Fundamentals of Electric Vehicles: Technology and Economics
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Lecture 19
Storage for Electrical Vehicles – Part 1

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So I will start now with a very important chapter called Storage for Electrical Vehicles. Now while I do that, I want to straight away attempt to answer a question that was post to me at the end of the last lecture by a student. The question was, we had talked about efficiency for motors and controllers thus battery also have efficiency. What does it mean?

First thing is when I charge battery do I lose energy? Yes, we will lose energy that will come as a charger (efficiency) inefficiency, not the battery, charger inefficiency. Where we discuss charger we will talk about the inefficiencies of that. But battery will have us after so we will have to always put in more energy then what goes into the battery.

The charge inefficiency could be 5 percent, 10 percent that much energy will be lost. In the charger finally some amount of energy that we will enter the battery. Battery inefficiency will be whether whatever is put in can I take out all of it? Well, yes or no? Remember battery also gets heated up I mentioned that. There is a internal resistance associated with the battery.

So to that extent energy that has gone in part of the energy will be lost. Except the lost is very small, typically 1 percent and therefore from efficiency point of view you do not worry about it, from the heating point of view you worry about it. So that is the answer, we will get into more detail because that is discussed in detail when we do storage for electric vehicles.

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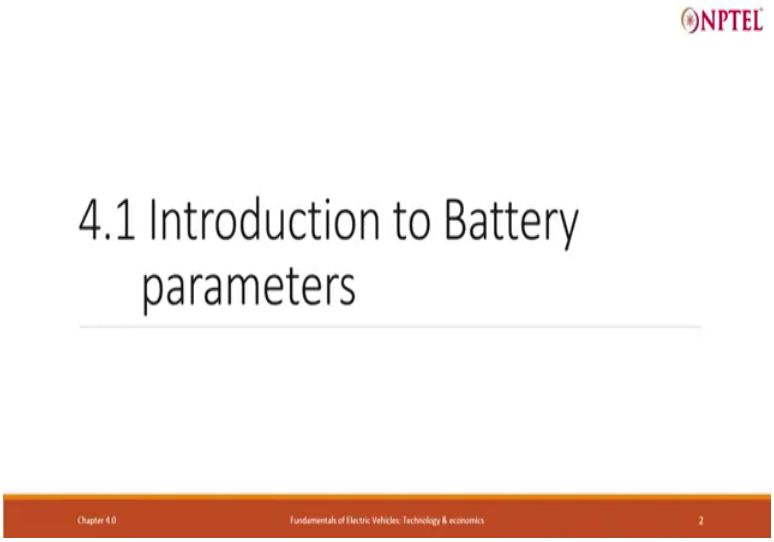

I will now start talking about battery parameters. And as it was pointed out battery consists of cells. It is a cells which are put together to make a battery. Now battery pack is much more than a cell not simply assembling of cells. But yet the characteristics of cells are going to become also characteristics of battery to a large extent. So when I talk about battery parameters it may also a cell parameter. Cell parameter which gets carried into battery and there will be additional parameters for battery.

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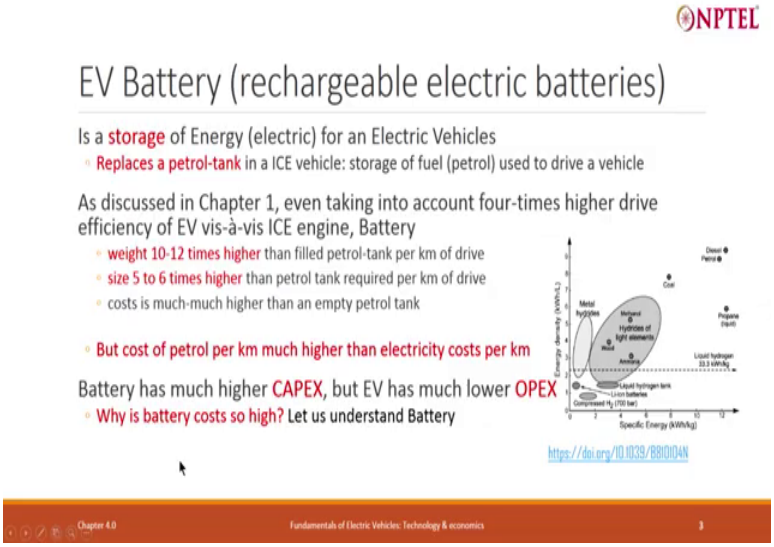

So as I pointed out what is electric vehicle? First of all is the rechargeable electric batteries. The electric batteries that we use for example in many devices I have a car key which uses a small battery. It is not a rechargeable, so I use it after it is used I throw it away, it is a onetime chargeable.

Whatever it, is not even onetime charge I do not charge it, it is factory charged, it comes as a built-in charge. There can be other batteries which are you bring it without buy it without charge and you can do onetime charge and then discharge it. It is like one cycle. Now those batteries are of very little use for electric vehicles or for a mobile phone for example or for a laptop, you want to keep on charging and discharging, charging and discharging, so they are rechargeable battery.

So that is the first important thing, there are batteries which are not reachable or one time chargeable we will discard, will not talk about it in this course. After that what is the battery? Battery is basically I have been telling you it is a storage of electrical energy for the in this case for electric vehicles. So in that sense battery is like a petrol tank, petrol tank is a storage of petrol or which is energy for ICE vehicle.

Battery is a storage of electricity which is used to drive a electric vehicles. So battery is like a storage tank. A storage tank is made, petrol tank is made from aluminium and made fairly large does not cost very much, you have to ensure that there is no leakage of course but does not cost that much. Not so with the battery, battery is a complex unit, it is a storage of electricity, costs a

lot, has a certain life, you will say even the petrol tank has a certain life, well its life is pretty much a life of car vehicle.

Battery tank does not of, you rarely hear of a battery tank something going wrong with the battery not battery tank with petrol tank. Now if there is accident it may crack or something but normally nothing happens. In fact, tank is design to withstand lot of pressure because you do not want petrol leaking, petrol is dangerous.

Electric battery on the other hand storage of electricity is very different, its costs a lot, it is the tank is useable only for certain number of cycles, certain number amount of time, after that it is to be thrown out, replaced. So in many ways it does the same function but very different. This was introduced in chapter 1 but I want to point out that again that electric vehicle by its very nature is 4 times more energy efficient than a petrol vehicle.

And even then when I compare a petrol tank, a filled petrol tank and a filled battery, battery fully charged, electricity fully charged. Weight of a battery is 10 to 12 times higher than petrol tank and its volume is 5 to 6 times higher than petrol tank. So in fact this curve thus shows very nicely if you look at energy density kilowatt hour per liter that is in volume terms.

You see the diesel and petrol are closed to 9, 9.5 kilowatt per liter. What about for lithium ion batteries? It is about 1.5 so 6 times remember, I talk to you about it and if I want to look at specific energy kilowatt hour per kg you see diesel and petrol comes to around 10-11 kilowatt hour per kg and here 0.2 probably 0.1 or 0.2 kilowatt hour per, well may be little more than that.

May be a 1, something like 1 kilowatt hour per kg, no-no it is not 1, it is what 250 watt hour per kg but because of the 4 times energy efficiency it effectively becomes 1, so it is 10 to 12 times with equivalent energy. So you have to worry about this, this is a key concern difference between a petrol tank and a battery. We have discussed this in detail on what can actually happen, we will look at it.

But another important aspect, while the tank is low cost petrol is expensive per kilometer. Battery is expensive electricity is inexpensive. So you have a very big dilemma. Battery, petrol tank therefore very little capital expenditure, comes with the car you have it or not have it, it would not make much a difference to the car cost. Battery is a high capital expenditure.

Electric vehicle once you have bought the battery is only electricity costs, operation expenditure OPEX is small, OPEX for petrol vehicle is high because petrol costs are high. But this is ofcourse in India petrol cost may be low in other states where things may be different. So why is the battery costs so high? Let us understand battery.

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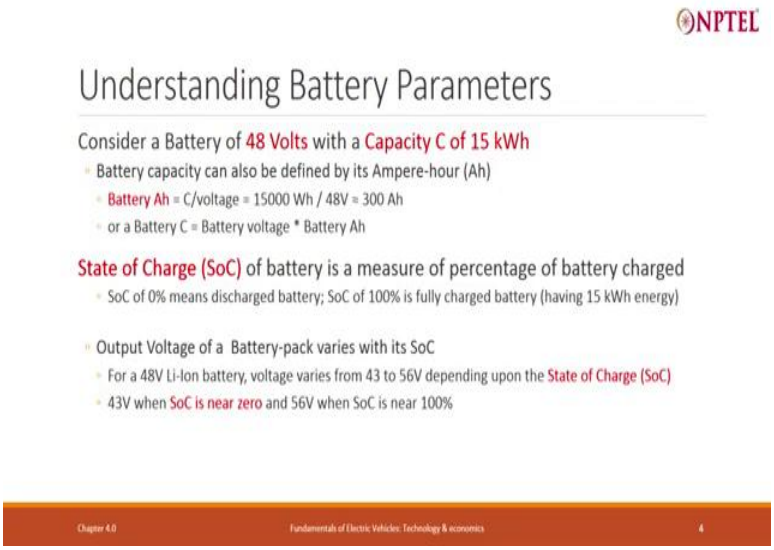

To understand let us start looking in detail of the battery. Consider a battery 48 volt battery, you can, could have chosen another number, and let us assume a capacity of 15 kilowatt hour. This is the example one could have taken any number but just to show. Battery capacity is defined in terms of ampere hour, so you take the capacity which is 15 in this case divide it by the voltage it gives you battery ampere hour.

So 15000 watt hour, 15 kilowatt hour divided by 48 it gives you approximately 300 ampere hour. So the battery is a 300 ampere hour. Remember when you buy even a pencil cell it gives you Ah or milli-ampere hour, so this is same ampere hour is the current, the voltage also has to be multiplied to get the capacity.

A battery capacity is battery voltage multiplied by battery ampere hour. So define, you must remember that battery ampere hour is not the capacity, very often you ask for a capacity and people talk about battery ampere hour but it assumes that there is a certain voltage, you have to know the voltage to really understand the capacity.

There is a very important parameter and I have defined that in the past I will redefine it, state of charge tells you how much is the battery charged. What is the percentage of battery that is charged? A zero percent basically means it is totally discharged. A 100 percent means it is fully charged. So 100 percent battery or 15 kilowatt hour basically means it is a 15 kilowatt hour energy is there. And zero percent basically means a zero energy is there.

So this SoC is very important parameter we will come to that again and again. How could voltage of a battery varies with SoC? Though we have said voltage is 48 volt, it is not 48 volt. For example, when SoC is 0 the battery voltage may go down to 43 volt. When SoC is closed to 100 battery voltage may go to 56 volt. As the battery is charged its voltage keeps on going up when is discharged voltage keeps on coming down.

43 is SoC of 0, 56 is near 100 percent this you must remember and we will come to that later on. Which basically means that motor people will say I want so much voltage, well voltage will vary, it is not going to be a constant voltage, motor has to worry about these things when it designs, motor controller has to worry about it.

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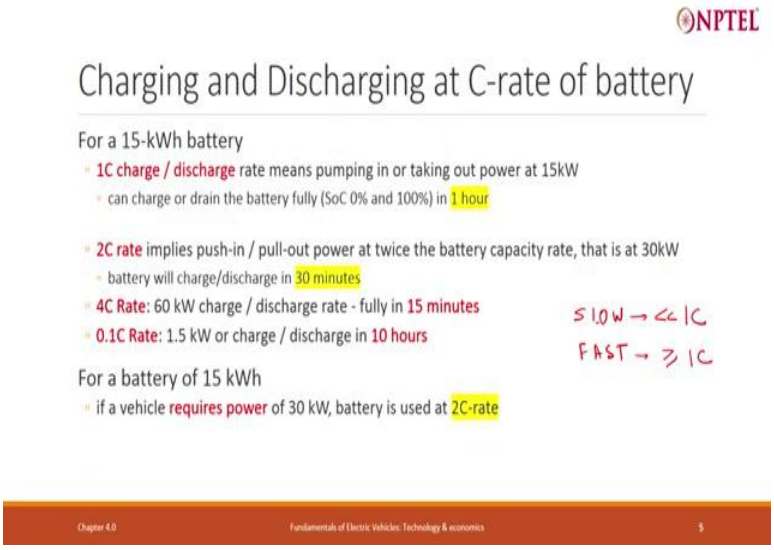

So for a, there is a parameter that I have been talking about, charging and discharging rates or charging and discharging at what is called C rate of a battery, C rate is somewhat called charging rate but it is also used for discharging rate, C rate of a battery. A 15 kilowatt hour battery you often talk about 1 C charge or 1 C discharge it is a 15 kilowatt hour, what does it mean?

It can actually have 15 kilowatt for 1 hour, it can charge within 1 hour 15 kilowatt hour kilowatt or it can (charge) discharge for 1 hour 15 kilowatts. So 1 C charge rate, a discharge rate for 15 kilowatt hour battery is 15 kilowatt. 1 C basically means in 1 hour you can charge or discharge battery that is called 1 C. One the C rate is in some sense hours. 1C basically means 1 hour.

Can discharge or charge battery from 0 percent to 100 percent in 1 hour. Now you may not use it from 0 percent to 100 percent so to that extent it will take less time that is a different matter. But if you did go to 0 percent you can go there, there is nothing prevents you, you can go to 100 percent and if you do it at 15 kilowatt it will take 1 hour and that is the reason it is called 15 kilowatt hour battery or 1 C charge and discharge is 15 kilowatt.

What about 2C rate? 2C rate means rate of charging and discharging double of 1C. 2C does not mean 2 hours, 2 C basically means half hour this is a very important, it is the double rate, it is the rate, C rate is the rate of charging and discharging, 2C means 1C is 1 hour, 2C is, 2C means it charging at half hour, it is double the rate. 2C basically means it will charge and discharge at 30 kilowatt.

So therefore it will take only 30 minutes half an hour. Do not make a mistake that 2C basically means 2 hours, it is 1 by C hours, 1 by C rate hours to C rate. Similarly, 4C will means you will charge discharge in 15 minutes, it means 60 kilowatt charge and discharging. On the other hand, if you make it not 1C but 0.1 C, 0.1 C means it will take 10 hours, 0.1 C is 1.5 kilowatt charging and discharging.

0.2 C will mean 3 kilowatt charging and discharging and it will take 5 hours, so is that understood? And so for a 15 kilowatt hour battery for vehicle requires a power of 30 kilowatt you have to discharge at 2C. It is a vehicle which decides how much power is to be done, it is not the battery. Whenever battery requires 30 kilowatt you are discharging at 2C.

If vehicles requires only 5 kilowatt you are discharging at one third C, C by 3. So the vehicle or the motor requirement will (()) (17:53) at what rate you will discharge a battery. Now generally I want to point out that there is something called slow and fast charge, this is the term that is used for charging. If it is much less than a C it is slow, 0.2 C, 0.3 C even 0.5 C you can just say, it is slow. And fast is greater or equal to 1C.

So a fast charger basically can be 1C that means in 1 hour you can charge from 0 to 100 percent or it can be 2 C which means half an hour you can charge or can be 4C you can charge in 15 minutes. So I have done the definitions so far depth of this charge, state of charge, so I have not done depth of discharge, state of charge of the battery, battery capacity, state of charge and then C rate of a battery, so far that is what I have done.

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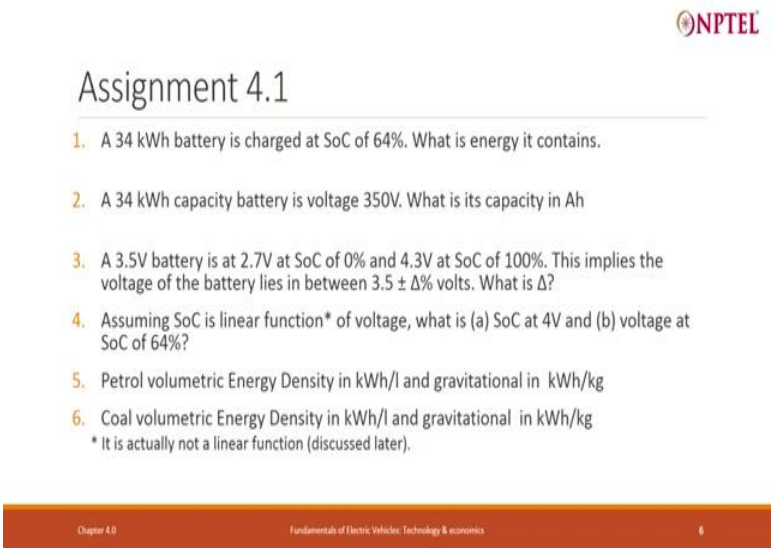

So I have given assignment just so that you can get familiar, a 34 kilowatt hour battery is charged at state of charge of 64 percent what is a, is at a SoC of 64 percent what is energy it contains? Or a 34 kilowatt hour battery is at 350 volt what is the capacity in Ah? A 3.5 volt battery is at 2.7 volt at a SoC of 0 percent and 4.3 where volt at SoC of 100 percent, so which is a 3.5 volt battery or a cell.

It varies from 0 to 100 percent. This implies the voltage of battery lies between 3.5 plus minus delta volt, 3.5 is a nominal voltage, is a plus minus delta, what is a delta? Assuming SoC is a linear function of the voltage that is assumption, in reality that is not true. What is a SoC at 4 volt and what is a SoC when it is 64 percent? When SoC of 64 percent what is the voltage?

Then I have also given you compare petrol volumetric energy density in kilowatt hour per liter and gravitational kilowatt hour per kg. Well I have given you in the diagram but take it out, coal volumetric energy density is kilowatt hour per liter and gravitational in kilowatt hour per kg.

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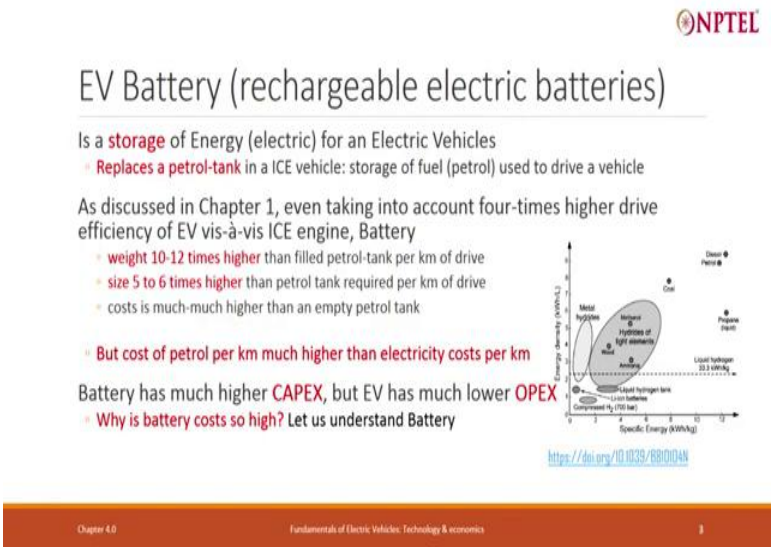

I do not the coal is there or not there I think I had given you an assignment earlier. Coal is there, so this picture gives you a very good idea.