Fundamentals of Electric Vehicles:
Technology and Economics
Professor Ashok Jhunjhunwala
Indian Institute of Technology, Madras
Lecture 4
Introduction

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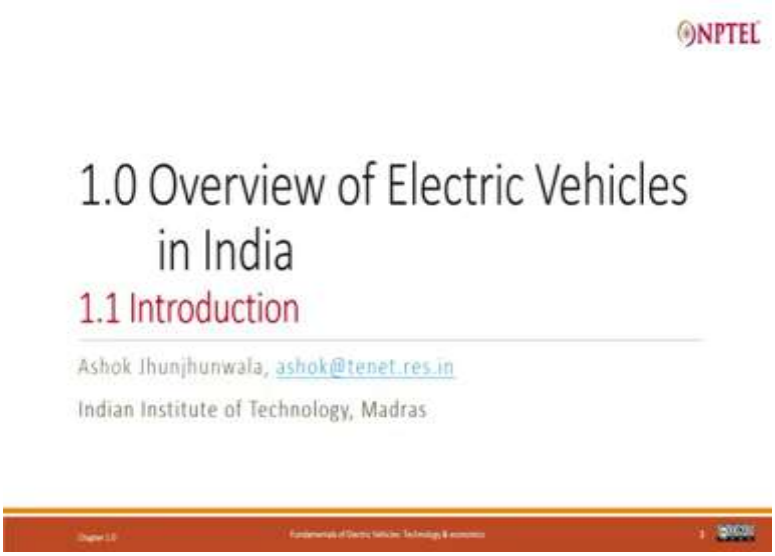

Welcome back to the class. Yesterday we had a brief introduction and we looked at why electric vehicles are starting to become big. And we started by saying that while it fights pollution, it means no oil import, makes a lot of difference for a country like India, we talked about that it also has much less number of moving parts and 4 times higher energy density.

And then we pointed out the biggest constraint is the energy density of batteries, which contains energy, vis-a-vis the petrol tank which contains petrol. And even with 4 times efficiency we are still of the ratio of between 7 to 10 times. If I take a battery, which is a container of energy, it is probably 10 times heavier for the same range as compared to a petrol tank.

And if I look at its volume, it is about 6 to 7 times higher. And we pointed that out and then sort of say the biggest gain is the battery energy density is continuously increasing. It has gone up by about 3 times or more in last 8 to 10 years. We also pointed out that as the energy density increases, the cost is coming down.

The cost was the second biggest constraint, the volume, weight and cost, but the cost is also dependent on the energy density; as the energy density improves, the cost comes down, this is

what we did. And so said that well, it is today viable and it is going to become more and more viable, that was a beginning. We then started looking at okay with that, how do you focus on the vehicles and we start saying let us look at India.

And we actually found out that and presented that India actually needs affordable and small vehicles dominated by 2-wheelers, some 3-wheelers and small cars. And we said that these are highly affordable, the cost of Indian vehicles are far-far less than the vehicles in the West.

And if we EV has to replace them they have to be a similar kind of pricing and this is a very big constraint. World over they are working on larger vehicles, they have got somewhere, their affordability is not as serious a constraint so EVs have taken off. In India, we have to make the small vehicles or 2-wheelers succeed, 3-wheelers succeed, small cars succeed.

And we started therefore sort of saying for making them successful, what do we need to do? And we figure out the big problem in that is, again, the high cost, size and weight of the battery and we also said that what can we do? And we talked about that if we improve the energy efficiency of the vehicle.

And energy efficiency of the vehicle can be improved by improving the motors and controllers, if we improve the tires, if we improve the aerodynamics and finally the weight it helps us improve the energy density. Ofcourse, all these things will add cost, but the savings that we will get in smaller battery is going to by far offset the expenses that we will incur in making the vehicle more efficient.

So, the first slogan for India will be, we will ask this question “kitna deti hai” and we will make our vehicles very-very efficient. We then said well, that is not enough and therefore we came up with the idea that why cannot we use smaller battery rather larger battery, the world over for larger range you go for larger battery and that increases the cost.

We said we reverse it and say we will put a smaller battery, but the smaller battery is smaller range and we said that will cause a serious usability issue, because charging takes time. Charging cannot be done in a few minutes like filling petrol can. And that is a time we came up with the concept of swappable battery.

If we swap battery rather than charge them whenever it runs out. We can do that in a few minutes and we came up with the concept of energy operator who will purchase battery and helps us set up charging cum swapping centres that will help us a lot and for a particularly we

said for a public vehicles we can get that started even for private vehicle, 2-wheeler and 4-wheeler, we can use that as a range extension, use a smaller battery built in plus a small battery, which is a range extension.

So we came with a totally different approach, of course we can follow the same approach that is followed in the rest of just making the battery larger, paying extra that is possible, so we talked about these three things.

Now, if you see, the key issue therefore has been batteries and for us to succeed in India with electric vehicles, we have to understand and innovate more and more on batteries. So this chapter is going to start looking at batteries. This is not a chapter sorry this is a part of the introduction.

We will introduce the battery, ofcourse in detail we will do, we will have two chapters on batteries later on. But right now let us just introduce the battery, we remember we have been repeatedly pointing out that the capital costs are high.

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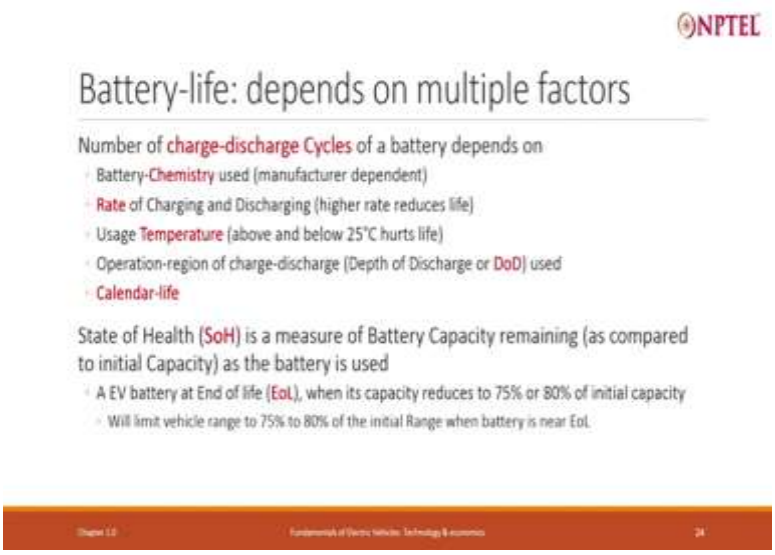

When capital costs are high, how long will the battery last? The life cycle of the battery becomes extremely critical. If the life cycles are small, we have to put that large capital cost again and again, if the life cycles are larger, I do not have to invest that on the battery again and again. So, the key parameter one of the most important parameters is, what is the number of charge-discharge cycle that a vehicle can support?

You may get some number from manufacturer saying 2000 cycles. But then the manufacturer will start putting lots of constraints because while the charge-discharge number of cycles depends on battery chemistry used, and that is done by the manufacturer, it also depends on the rate of charging, how fast are we recharging and how fast are the discharging, rate of charging and discharging plays a very important role.

We will see that if we increase the rate of charging, the battery life comes down like anything and same thing with discharging, we will get into this little more detail. The next important thing is temperature, the batteries, lithium ion batteries best behave at 25 degree centigrade. If we go below 25 degrees, if you go to 15 it is still okay, if you go to 10, 5 degrees, 0 degrees, battery does not work does not work well first, and then does not work at all.

Similarly, if we go for 35 degrees, it is okay it works. It has a little deterioration not as bad, if you go to 40, 45, 50, then it works but the life cycle deteriorates like anything. Now remember it is a large capital costs, and we are depending that it will last long now it will not last long.

And unfortunately India very often the temperature is above 35 degrees centigrade; 40, 45 is not all that common, even 50 we hit upon that, what happens to the battery is the lifecycle going to severely get impacted. And the third thing is what is called depth of discharge. We will look into that a little bit more in detail. But do we charge battery full and or do we empty battery completely?

If we empty battery completely or charge it to 100 percent, it does not work. What we will figure out is that we have to charge up to certain percentage and not above that and we have to discharge up to certain percentage that is called depth of discharge that is going to be another parameter which will impact the life cycles like anything.

And finally calendar life, if you do not do any of these things, but still keep the battery, it deteriorate small amount, but deteriorate. 4-5 years calendar life deterioration is not that bad. Beyond that it starts deteriorate, if you do 10 years, yes it is a serious problem so we will look at that. There is a very important parameter that we have to worry about is what is called state of health of a battery.

When there is a new battery, state of health is very good. As we start using it, the capacity that we have starts declining, as more and more number of cycles are used, you will see its capacity keeps on declining. And the capacity at any time is called state of health, it is a

measure of capacity that is present at any time, it started with a capacity see, but it has gone down. Why is it so important? Because if the capacity declines to let us say 80 percent, what does it mean? That we started with a battery of certain size it gave me so many kilometres of range.

Now it is giving you only 80 percent of that range, a user will not like it. It was giving me 90 percent is okay, by the time it comes to 80 percent, it was giving me 100 kilometre, now only gives me 80 kilometre, my anxiety will increase. And generally I will say well, at this point of time, I like to replace the battery that is called end of life of the battery end of life EOL of the battery in a vehicle.

Now, I may choose that no-no I can continue drive it, but maybe 75 percent will be the end of life or maybe 70 percent will be the end of life. I can choose whatever it basically means what compromise am I willing to make as a user in terms of range. But there is always a end of life, typically 80 percent, sometimes 75 percent in some situation even 70 percent.

So if battery reaches its end of life you no longer use it, you have to replace it. So the lifecycles that really matters to us is only from a new battery to the end of life. When state of health reaches that terminal point, you will say well, battery's lifecycle has been used.

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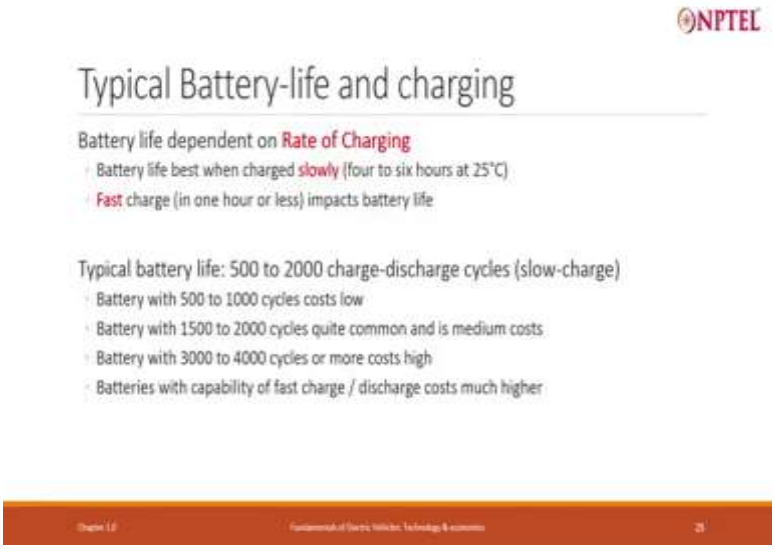

As has been pointing out, the battery life also is significantly dependent on rate of charge. A lithium ion battery is best charged slowly. If you charge in say 5 hours, 6 hours, it gives you very good life. If you charge in 4 hours, gives you decent life, 3 hours slightly worse, 2 hours

slightly worse life. If you start charging faster than 2 hours, you will see the number of cycles that it can support keeps going down.

So there is a concept of what is called slow charge and there is a fast charge. Slow charge is typically 3 to 5 hours, sometimes 2 hours. Fast charge is 1 hour or less. The fast charge impacts battery life that is the first important thing that we must remember.

So for example, typical battery life for a new cells, new battery, when it comes out of the factory could be 500 to 2000 cycles. The battery life can be anywhere from 500 to 2000 cycles. For example, those batteries which are 500 to 1000 cycles cost low. If you are looking at 1500 to 2000 cycles will cost slightly higher medium cost. If you are looking at 3000 to 4000 cycles, the cost will become very high.

So, general and then on top of it, if you do not want the life to deteriorate when it is charged fast, the cost becomes even higher. So the battery cost while we talked about the target being 100 dollars per kilowatt hour that is a cell cost that is only for something medium. If you want fast charge, then cost goes up like anything. If you want more life cycles cost goes up. So you must always understand the rate of your charging and discharging in figuring out what the lifecycles are.

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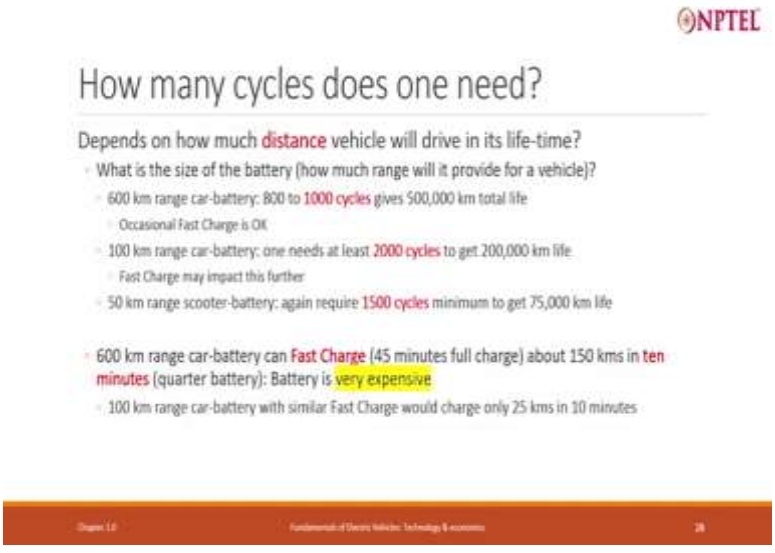

A important question that when ask is how many cycles does one need? It depends on distance that one can travel with the battery in one cycle and also depends on what is the total distance that we expect to travel in the lifetime. For example, suppose there is a battery which travels which enables you to travel 600 kilometres and you are there in a car.

And suppose the life cycle is 1000 cycles, you can travel 600000 kilometres that is not bad at all because a car is unlikely to last beyond 600000. So, a 600 kilometre range battery 1000 cycles is more than enough. On the other hand, if I have a battery in a vehicle which gives you only 100 kilometre range, if I only have 1000 cycle it will only give you 100000 kilometre, a vehicle is expected to go (long) higher than that.

So we will probably need more like 2000 cycles so it gives you 200,000 kilometres that may be acceptable, you will support it, you will replace it or maybe the vehicle itself may be worn out. Similarly, for example, if you have a scooter and suppose you have a battery of 50 kilometres and suppose there is a 1500 cycles then I should be able to use it for 75000 kilometres which for a scooter is not bad.

So what is the size of the battery and what is the number of cycles that you need will depend on your usage. Similarly, sometimes people say I have a 600 kilometre battery, for example, that is a typical size of a battery in a Tesla car. And if I fast charge it at 1 C, we will come to the definition of 1 C, it takes 45 minutes.

Now, if it takes 45 minutes to charge fully, fully is 600 kilometres, how much time will it take to charge for 150 kilometres? One fourth of that and that is only about 12 minutes or so. So, if I have the ability to do fast charge in about 45 minutes to an hour, actually I can charge only for 12 minutes to 15 minutes and still get 150 kilometre range but this is provided the battery itself is 600 kilometre range.

Sometime in advertisement etc it come or you can charge it in 15 minutes or 12 minutes. You can do so, provided I had right in the beginning the battery is large and supports 600 kilometres and therefore it is extremely expensive and you can charge for 12 minutes and 15 minutes you can get 150 kilometres.

But suppose my vehicle, I have a electric vehicle, it has 100 kilometre range. Now I can fast charge in about 45 minutes to an hour, in 12 minutes therefore I can only charge about 25 kilometres, but 25 kilometre if I sit down and spend an hour, I spend about 15 minutes and charge 25 kilometre it does not give me of much, 150 kilometres is a lot.

If I am somewhere if I am going and I have still not reached my hometown, I still need to drive I can stop for 15 minutes charge, take another 150 kilometre which may be good enough, but not for a small car with 100 kilometre range of battery. So, this is important

because very often the advertisement is misleading, it says in 12 minutes I can charge 450 kilometres. Sure, if your battery is 600 kilometre and if have you paid fortune for that.

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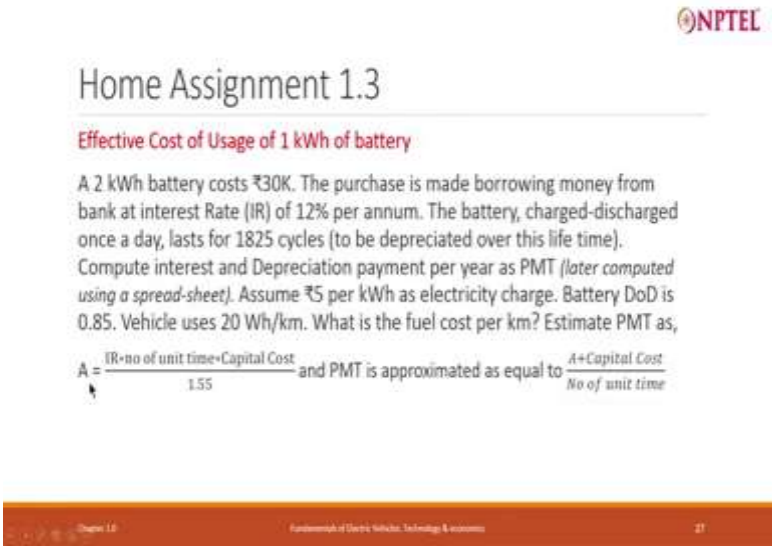

So there is an assignment problem that I want to do and this is that suppose you take a two kilowatt battery and sub-hour battery and it costs about 30000 rupees. Suppose the purchase is made borrowing money, borrowing money. So, here is my third assignment problem, home assignment 3.

What we are trying to do is remember that at a point of time we had said that we would like to figure out what is the effective cost of usage of a battery. So, this assignment problem is a first problem to watch that. Suppose, I purchase a 2 kilowatt hour battery and it costs about 30000 rupees and suppose I borrow money to purchase this and I have an interest payment of 12 percent.

Suppose battery is charged about 1800 cycles this is a lifetime over which it has to be depreciated. The question is compute interest and depreciation payment per year. We will find later on that if you do this using Excel there is a function called PMT which does this interest and depreciation payment.

What we will do is that we will estimate that, we are not going to use a spread-sheet right now. Assume that electricity cost 5 rupees per kilowatt hour. Battery depth of discharge is 0.85, so I can use only 85 percent of the battery at any time. Suppose we assume vehicle uses 20 watt hour per kilometre, something like 2-wheeler, what is the fuel cost per kilometre?

Remember, what I have to do, I am buying the battery at 30000 rupees and I am going to use it over 1825 cycles.

Let us also assume here which I have not, there is charge-discharge once a day. So, basically, I have 1825 days. How do you estimate this PMT? You estimate this is a very formula just use this, later on we will figure out what it is, that you first estimate what is called A, calculate what is A, which is interest rate, number of unit time. For example in this case 1825 days and what is the capital cost; 30000 thousand rupees divided by 1.55, you compute this A.

Why does this 1.55 comes is leave it now, later on when you do PMT, you will understand that better. And next you find out the payment that needs to be done every year is equal to the cap A this quantity that you calculated plus the capital cost divided by number of unit of time, number of units of time is 1825 days, you can convert it into years. This is a problem that I want to give you, please try to solve this you will get how much is the cost per kilowatt hour.

We have said that how much is a battery charge-discharge once a day that is important parameter thing that was missing I will add that and the vehicle uses 20 watt hour per kilometre, vehicle every day will travel a certain distance. So you can figure out the total cost of the battery for a year.

Also figure out what is the total travel for the vehicle in a year and from there you can compute what is the fuel cost per kilometre. Okay, please try to solve this problem. It will take a little effort, but you will learn a lot in this process.