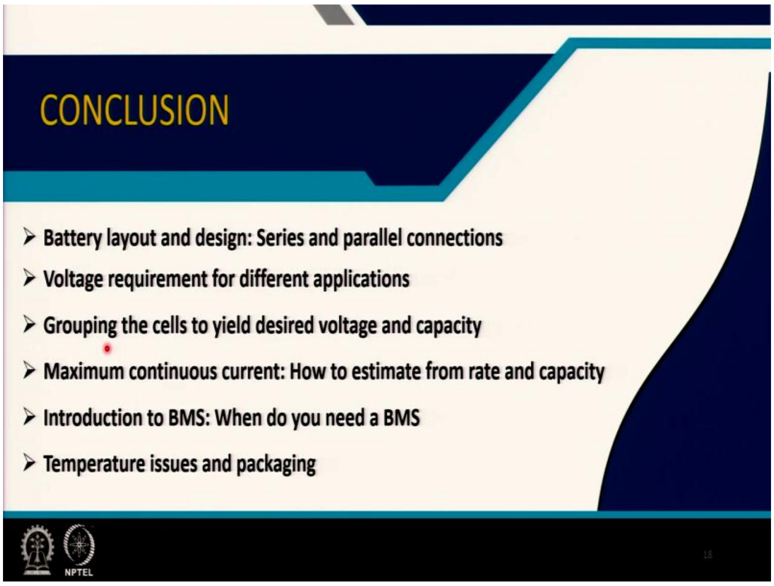
(Refer Slide Time: 35:08)



So, this book I was talking about by Micah Toll, Do it Yourself Lithium Ion Battery; how to build your own battery packs. And this is the it is available in an Amazon and this is the link for this book. And for this kind of thing once you know the battery chemistry and other parts of the battery which I was talking about. What is their positive electrode, cathode electrode, electrolyte, you have a cell.

Then how to make a battery for various useful purpose for e-bike, for UPS storage, for other types of application including a small E V battery, it is throughout the book he has explained it quite nicely. So, that is the study material and I will ask you to go through it, just like a reading material, just like a storybook and you will enjoy this book.

(Refer Slide Time: 36:01)



So, in this particular lecture, the battery layout and design, serial and parallel connections, I have introduced then the voltage requirement for different applications. I gave you some idea then grouping the cells to yield desired voltage and capacity, how to do that then maximum and continuous current how to estimate it from the rate and capacity that was taught.

And introduction to BMS and why do you need and when do you need a BMS that is illustrated. And finally, the temperature issues and packaging have been talked about.

Thank you for your attention.