Fundamentals of Electric Vehicles Technology & Economics

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Lecture No. 29

Computation of Effective cost of battery - Part 1

We have actually done a lot on battery, we have basically started with the characteristics of the battery, rechargeable battery, we looked at issues like lifecycle of a battery, charging rate of the battery and the dependence of life cycle on the charging rate of the battery, discharging rate of the battery, we have looked at parameters like depth of discharge, we have looked at parameters like state of charge, we have looked at the lifetime of the battery and the state of health of the battery indicating the life. We talked about how temperature affects the battery and of course, charge rate and depth of discharge effects the battery.

After having looked at that we had gone into what are the kind of different cells that are available? We looked at the prismatic cells, pouch cells, cylindrical cells, all of that we actually did that. We look before that into chemistry, we looked at various lithium ion chemistries starting from a LMO, LCO used in the cell phones, we started looking at LFP batteries, how is it just going away, then we looked at NMC and NCA, we looked at all these things.

Then we also looked at the new chemistry is being promised, various lithium chemistry is first we looked at and various new chemistry is pretty much in the same light, the solid state batteries and variety of batteries and what their promises are when can they be available, and all the time we looked at all the parameters, number of charge-discharge cycles, the rate of charging-discharging, the cost of the battery and all these parameters we kept in mind while looking at that.

We also looked at some other new chemistries that are being promised, there are a lot of newspaper articles here and there including things like hydrogen cell, we looked at of course, the older batteries like lead acid and all that and we looked at what is actually feasible in near term, midterm and long term. Long term lots of things are feasible, near term was about 3 to 5 years, we said very little option except lithium chemistry itself will keep on improving. If I looked at the midterm like 10 years, we will see variations of lithium, we may see solid state batteries, we may and we have looked at the pros and cons and looked at each kind of batteries that are available.

After doing all this, we started looking at how do you make a pack out of cells? So, we looked at what are the things that we need to do? We talked about the simplest thing that we have to do is nPmS or nSmP and we looked at the differences and what does it really imply and what kind of batteries are actually being made, we looked at that. Then we looked at in actually designing a battery, what do you really have to worry about, of course the voltage is one thing, the watt hour rating, current rating, and we looked at that when you are trying to make a pack you have to actually carry out very good electrical design.

I talked about pitfalls of poor electrical design, and how the battery life can go for a toss. We have not talked about the pitfalls of mechanical design, I did indicate that mechanical design becomes extremely important because even the smallest vibrations will matter and the compression of the cells makes a huge difference and that will be covered in detail by Doctor Kaushal in next set of lectures that will be done. We did not look at the thermal design, we said that is going to play a major role in the life of the battery and yet we did not look at it. So the thermal design will be another thing Dr Kaushal is going to look at that.

The fourth thing that makes an impact in making a battery pack is the BMS. And we very casually talked about what BMS will do, we have not got into the depth of it, again Dr Kaushal will get into the depth of it, that how it has to be both the hardware and the software has to be done in such a manner that it gives you the maximum value out of the cells and the pack. We also talked a little bit about the kind of failures that take place in a battery, and we talked about a single cell failure can completely hurt the battery.

So, we talked about what can be mitigated, what cannot be mitigated, I will leave Dr Kaushal to talk more about it, even the issue of whether a cell can be taken out and put back. One of the warning that I want to again point out and I want Doctor Kaushal to elaborate upon it, unless cells are balanced, if you put unbalanced cells with one kind of life cycle and you combine with cells of another kind of life cycle, it actually goes to hurt the battery rather than help the battery. So, replacement is said as to very carefully looked at.

I think after having done that, this material, I did talk about even references where these things are available. But these are still something generally available. What I am going to do today is not available most of the times, it actually takes us away from pure technology domain to somewhat of economics to be. We are talking about computation of effective cost of a battery. What does it mean by effective cost of a battery? All of us know that battery is a huge upfront cost and completely balances the equation.

Otherwise, if you leave out the battery, and batteries of course are all a container of electricity. So just like you do not buy all the petrol with the vehicle, suppose you do not buy the battery and you buy the rest of the vehicle, rest of the vehicle electrical vehicle is going to be much cheaper than IC engine vehicle. Where replacing IC engine by actually electrical drive which is motors controller somewhat difficult to design, but once you design it and make it works out to be much cheaper, much more reliable.

The problem comes is this heavy cost of battery which is a container of electricity, the in a conventional vehicle IC engine vehicle you have a container of fuel is a tank, tank does not cost that much, the cost of the container, cost of the is very large. The advantage on the other hand is in fuel, if you take conventional fuel, petrol costs are high, the cost of electricity is not that high, electricity is also renewable so, all those advantages exist. But still the battery has a certain life, battery's life is dependent on the way it is used, the rate of charging-discharging, the temperature at which it is stored, driven, charged, the depth of discharge used, so it has a certain life and after that you have to replace the battery.

So, a big concern that in a vehicle you just buy a conventional vehicle, IC engine vehicle you buy a battery, you only buy petrol, you not only have to buy the electricity, which by the way, we know the cost and things like that, we also have to maybe change the container. And since container comes out to be the major cost container for electricity comes out to be the major cost. An alternative way of looking at it is that I do not pay upfront for the container, for the battery or the electricity. But can I convert that into a variable cost?

One simple way of doing it is that let us say the battery is financed by a by a bank. So, the I pay it in instalments to the bank, and of course pay for the electricity. In which case I have converted the fixed capital cost into a variable cost. And this is exactly what I am going to sort of say, I am going to talk about computation of effective cost of battery per kilowatt hour of usage per unit usage. If I put in 1 kilowatt of electricity and take out 1 kilowatt of electricity, how much is that battery costing, how much of the initial costs the battery will contribute to 1 cycle of charge and discharge?

So, I am going to calculate cost of effective usage of battery for 1 kilowatt hour. Now, what do I need to do for that? Well, I need to know of course, what my capital cost was, and let us assume that I got that cost from the bank, bank will so say how long will the battery last? Because they will have to recover the cost through what is called depreciation. How long will the battery last? Based on that then they will compute the instalments.

They of course, have their interest charges, but depreciation interest charges is what the bank will take for the battery, but for that the life of the battery is to be known. So, the life of the battery itself is now a complex phenomenon, it depends on rate of charging-discharging, the temperature it is used, the depth of discharge it is used. So, actually the banks must understand that and then sort of say, well, fine therefore, I will give you this battery, I buy and give it to you this battery, have you pay me the monthly instalment, but monthly instalments or yearly instalment, in itself does not tell me very much.

It does not tell me each time I use the battery, suppose the battery gives me 100 kilometres, each time I drive 100 kilometres, how much is the cost of the battery? Of course, on top of it, there will be cost of electricity, electricity costs can be known, this is what we will do in this exercise.

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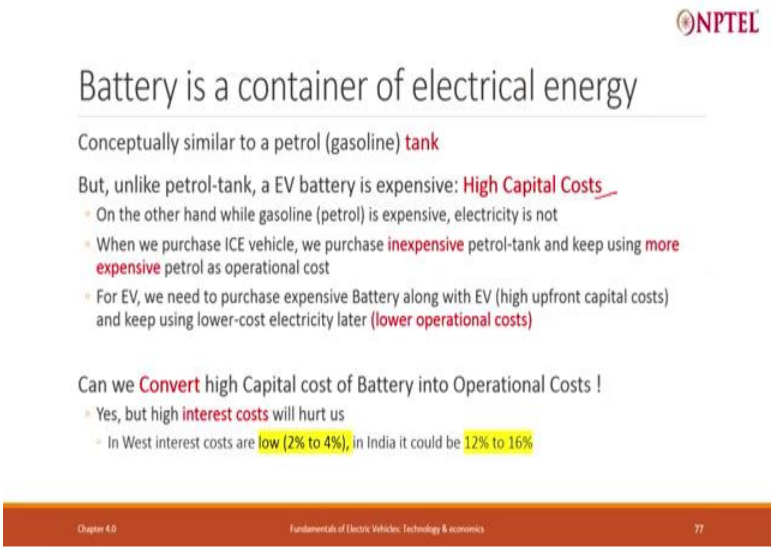

So the method is, battery is a container of electrical energy conceptually similar to petrol gas tank, but unlike petrol tank, EV battery is expensive. So, high capital cost plays a major role. On the other end, gasoline is expensive, electricity is not so we have this reverse situation, when we purchase IC vehicle, we purchase inexpensive petrol tank and then we keep on adding more expensive petrol as operational cost.

In EV, we need to purchase the container, the battery upfront and at high capital cost that takes up the cost high and then keep on the using lower cost electricity as a fuel and this is lower operational costs. So, this is what I said that we are going to try to convert, can we convert high capital cost of battery into an operational cost? Yes, the problem is high interest rates will hurt us. But that is exactly what we need to calculate. For example, if you do it in Europe, see why is this work not done in the west Europe, USA, this is not done. The reason it is not done is because the interest charges are low 2 percent to 4 percent, 2 percent mostly, 3 percent.

In India, interest charge can be 10 percent, 12 percent, 14 percent even 16 percent. And I think the gravity of what the difference shall interest between west and India, what it does to the competition is not understood well. For them well, first of all upfront cost is high, but already you can still afford it and even if you break it into instalments it is fine. For us the interest costs will make a huge difference and will show because of the interest cost make things different, we will have to calculate this in a different manner.

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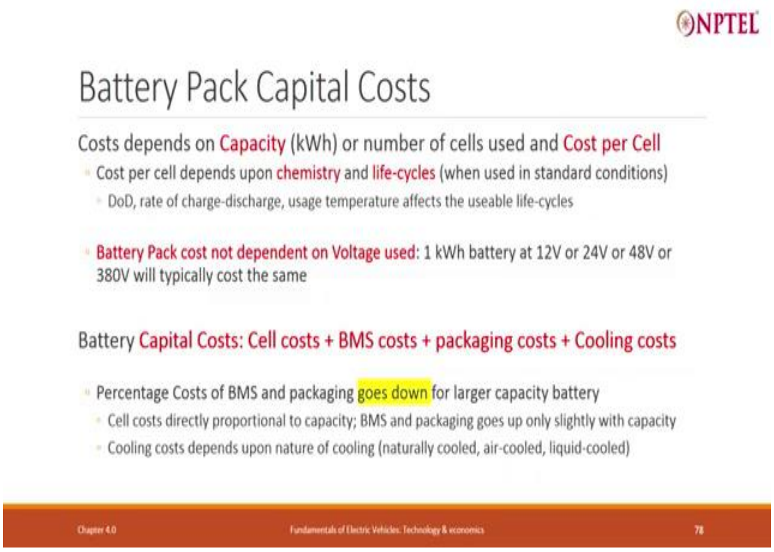

So, battery capital cost will depend on what is the size of the battery, kilowatt hour of the battery, capacity of the battery or number of cells used and the cost per cell, cost of the pack, cost per cell will depend on the chemistry, will depend on the life cycles. When used in standard conditions? Depth of discharge, rate of charge-discharge, usage temperature affects the usable life cycles, so that complicates, I do not know the real life. So, I have to just estimate based on some standard uses of charges-discharge standard temperature and standard life cycles, then I can estimate how long will it last, so that is how we can calculate.

We will do it per kilowatt hour, if it is a 10 kilowatt hour, well, it will be just 10 times the cost. Battery pack cost not dependent on voltages that is a very important thing. I want to point out because even some of the very senior people get confused. Suppose I am using 12 volt battery and not 24 volt battery or not 48 volt battery, or 380 volt battery, it is actually not important, it is a kilowatt hour, battery is sold in terms of kilowatt hour because kilowatt hour determines the amount of material that you will use, remember energy density and that is what determines the cost.

So, battery capital cost, of course is the cell cost that is the dominant cost plus BMS cost plus all the mechanical and thermal packaging cost plus the cooling cost, all this has to be included, still dominated by capital cost. For a large battery, maybe it will be some 1.25, 1.3 of the cell cost, the rest is only contributes more. For small battery, well these two things will contribute quite a bit, it can become 1.7 times even 2 times.

Percentage cost of BMS and packaging goes down for larger capacity battery, cell costs are directly proportional to capacity, BMS and packaging costs are not are not depending on the capacity, BMS and packaging cost goes up only slightly with capacity. Cooling costs depend on the nature of cooling, is it air cooled, liquid cooled that is what dominates. Yes, to some extent on the size of the battery, but not not not as much.

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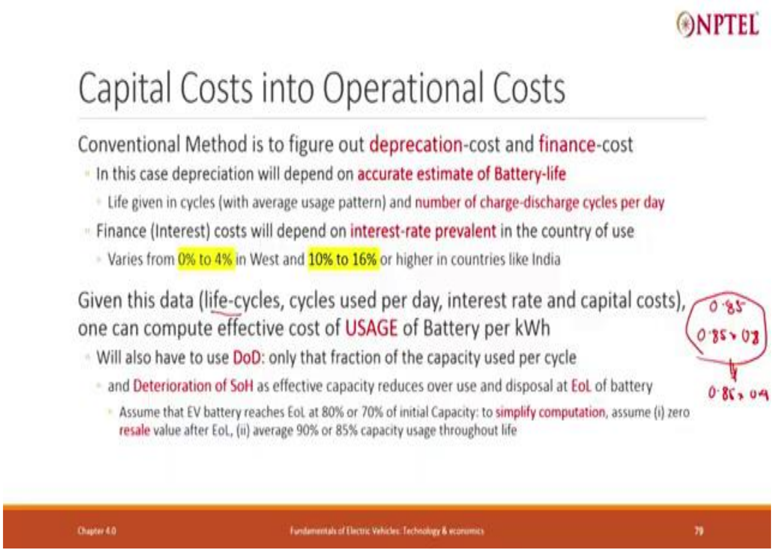

So, capital cost, how do you convert it into operational cost? Conventional method is figured out the depreciation and their finance cost. Now, what is the depreciation? Well, you have to estimate the battery life, and the battery life cycles are given, but number of charge cycles totally given. Suppose the charge, battery can last for 1000 cycles. Now, it depends on how are you going to use it. Are you going to use one cycle per day or two cycle per day? if it is 1 cycle per day, it will last 1000g days, if you use 2 cycles per day, it will last only 500 days, if you use 1.5 cycles per day, it will last somewhere close to 700 days or less.

So, it depends on how you are going to use, so another very important parameter, what is the number of cycles that you use on the average. Every day you do not have to worry about, finance cost makes a huge difference as I talked about that you will see the finance cost dominates. Given this data life-cycle, cycles used per day and of course life-cycles itself depend on temperature, the depth of discharge used, the rate of charging-discharging, let us assume that you fixed all this and you have got the life cycles, then you of course, need cycles per day, interest rate and capital cost.

So, the 4 things life-cycles, cycles per day, interest rate and capital cost, then one can compute the effective cost of usage of battery per kilowatt hour, we have 4 parameters. Now, this parameter lifecycle itself will depend on 4 parameters, remember 3 parameters; depth of discharge, of course, it will depend on the battery itself, then depth of discharge, temperature at which it is charged and discharged, and it will also depend on rate of charging-discharging. These are very important parameters and therefore the cost can get computed.

So, we will have to use a certain depth of discharge, only that fraction of the electricity can be used. If your depth of discharge is 85 percent you can only use 85 percent of the battery at a time, it is not that alone, state of health matters. When the battery is new, state of health is 1 and if you are using depth of discharge of 85 percent so suppose it was 1 kilowatt hour of battery, it was new so it is 1 kilowatt hour, depth of discharge is 85 percent so we are using 0.85 kilowatt hour. As the battery becomes old and suppose nearly enough life, let us say it is at 80 percent, it is 85 percent or 80 percent. So, you have to take that into account in the calculation.

Normally, when the interest and depreciation is taken and bank calculates the rate, it assumes that anything will remain the same, here it is not remaining the same, it is actually capacity is going down. So, it is not per kilowatt hour, it is 1 kilowatt hour is only notional, actually it starts at 0.85, and goes down to 0.85 into 0.8 or 0.7, which is almost close to 0.6 kilowatt hour so you have to take all these things. We will assume two things for computing, and one can do more detailed calculation only just making it easier.

Saying that, let us say end of life is 80 percent, or 70 percent, we will choose either of them. And let us take that and multiply it by the depth of discharge which is 90 percent 95 percent, and take the average of that, average of new and nearly at end of life and use that as per cycle. So, do you understand what I am saying? What I am saying, suppose when battery is new, let us say we are using 0.85, when battery is merely end of life, I am using 0.85 into, let us say 0.8. So, what is the average cycle will consume? Average cycle will consume 0.85 into 0.9, average between 1 and 0.8 that will simplify calculation. If you want to do more detailed calculation, you can do it, it gets more complicated.

Similarly, the question is that once the battery gets to end of life, is there any value of it? Is there a resale value? Probably there is because still 80 percent of the capacity still exists. For the first calculation, we will ignore that, we will assume it is 0. It is actually much less than the initial. If you ask me what will it be? Maybe 20 percent. But the market has not yet developed and it is something that we will still see in future. So currently, let us take it 0 that is a worst case, in reality we will do better than that.

So, that is another (asum) these two things that we will do, this is to simplify calculation, you can of course, if you know their end of life value, you can put that in and if you know your, if you want to do more detail then on day 1 it is 100 percent SoH, on day 24 it has gone to 99 percent as such, you can do that it will make things more complicated. First of all you need to know SoH exactly as a percentage of cycle which exists but the things will become computed, so this will simplify the calculation.