Fundamentals of Electric Vehicles: Technology and Economics
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Lecture No. 31
Charging Batteries

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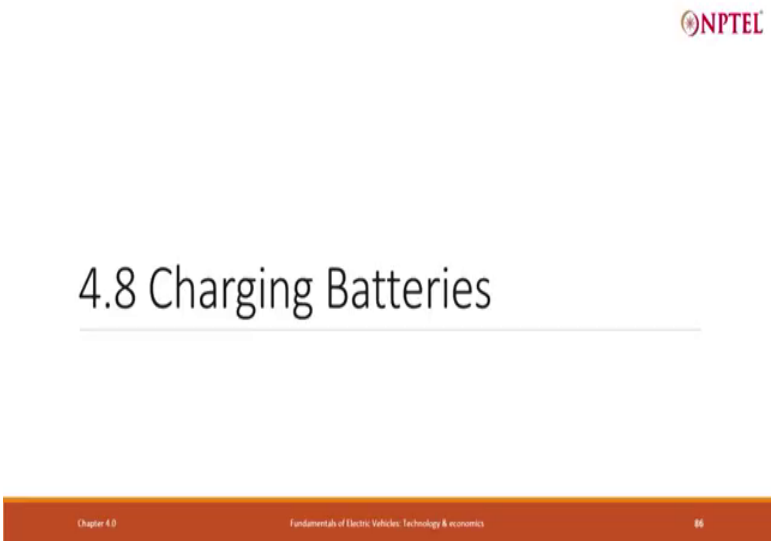

Now I come to my last section of batteries and frankly speaking this charging of batteries I will talk about Charging Batteries. I am going to discuss this in very brief as a part of batteries because there is a full chapter, Chapter 7 which ofcourse comes after we discuss the motors in detail and battery pack design in detail, is going to get into depth on charges, what does are the chargers and charging infrastructure. But let me still get into what does simple charging of batteries imply?

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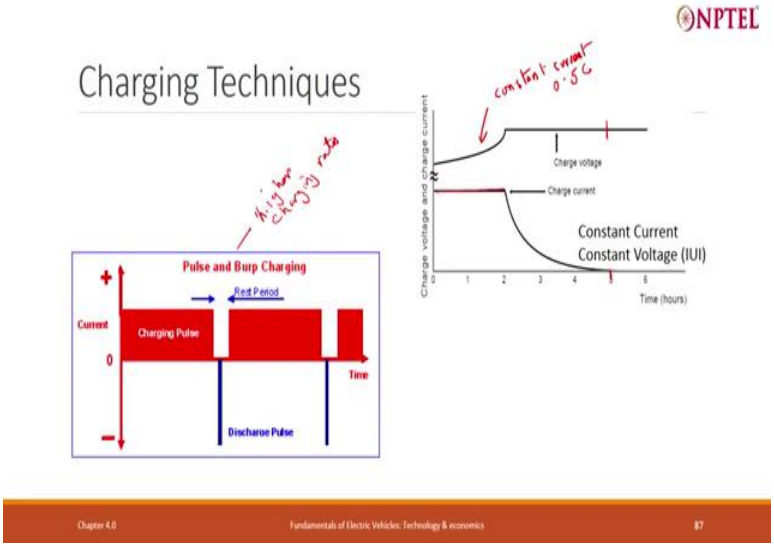

First, important point that I want to make, I start with a diagram and the diagram clearly shows two things; the voltage as the battery charged and the current as the battery charged. Suppose there is a near empty battery at 0 hours I told you typically it take 3-4 hours to charge, this normally the battery charged and will get into details of this later on into, in the early phase, in the first phase, first part of the battery charging from here to roughly 2 hours I have shown here could be 2.5 hours. This is called constant current charging, current is constant you see this is the current.

Current is constant, voltage of each cell and therefore the pack will start from small value, if it is a cell will start typically from 3, 3.1 volt and will keep on going to maximum value 4.15, if it is a pack it is the same 3.1 volt multiplied by number of cells in series and 4.15 multiplied by number of cells in series. The voltage will go and hit, so normally it is almost fully charged, well it is not fully charged battery is still not fully charged you will see the percentage of charge is not still 100 percent. It will depend, it could be rate of, depends on the rate of charging. You will see that it could be 80 percent charge, 90 percent charge, 95 percent charge but still not be fully charged.

And then you do very low rate charge, the current keeps on going down, you clamp the voltage. Initially, you clamp the current later on you clamp the voltage. This is called constant current in the beginning then constant voltage. You clamp the voltage and the small current will keep on flowing as the maximum voltage reaches the charging voltage you will see trickle current for a

long time. So, only around 5 hours here the battery is fully charged, no more current goes in. This is the way a battery charged and this is the best way of charging battery this is also best way of preserving life of the battery.

So, constant current and constant current can be at 0.5C, 0.2C here it is seems to be 2 hours so closure to 0.5C, this is constant current closer to 0.5C. So, in about 2 hours is almost looks like it is reached but does not reach and then it is a constant voltage. You can charge ofcourse faster what happens when you charge faster? Will look at all these things, this is one method of charging, this is the better, common method of charging. There is another method of charging and that is you send a charging pulse, you send a large amount of current for a short period of time, so not a constant current.

What will happen when you put the large amount of current? Ofcourse of it is a large amount of current suppose it is 1 C or 1.5C this is normally used for higher charging units. When you try to charge at a high charging rate for a the battery will tend to heat up, why this heat will be dissipated? Will get into detail when we do thermal design of the battery will get into how much heat will be dissipated.

Now when it is heats up there is a internal resistance associated with the battery and I square R losses will be there that is a loss but the electrical energy is getting converted into heat. Now when it gets converted to heat the battery temperature will keep on going up. As the battery temperature goes up, it will hurt the battery life. So, you need to stop, so you create for a pulse and then you stop. You can ofcourse there are two ways; one way is just wait for period of time and then again give another positive pulse.

Another is put a small discharging pulse also, it have been shown that a small discharging pulse helps sometime the battery, battery life. Even though temperature does not go up, go down so much it helps, so it is a small, very thin, very short time it is like somewhat you are trying to get charge settled, very small. Then you again wait for some time then you put a charging pulse, so this is called pulse and bub charging. Particularly for fast charging this has been found to be useful.

Of course, this will have to be associated with cooling, you cannot do it without cooling. So, essentially what does it mean? You have to put at a certain voltage, a constant current or constant

voltage. Here again you are putting constant current then you are making current 0, then you are putting a large negative current.

Student: Negative current also does not positive, I square.

Professor: Yes, it will give different heat but yes it also resulted heat. So, it does not help in heat dissipation, it actually helps in charge settling down. Heat dissipation there has to be cooling, this this is done along with cooling.

Student: (())(07:28).

Professor: So, in fact when you get into detail you will see that it kind of helps settle down, will come to the settling down later on.

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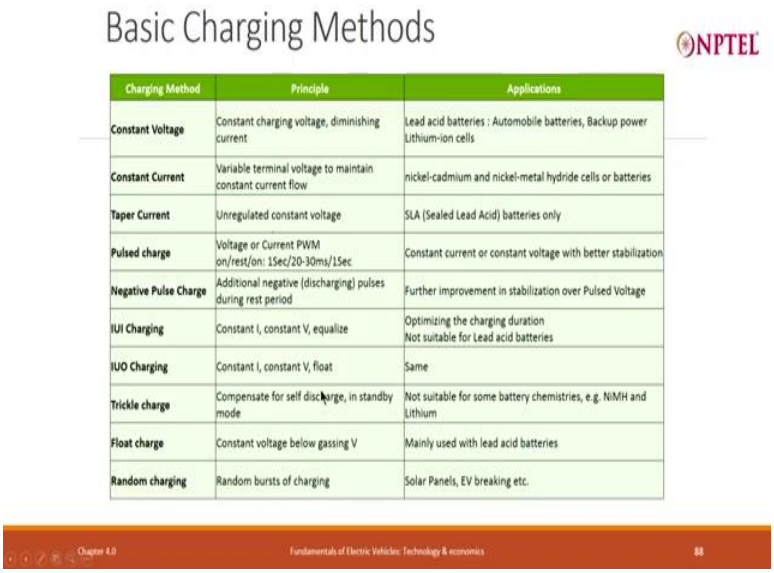

Charging Method	Principle	Applications
Constant Voltage	Constant charging voltage, diminishing current	Lead acid batteries : Automobile batteries, Backup power Lithium-ion cells
Constant Current	Variable terminal voltage to maintain constant current flow	nickel-cadmium and nickel-metal hydride cells or batteries
Taper Current	Unregulated constant voltage	SLA (Sealed Lead Acid) batteries only
Pulsed charge	Voltage or Current PWM on/rest/on: 1Sec/20-30ms/1Sec	Constant current or constant voltage with better stabilization
Negative Pulse Charge	Additional negative (discharging) pulses during rest period	Further improvement in stabilization over Pulsed Voltage
IUI Charging	Constant I, constant V, equalize	Optimizing the charging duration Not suitable for Lead acid batteries
IUO Charging	Constant I, constant V, float	Same
Trickle charge	Compensate for self discharge, in standby mode	Not suitable for some battery chemistries, e.g. NiMH and Lithium
Float charge	Constant voltage below gassing V	Mainly used with lead acid batteries
Random charging	Random bursts of charging	Solar Panels, EV breaking etc.

These are two methods that I gave you but there are many-many methods; constant voltage charging, that is commonly used for lead-acid battery. Constant current charging, nickel cadmium batteries just current remains, now how do you make the current constant? You have to design your (volt) charger to have a voltage which takes feedback, voltage should be just above the voltage of the battery. So, there are sudden current flows, if the voltage of the battery starts increasing, the voltage for charging has to keep on increasing.

But you have to keep on getting feedback such there a constant current flows that is a very common way of doing this you design a voltage source which keeps on changing by taking feedback of the current. So, it maintains the current. Paper current that is used in lead-acid battery, pulse charge, you charge stop charge, negative pulse charge I just showed you. IUI constant current followed by constant voltage then equalize there are various other technique. Constant current, constant voltage and then you float keep there same voltage, there is a trickle charge, very slow charge. Float charge, random charging these are all different methods.

Random charging for example is very important, for example for regeneration. When you do a breaking of the then you are able to regenerate the electricity, the motor will go reverse and you will get a reverse electricity. I hope you will over the regeneration, that is an important component of motor. So, that will give rise to a putting current back into the battery that you cannot control. So, that is a charging which is random charging. These are more we normally use constant voltage, constant current, constant current-constant voltage and some amount of random bus charging particularly for reverse charging that is all that is used in electric vehicles for lithium-ion batteries.

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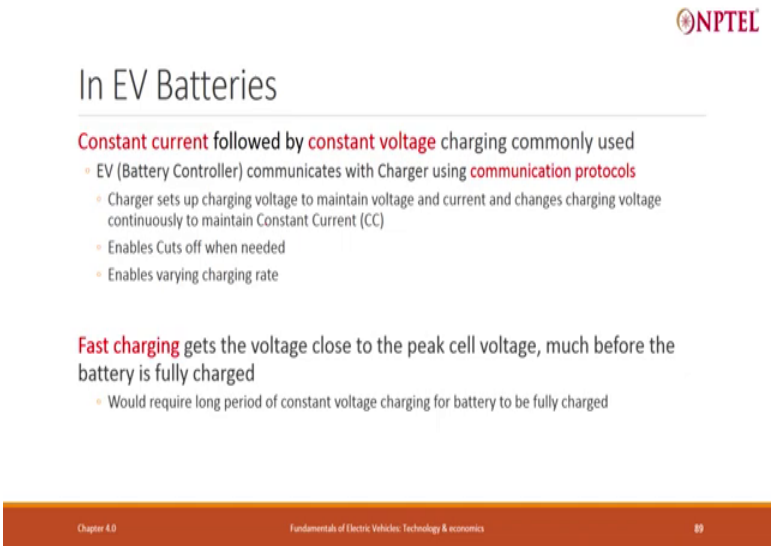

So, constant current followed by constant voltage charging commonly used EV, now electrical vehicles will constantly communicate with charger. So, the vehicle has a battery, there is a charger the two will be talking to each other. And saying no-no-no my current is becoming like

this and there is a communication protocol, there are messages sent, digital messages. Saying now increased-decreased, do not do that, I am heating up, do not do that, stop charging, all this is a part of communication purpose. This is a communication between battery and a charger. So, charger sets of a charging voltage to maintain voltage and current and change in charging voltage continuous to maintain constant current.

For constant voltage it just maintains the voltage, for constant current it will continuously change the voltage maintain constant current. Now this communication also helps us to cutoff when needed. Anytime say a cell is getting heated up BMS will constantly monitor any cell has got heated up, cut-off enables the varying the charging rate. Say now I can take more charging rate. Fast charging gets the voltage closed to the peak cell voltage very quickly. Much before battery is fully charged.

And then it is a constant voltage charging so that will take a long time to get it fully charged. I think it is not even shown, but in the next chapter which I will straight away start you will see all this charging.

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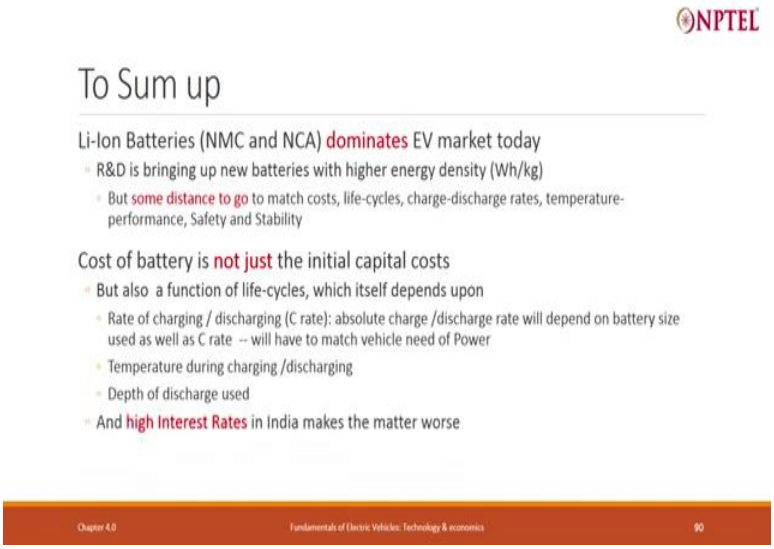

So basically, here I am saying lithium-ion battery NMC and NCA dominates in the market today. RND is bringing up new batteries with higher energy density but some distance to match cost, lifecycle, charge-discharge rate, temperature performance, safety and stability. Constantly evolving. Cost of battery is not just the initial capital cost but also function of lifecycle which

itself depends on rate of charging discharging. Absolute charge discharge rate will depend on the battery size used as well as the C rate will have to match vehicle power, need of the power.

So, the C rate is not something that you can decide arbitrarily particularly for discharge. Charging you have little more on control, discharging whatever motor requires you have to give. Temperature during charging discharging impacts the lifecycle, depth of discharge used impacts the lifecycle and high interest rates in India makes the matter worse.

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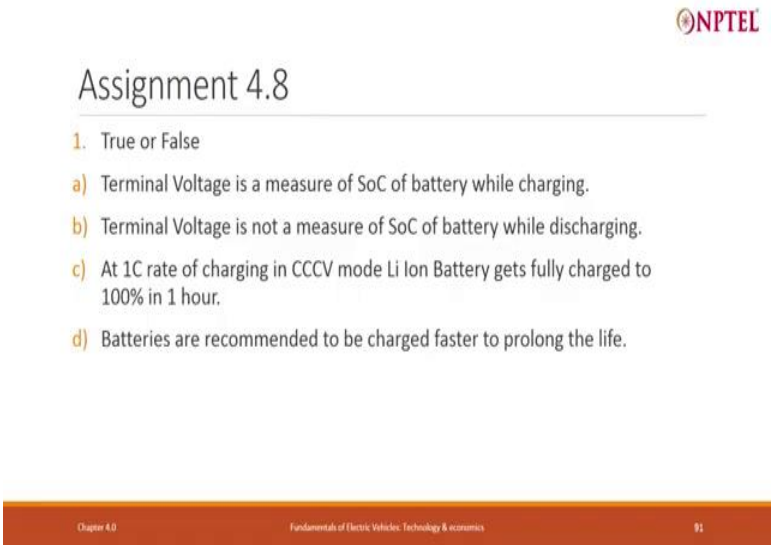

Well there are some assignments questions, these are mostly true and false and I think I will stop with this for chapter 4, this chapter 4 done.