Fundamentals of Electric Vehicles: Technology and Economics
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Lecture No. 26
Technology and Economics

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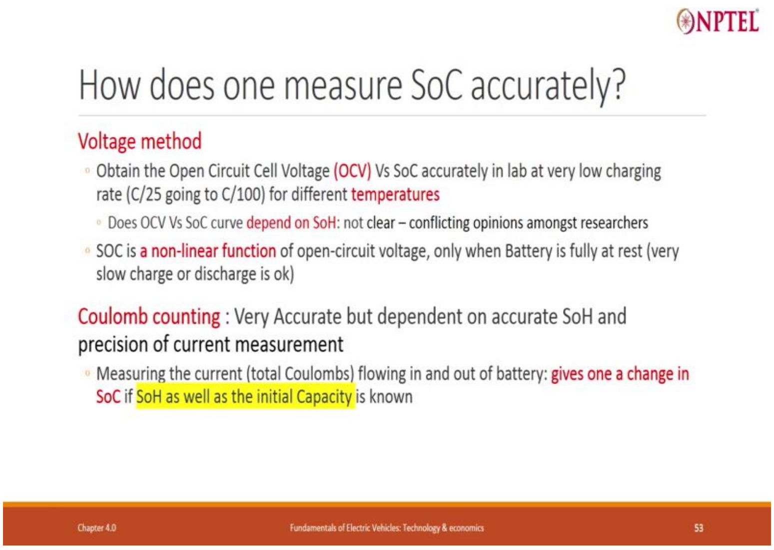

So, how does one make measure SOC accurately? Voltage method can be applied, if you use the open circuit voltage, that means 0 current. So generally, when you use that, we use a current between C by 25 to C by 100, very, very slow rate of charging, then you get nearly OCB, and you use that as a curve which gives you the relationship. The question that I am asking is what is the state of health? So, if it is a good battery nearly 100 percent, you will get one OCV versus SOC curve.

If the battery is getting deteriorated, we will get another, this is not clear from the literature. In fact, this should be a important exercise that you should convey to Sushant, he himself should do enough experiments and do this measurement and should be something get your data. SOC is a nonlinear function of open circuit voltage come only in batteries fully addressed very slow charger discharged, not otherwise.

So, the other method, what is the method therefore using lithium and battery, it is not the voltage method, it is a Coulomb counting method. What is the Coulomb counting method? You count the number of Coulombs that goes in, you start at a certain state of charge, and then you start counting and this much ampere current for so much time, you calculate the Coulomb. And as you calculate the Coulombs and Coulomb as a percentage of total capacity, SOC keeps on going up.

So, this is very important Coulomb counting. Very accurate method but dependent on accurate SOH and the precision of current measurement. Measuring the total current flowing in and out only gives you a change of SOC, it does not give you actual value of SOC. And that is if state of health and the initial capacity is known. There also only it will give you change. So, the reference point is missing in the Coulomb counting you have to assume that your initial reference point it was okay.

So, the very interesting method is used, that you use your initial reference point at any time with open circuit voltage. And with the curves which have been already taken in the lab, during the design of the battery, use those curves, keep the battery at rest, no current going in and out, now measure the open circuit voltage. From that open circuit voltage, you measure the initial state of charge, that can be done. So, you know your initial state of charge.

Now you keep on looking at the Coulombs coming in and you can say, as the Coulombs are coming in, or going out, what is the state of charge that itself will depend on state of health.

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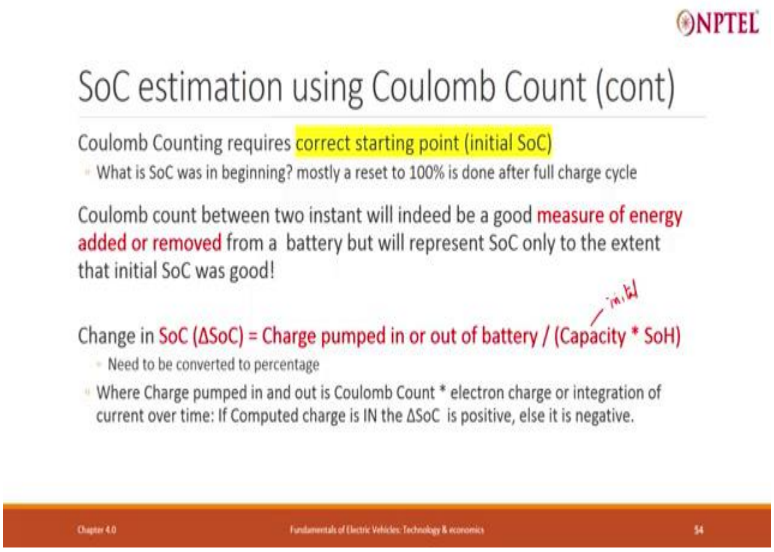

And I will come to do. Coulomb counting different requires correct starting point. This is the point that I am making. Correct starting point is very important. Now normally what happens, if it is a fully charged sometime you charge it fully. So, you know it is a fully charged it is close to 100 percent that is the time you can actually then say this is a counting down. As I said discharge you can count it correctly. Coulomb count between two instant will give you a good measure of energy added or removed from battery.

But will represent the SOC only to the extent that initial SOC was good and this is important. So, delta SOC change in SOC, the charge pumped in and out of the battery divided by the current capacity of the battery. Now current capacity the battery is the initial capacity, this is the initial capacity into SOH, this is the initial capacity. So suppose, you are taking 1 kilowatt hour or 10 kilowatt hour battery, and if it is a new battery SOH is 1.

So, charge pumped in or out of the battery divided by 10 kilowatt hour, you convert the charge into again energy and that will give you the change and that will give you change in state of charge change in state of charge. If the battery is not new, you have to know what the state of health of the battery is. Suppose the battery, state of health of the battery was 90 percent then you say 0.9 into initial capacity, take the charge pumped in and out and that will give you the actual Delta SOC.

So, this needs to be converted to percentage, where charge pumped in and out is Coulomb count multiplied by electron charge e 1.6 into minus 19 or integration of current overtime that is a Coulomb count. Coulomb count is the integration current over time. If computed charge is charge is IN, the Delta SOH is positive, else it is negative. If the computed charge comes as in or out, if it is in, delta SOC is positive that means it is getting charged SOC will increase, if it is out then it is negative.

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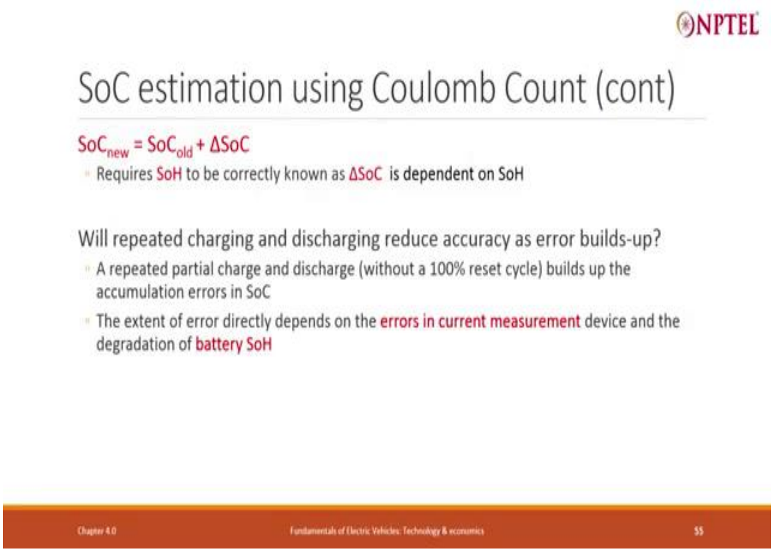

So, SOC new is equal to SOC old plus Delta SOC that is a result that we have. Now, this delta SOC depends on a SOH. Of course, you know the initial capacity plus you need to know the SOH. The question is therefore, how do you know what is the SOH? I have been using the battery for last 3 months, how much has the SOH gone down? With repeated charging and discharging, what happens this delta SOC is a little problematic, you may make small errors and the error will keep building up.

Now, error keeps building up if you are careless and keep on using this formula, again again your SOC new may be very different than actually SOC. I have seen the battery was charged 60 percent and battery was showing 0, nearly 0 SOC, why because error kept on building up. And so, this method, because it was initialized it depends on the initial value and SOH value, all of that are changing. So, you can use it for a short period of time, you have to reset and recalibrate the battery after that time.

So, this is a involved process, which a battery designer actually have to do using the BMS algorithm and this is where most people do not design good batteries. In Lead Acid this was not there. Now, the question is if your SOC is wrong, how does it matter? Well, you know when you are driving, it shows you how many miles left, how many kilometers to travel, how much battery is charged, that will be wrong, nothing else will happen.

You can keep on charging discharging, your estimate is wrong means you do not know how much more kilometers traveled and this is very critical in electric vehicles. If it shows that you can charge to go 50 kilometer, but in real you could only 20 kilometer you will get stuck somewhere. So, this is a important thing which creates a lot of problem at times. You often think that the problem is with the dial meter, actually there is no problem with the meter.

The problem comes because the algorithms have not been implemented correctly in the battery and this is very common. Not very difficult in the beginning because in the beginning SOH is clearly close to 1. So, your result will not be that bad. As SOH starts falling this, this in a way will keep on. So the error, external error directly depends on error in current measurement and the degradation of SOH.

So delta SOC is okay, but both degradation in a SOH as well as accuracy of the current, you are measuring only so many 0.01 ampere, so to that extent, you will be piling up there. And if it happens to just, sometimes it cancels out, sometimes it just keeps on building on one side. So, what do you do? Well, you periodically recalibrate, you again take the battery to full and take that as SOC 100 or take it to absolutely 0, take it to SOC 0 and then restart because this is the increment we.

So, what I am pointing out, two problems with the lithium ion battery and this is the reason BMS becomes very very important. First problem is, no really linear relationship between voltage and state of charge. Problem number 2 is that not just there is no linear relationship, but to the extent that you know the relationship between state of charge and voltage, it is only when the current is 0, open circuit voltage.

In reality, open circuit voltage is not there, open circuit voltage is there if your battery is not being used, no current is supplied. Therefore, voltage versus SOC is a bad method, voltage changes with the with the rate of charge discharge and changes during charging and discharge.

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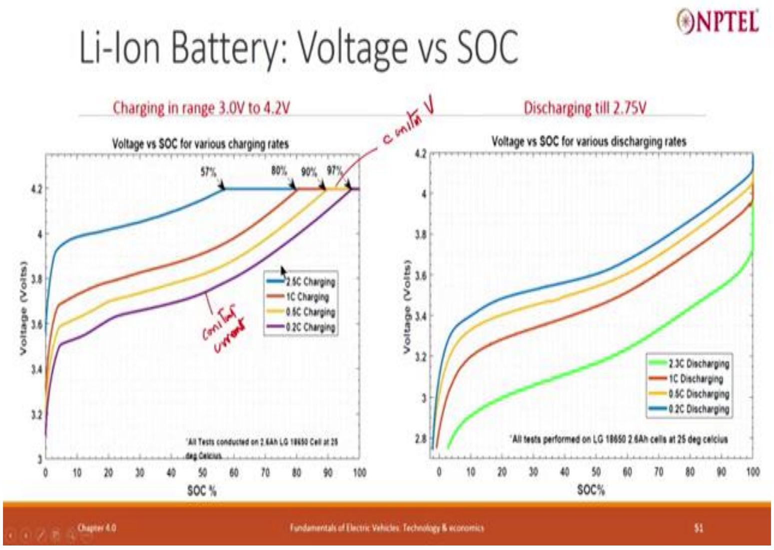

A battery which is 100 percent full, you start discharging immediately if you see immediately your this curve is very important, it starts fall you start discharging at 2.5 C and your voltage immediately falls. Now, you take this voltage and you try to estimate SOC, you will be totally wrong. Similarly with charging you depending on the current it significantly changes, very significantly. You look at this point, this point says that SOC is nearly 100, this is or different SOC, you can do like this, same voltage 4 volt here SOC will be nearly 0.

In this case SOC will be quite close to 85, 90 percent, 80 percent. So, voltage versus SOC cannot be blindly used. And yet that is a very important parameter. The problem number 3 that you have, there is another method called Coulomb count, which is more accurate. But Coulomb count only tells you if you knew what the SOC was, I will tell you what is SOC now. So, your initial estimate still depends on the voltage and with all the complication. Now, even the Delta SOC that you calculate depends on how accurately you know the state of health and how accurately you have done the measurement. So, that itself error keeps building up, so it becomes very complex.

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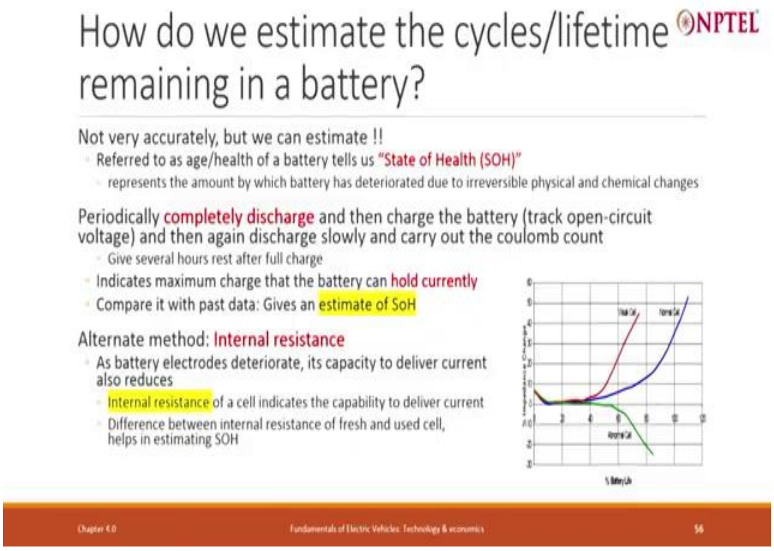

So, how do you estimate the cycle, lifetime remaining in a in a battery, that is what state of health is, referred to as a state of health. How do you estimate that correctly? Well, the best way is take a battery, completely discharge it and discharge it at a very low current, in the end at least completely discharged it. When you completely discharge it and track open circuit voltage, when the cells have become close to 3.0 volt, batteries nearly completely discharge, that is close to 0 percent, 1 percent SOC. So, that is what you get one way.

Sometimes you completely charge it also. And you have to worry about remember that we had talked to you about depth of discharge, the battery is never fully charged, but is never fully discharged. So, what are we talking about? So, there is a mechanism during the determining the state of health, you have to override that and you have to actually almost fully discharge. The lower percentage you will otherwise not go below let us say 5 percent.

But in this time you may have to go or you may have to fully charge because otherwise it can be 5 percent or 90 percent, we think 90 percent is fully charged. So, if you are starting with 5 to 10 percent error, you can get into total problem. After discharging the new charge slowly, slowly is very important and carry out the Coulomb count, give some rest, say several hours, at least I will say half an hour and then you start charge slowly.

That you do the Coulomb count and that will give you the estimate of the state of health. This is the total capacity, this is the total from totally empty to totally full, this is what I have measured. At that time it will give you a state of health and you use that a state of health then again. So, it indicates maximum charge to the battery can hold, what was the initially when it was new, what was the charge that it hold compared to past data it gives an estimate on SOH.

There is an alternate method. But it depends on cell to cell. The internal resistance of the battery itself sometime is a function of battery life. Now that depends on cell to cell. But if you can do that and measure internal resistance, that is easier to measure, you can measure state of health. So, the point that I am making is state of health determination, state of charge determination is crucial to use in lithium ion battery, not as important in lead acid battery. And that is the reason you require a BMS to do that.

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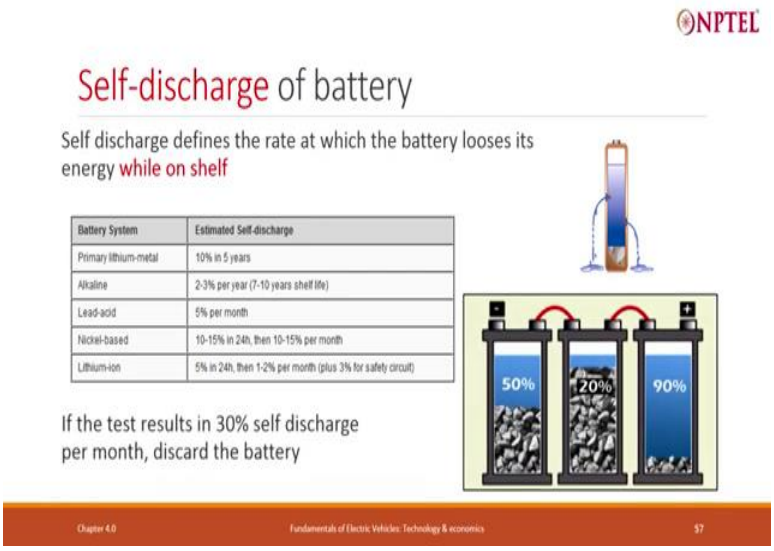

There is a self discharge of battery, when the battery is on shelf is slowly leaking. How much does it leak? If I look at lithium ion battery, will it leak 5 percent in 24 hours that the first time you use it, it does that, but after that 1 to 2 percent per month, that is a typical. So, battery once you keep it charged, it will stay for 10-50 even one month it will be 1 or 2 percent or less.

If on the other hand, I look at some others, nickel based is 10 to 15 percent 24 hours and then 10 to 15 percent per month. So this is much worse, lead acid 5 percent per month, primary Lithium Ion 10 percent in five years, so there are some good batteries. The self leakage is important, self discharge is important and you do not want more than 1 or 2 percent in a month. So, that is the point that I was making.

If test results shows that there is a 30 percent self discharge per month, battery is, discard the battery. Because something is going wrong with self discharge.

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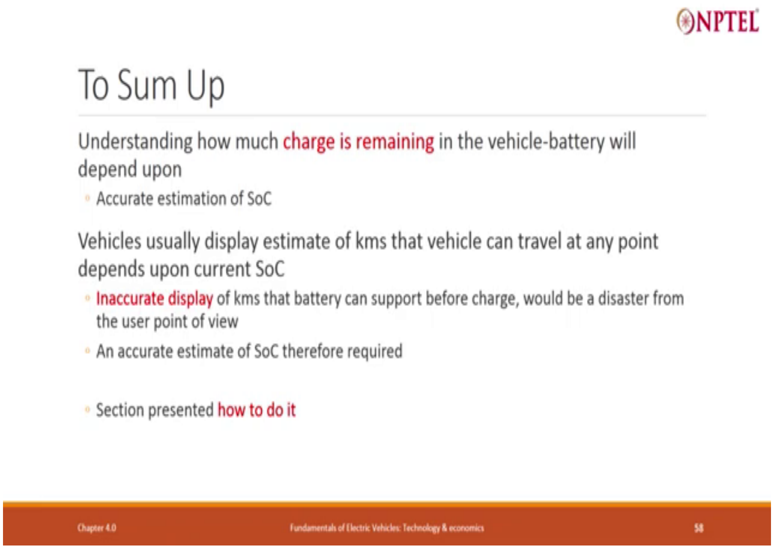

To sum up, understanding how much charge is remaining in the vehicle battery will depend on accurate estimation of SOC and accurate vehicle usually display the kilometers that you will still have to travel you can travel depends on the current SOC and inaccurate display of kilometers that battery can support before charge good lead to disaster from a user point of view. One day I was driving an electric vehicle, I thought I had a decent SOC, it showed me about 35-37 kilometers to travel.

After a few minutes, I suddenly see 0 percent SOC. So, I did not know what to do, should I drive, should I stop. If I stopped in the middle of the road will it ever revive. What will I do? I kept on driving slowly. It kept on giving me warning there is now 0 percent SOC. Fortunately, I could drive 3-4 kilometres, then put it onto a charger. When I put on a charger, for some time it remained 0 percent and then it corrected and gave me 30-35 percent.

So, it was actually not really 0 percent. But that is a mistake that was Delta SOC was wrongly calculated and gone for a toss. We cannot let this kind of thing happen in a vehicle and battery designers have to therefore, the software people the BMS hardware people have really work hard to make sure that this works all right. This section kind of gave how to do it overview, it did not give it accurately, accurately you still have to work quite a bit.

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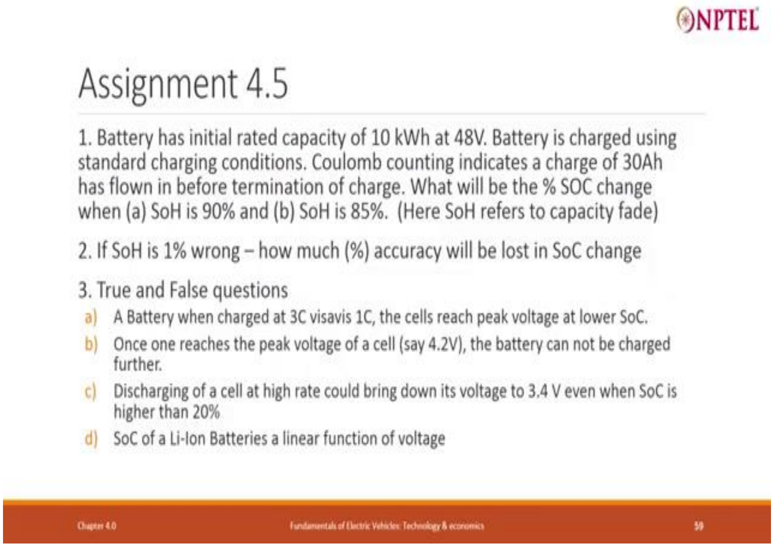

Get those curves from the measurement etc etc. And I am giving you an assignment problem, that battery has initial rated capacity of 10 kilowatt at 48 volts, batteries are charged using a standard charging conditions, Coulomb counting indicates that a 30 Ah has flown in before termination of charge, what will be the percentage SOC change when SOH is 90 percent, SOC is 85 percent. If SOH is 1 percent wrong, how much inaccuracy will you see in SOC?

And then there are some true and false questions. Please try to answer them. The questions have been designed to really get you to understand the battery much better.

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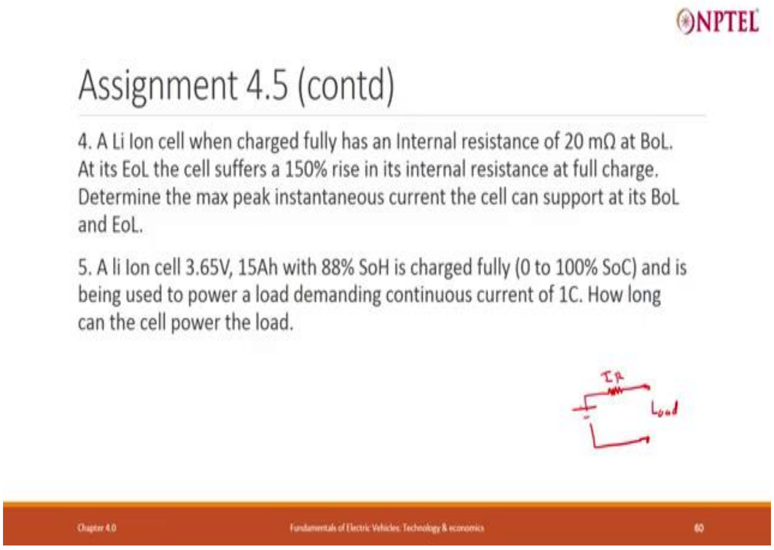

There is another one, it is a lithium ion cell when fully charged fully has an internal resistance of 20 milliohms, at its end of life, that is the beginning of life, at the end of life the cell surface of 150 percent rise in internal resistance. Determine the maximum peak instantaneous current that the cell can support at its beginning of life and end of life. This 20 milliohms is the resistance so and it will become 30 milliohms. Based on that, you can actually estimate what is peak current can it sustain.

Because if you put very large current, the voltage will go to 0, effective voltage is going to 0. Think of equivalent circuit there is open circuit and this is your load. Minus the current I becomes high all your voltage will virtually get eaten by by the this itself. So that is what you have to use. Of course, the load is designed for certain current. So suppose you want to try to draw 4C. So the load you can calculate. If I was 0, you can calculate what the load will be.

And then you can see what will happen. A lithium ion cell of 3.65 volt 15 ampere hour with 88 percent SOH is charged fully and it is being used to power the load demanding continuous current of 1C, how long can the cell power the load. It started with 88 percent SOH.