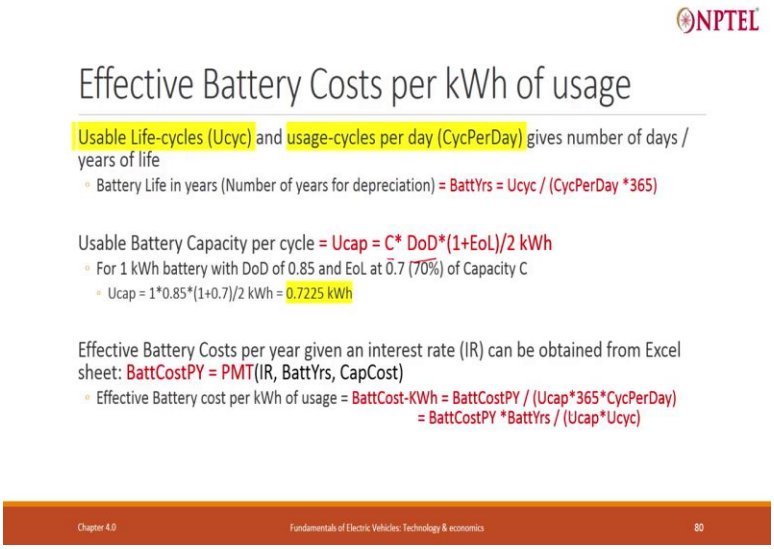
Fundamentals of Electric Vehicles Technology & Economics
Professor. Ashok Jhunjhunwala
Indian Institute of Technology, Madras
Lecture No. 30
Computation of Effective cost of battery - Part 2

(Refer Slide Time: 0:17)



There are many parameters that I am going to define. So, first parameter that I am defining is usable life cycles, usable life cycles total usable life cycles I call it Ucyc usable life. This is a parameter that will come from manufacturer usable lifecycle. And then I will use another parameter called cycle per day usable cycles per day. So, what is the effective number of days usable life cycles mile divided by cycles per day.

And if I want to calculate in terms of number of years including the fraction that battery in years, it will be usable cycle divided by cycle per day multiplied by 365. I am assuming that all 365 days I am doing the same thing. Is that all right? This is the effective life of the battery in years. It may come out to be 4.73 years. So, it is so many years so many days you can actually calculate that. This is important but this is what the depreciation the term depreciation means I start with a new full cost at the end of life it is say 0 cost.

And depreciation means if it is going to last for 4.7 years over 4.7 years I will keep on losing linearly its life. Now there are nonlinear depreciation but we will leave that will make it a linear depreciation. So, loser so its value becomes 0 starts with a value of let us say 20000 rupees end

of life it is 0 and 4.73 years, so you can see how it is going to impact. Usable battery cycles per day now this is important parameter, the usual battery capacity per day usable battery capacity per day per cycle per cycle.

Now this is if the battery is new of course is a C, C is the capacity, depth of discharge because I am not going to use the rest of the battery. I am only going to use CoC. So, C into DoD is what I am going to actually use per day. But that is what I will use when it is a new. When it is a old I will actually use C into DoD into what is EOL. So, actually I take c into DoD multiplied by 0 plus EOL by 2, this is the average. This is the average usable battery capacity per cycle.

Now this is a simplification that I do which helps as me. For 1 kilowatt hour battery whose depth of discharge suppose I use 0.85 and end of life if I use 0.7, 70 percent of capacity. The usable battery capacity per cycle is works out to be 07225 kilowatt hour. So, though I am buying one kilowatt hue or a battery I am actually using only 0.7225 kilowatt hour on the average. When it is new I am using 0.85. When it is old I am using 0.85 multiplied by 0.7. So, on the average I am using 0.7225 kilowatt hour.

So, I have to actually calculate the cost that I will calculate per day for the battery will be this not for 1 kilowatt hour. So, I have to for 1 kilowatt hour it will be more. So, a effective battery cost per year given an interest rate can be obtained. Now it is like a mortgage, I have taken loan against some entity and I know its life depreciation. I will do linear depreciation and I know the interest rate the bank charges and I want to compute what is the effective money that I have to give for mortgage payment.

I can do it every year I can do every month theoretically I can do it every day. And there is a very simple formula in excel called PMT the payment against mortgage. So, if you open the excel sheet and use PMT you have to give three parameters the interest rate which I just saw said it could be 12 percent, 16 percent whatever. Battery years which will come from whatever we have just calculated battery years we can calculate battery days instead of battery years. Battery days will 365 will not be there.

Then it will give you the battery cost per day instead of per year and the capital cost the capital cost. This will be the battery cost per year I can also calculate battery cost per month, battery cost per day. So, that will give me battery cost per year. Now battery cost per year so I know but

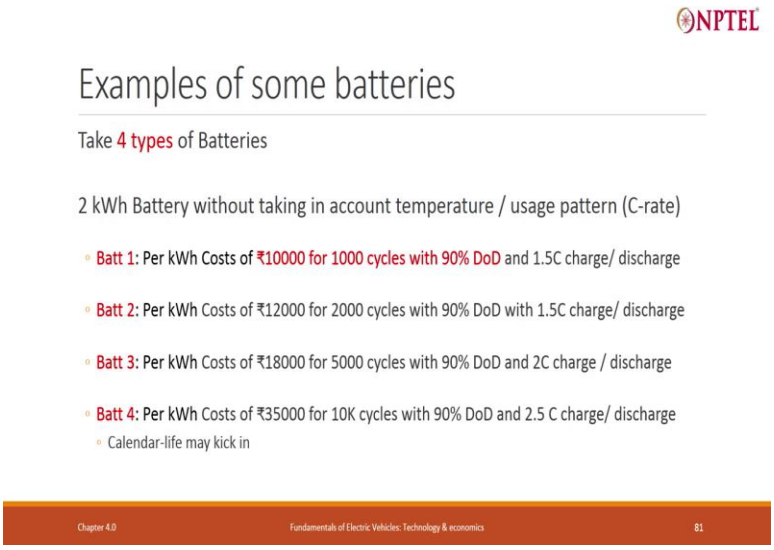
effective battery cost per kilowatt hour because battery cost per year is this but how much do I use per year?

I use 365 into 365 into Ucap. The the usable cycles per day is U-cycle Ucap is the battery capacity average battery capacity multiplied by 365 will be the actual number of number of the total capacity that I use in a year. Now, so the battery cost per year I have already found out but depends on how many times I charge this charge. If I charge this charge once a day, it is simply battery cost per year divided by Ucap into 365. But what if I use two times a day?

Well, then it will come to battery cost per year divided by Ucap into 365 multiplied by 2 divided by 2 also which is same as battery you can simplify battery cost per year, per year battery cost per year that is a comes from here into battery years because I have simplified this divided by ucap into ucyc. This is actually simplification. This is the actual cost per kilowatt hour. I have taken into account the capital cost the interest cost its usable cycles converted into usable years or usable month. I have taken into account number of cycles it has used per day. I have taken into account the end of life. I have taken into account depth of discharge.

So, this formula battery per cost per kilowatt hour you can just go to the excel do this and then just do this. This is basically a very simple if you know all the parameters. It is a very simple calculation on a excel sheet.

(Refer Slide Time: 8:24)



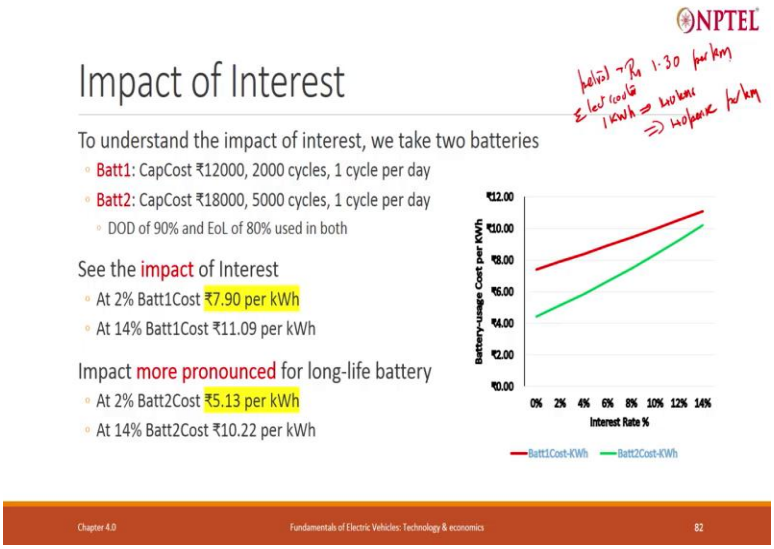
And I should have embedded the excel sheet and I did not I will do that embed the excel sheet. Now what I will do actually I will try to compute and see what it impacts. So, I take 4 kilowatt hour batteries, I will take 2 kilowatt hour and let us assume the usage pattern and temperature is all fixed C rate is all fixed. The battery 1, I will take 4 different kinds of battery cost 10000 rupees per kilowatt hour, very low cost battery, 1000 cycles, 90 percent depth of discharge, 1.5 C charge discharge. 1.5 cycle this is charge discharge (cyc) 1.5 C, I think 1.5 cycles I think this is 1.5 cycles of charge discharge a day as far as I remember.

I think I will double check this I need to double check this because this is not right I think it is not 1.5 C, it is not C rate, 1.5 cycles per day. I think that is what it is as far as I remember I should not have written it is not I think it is their battery 1 is given as that if you charge discharge at 1.5 five C rate and 90 percent DoD you will get a 1000 cycle. So, what I have written is right. So, these are 4 cells available battery available one is a 10000 another is 12000, 18000 and 35000. This can last for 1000 cycles. This is 22000 cycle, 5000 cycles and 1000 cycles.

And I have taken 10(thou) 90 percent DoD and charge discharge 1.5 C, 1.5 C, 2 C and 2.5 C actually the numbers here are slightly underestimate, the actual cost will be higher. This may even for a large battery the actual cost may be higher but I have I have taken this example it does not matter we will show what actually it means. If I take this and remember that if I am only going to to have 10000 cycles. 10000 cycles means battery can last for 10 years, 15 years, 20 years depending on number of cycles that I use per day.

So, then calendar life also going may kick in, not just the deterioration due to charge-discharge cycle. And I have not taken calendar life in my computation. So, I have to add that at some point of time but one can add that. So, far we have ignored calendar life.

(Refer Slide Time: 11:38)



Now, so we take two batteries out of these 4. The first battery is 12000 rupees, 2000 cycle, 1 cycle per day, another is 18000 rupees, 5000 cycle, 1 cycle per day. Here I am taking 1 cycle per day let us assume DoD of 90 percent and end of life is 80 percent. This is a little estimated to be little low cost and actual costs are going to be higher. But with this aggressive cost look at this. This is what I wanted to show you effective cost for this battery 1 is in red color. It starts around 7 rupee 50 paise at close to 0 percent interest.

But look at as the interest rate goes up 14 percent, the 750 becomes close to 11 rupees. See how badly this interest rate impacts things. This is for battery 1. For battery 2 which is a more expensive battery but it has a large life of 5000 cycles. Look at this, this gets even worse. It is a very good battery only cost about 5 rupee. This has not taken electricity cost plus electricity cost. So, only 5 rupees less than 5 rupee 4 rupee 50 paise. If there was no interest because the interest it can become almost 10 rupees.

This I wanted to point that out. The biggest determinant is interest rate. Of course life cycles will matter, number of cycles per day will matter. As those changes will see things impact the initial capital cost does matter but it is the interest rate that dominates the cost and this is Europe, United States cost, this is India cost. And the numbers are not small difference from 4 rupees to 10 rupees, 2 and half times.

So, when you optimize what do I have to do? Well my interest rate is higher I have to I have to somehow figure out a sweet spot. Where do I operate? Do I keep 2000 cycle? Do I keep 5000 cycles? Do I use 1 cycle per day? How do I add cost? What do I have to do? This is the most important issue. It is the interest rate that matters. So, this is the same thing that I am showing you. Impact cost for battery one 790 to 1109. Now actually this is not something limited to battery. In many things that India uses this is something that hurts us (())(15:03) Europe.

On the one hand the affordability in India is lower, on the other hand high interest rate means we have to pay really through our nose and its huge difference 790 to 1109 and for the second battery is worse. It is 513 to at 2 percent is 513 for fourteen percent it is 10.22 double. The cost per kilowatt hour per kilowatt hour. So, if you can get lower interest rate makes a huge difference but at every interest rate you have to optimize what is the best thing that I can do? It is not a universal truth that we often.

Now this is something that nobody else will teach you. Now one says well I would not go to the bank well wherever you go you put the money costs the interest rate is a reflection of what does the money cost? Even if you borrow from someone else. If you have your own fine, but you could have earned interest so that will be denied so the effective usage cost you may say I do not know the effective my effective interest rate I will take it is only nine percent that is fine but whatever the interest rate you assume you need to compute the effective cost of usage of a battery. This plus electricity cost.

So, 10 rupee 22 paise in India plus 5 rupees electricity. Suddenly it is a 15 rupees of usage cost per kilowatt hour. So, if 1 kilowatt hour is going to give me whatever depending on the vehicle 30 kilometers. Suppose I have a two wheeler let us say it gives me 40 kilometers. So, my 40 kilometer may cost me 50 rupees, 15 rupees. So, I need to compute that. You will find still it is lower than petrol vehicles because the cost of petrol would be much, much higher.

Let us do a simple calculation some numbers for a two wheeler. Let us take a smaller size two wheeler. What is the mileage that you get? 50 kilometer per hour per liter and the petrol let us say it costs about 75 rupees, 80 rupees. So, it is approximately 130 per kilometer for petrol. Now according to this at 14 percent interest rate, it is a 10 plus 5; 15 rupees suppose my is the cost per kilowatt hour.

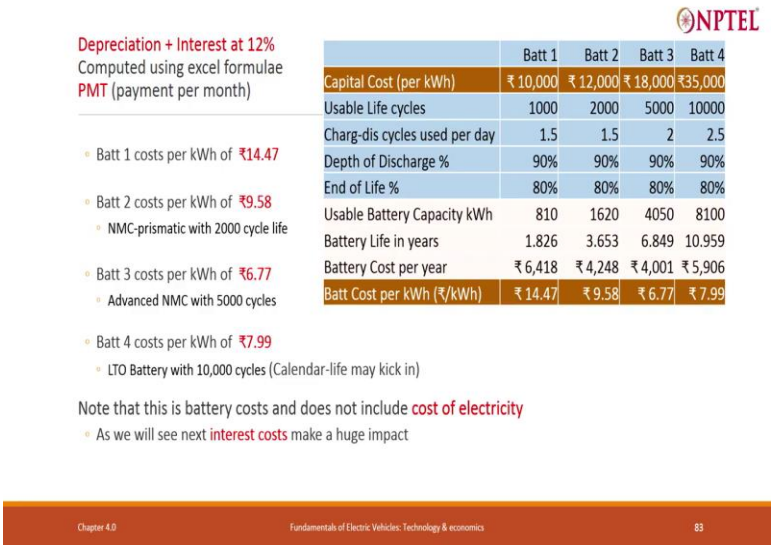
And 1 kilowatt hour suppose gives me 20, 1 kilowatt hour may give me 40 kilometers. So, for EV for electric scooter, 1 kilowatt hour may give me 40 kilometers. So, 40 kilometers will cost me 16 rupees so it is only about 40 paise per kilometer. So, see this calculation. This is assuming 14 percent interest rate and assuming that you are not buying battery.

Now as I told you that the battery cost that I had assumed 12000 rupees and 18000 rupees is a little bit optimistic and normally for 5000 cycles you are not likely to keep it. So, it may not be 40 paise it maybe 60 paise. This includes the cost of your battery. So, tor if you ever talk about total cost of battery it is 60 paise versus 1 rupee 30, it is half as expensive.

But here you have to give either a front cost of the battery or you have to convert into lease and things like that. The problem is banks would not give you easily the money for the battery because they do not understand fully the usage or life cycle of the battery. That is a critical issue but this is what I was talking about the most important thing and this needs to be really understood long term its cost is lower.

Electricity we can generate in India, petrol we have to import this is a far, far superior solution. This is even assuming 14 percent. If you are in Europe and there are only 2 percent and maybe the cost would have been only 7, 8 rupees you would have been you would have got huge, huge advantage. Of course there the petrol cost also may be lower but anyway that in Europe it is not, US it is. So, do you understand and the reason I try to calculate.

(Refer Slide Time: 20:34)



Let me take another one and this is what I took for all the 4 batteries and as I told you that I have underestimated the cost of the, these actually costs this is a little underestimate for all of them. Let us take depreciation, let us take 12 percent interest not 14 percent. And I have computed excel sheet I have taken a battery 1, 1.5 cycles per day. Battery 2, 1.5 cycles, battery 3, 2 cycles, battery 4, 2.4 cycles. In fact, you will see if I change this number of cycles per day your cost changes quite a bit.

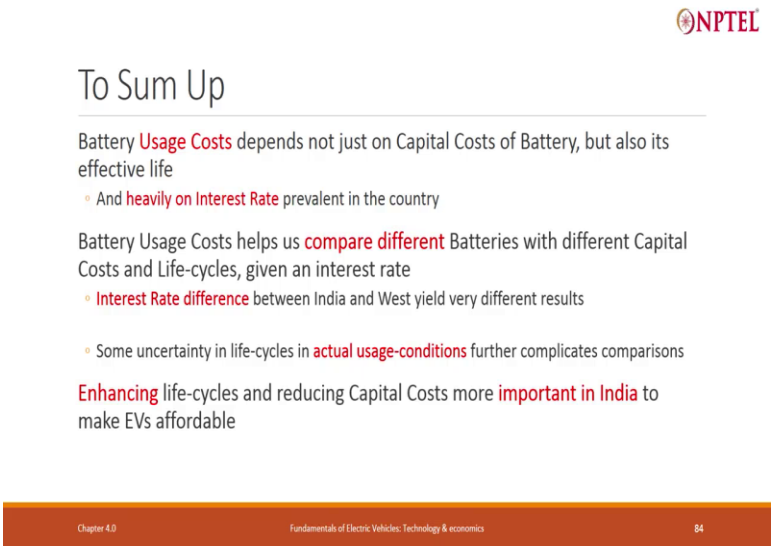
And I have taken 90 percent depth of discharge and 80 percent which may not be so easily doable. You may actually do a 80 depth of discharge and through this excel sheet then I have calculated effective cost of battery 1 comes to 15 rupees which is similar to what you got here. At 14 at 12 percent interest you got 11 rupees but I think that is because I have taken here I have taken 1.5 cycles. So, battery 2 on the other hand comes to around 10 rupees this is also 1.5 cycles. Battery 3, two cycles 677. Battery 4, 2.5 cycles.

So, depending on my usage pattern am I going to charge discharge once a day, twice a day, 3 times a day. Normally a person may charge discharge only once in 2 days. Then I have to take that make that as a 0.5, but the simple excel sheet which has actually calculated each of these parameters. I am going to give you a homework problem to build this spreadsheet. All the equations are here. There is nothing this is this is all that you need to do. This is the parameters that I am using there.

These are the 5, 6 parameters that I am using battery cost per year, battery life per years, usable battery capacity, end of life, depth of discharge. You put this in and you get it. So, battery 1 cost at 12 percent 1447, battery 2 cost 10 rupees, battery 3 cost 677, battery 4 cost 8 rupees. So, you will see this 5000 cycles really makes a huge difference. This is because if I am using 2 cycles per day. If I do not use 2 cycles per day, this will not and 2 cycles may not be so easy, two times you charge discharge may not be. Only a personal vehicle no you know in a taxi yes. So, that is what we will come to.

Note that battery cost does not includes the cost of electricity and we will see next interest cost makes a huge difference.

(Refer Slide Time: 23:25)



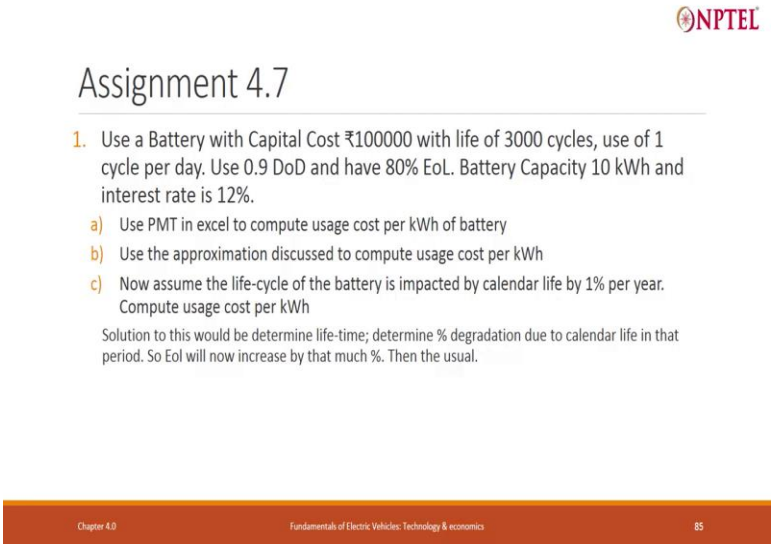
So, we have already seen that in the earlier slide. Battery usage cost depend not just on capital cost of the battery but also its effective lifetime which and heavily on interest rate prevalent in the country. Battery usage helps us cost compare multiple batteries with different capital cost, life cycles and interest rate. You must keep interest rate you will certainly find that a two percent interest rate one battery is better at 12 percent, another battery is better.

Number of cycles of usage per day also has to be taken into account. Interest rates diff between India and West vary different results. There is some uncertainty in life cycles. Actually you see because actual life will depend on certain actual usual tradition. You can do a factor saying that

well 5000 was what it was supposed to give me or 2000 was supposed to give me effectively I will get about 80 percent of that.

You can only estimate because you do not know what the temperatures will be and this is something that has to be learn. This is what the banks or those who lease battery really want to give it to you. Enhancing live life cycles and reducing capital costs more important in India to make EV affordable. Ideally I should change more realistic cost this is a little underestimated cost. But gives you the trend of what has to be done.

(Refer Slide Time: 25:08)



So, here is a assignment I have taken a battery which cost 100000 rupees and suppose you use 3000 cycle and only use 1 cycle per day, use 0.9 depth of discharge and 80 percent end of life. Let us assume battery capacity is 10 kilowatt hour 10 kilowatt hour is 100000 which is again little bit low and let us assume interest rate is 12 percent.

Use the PMT in excel to compute usage cost per k battery so just do exactly that what that table is. Write down the formula and then compute that use the approximation discussed. There was an approximation discussed earlier in chapter 1 on what the PMT will be. PMT I should have brought that here that PMT can be approximated. PMT will require to do use excel sheet. What if you do not have a computer and you do not have an excel sheet?

You can still estimate PMT and in the introduction chapter I had given you an estimating of PMT. So, I am saying use the approximation discussed to compute usage cost per kilowatt hour. Now assume the life cycle the battery is impacted by calendar life by 1 percent per year. So, now you redo that formula. Assume that 1 percent per year also you are getting impacted. Redo the exercise this will require work.

Solution to this would be to determine lifetime, determine percentage degradation due to life calendar life in the same period. So, UI will now increase by that much percentage. So, suppose you sort of say that calendar degradation you compute the approximation number of years so this is approximate number of years for depreciation is 5 years and so calendar life will actually take it down by 5 percent.

Now the end of life you are taken to let us say 80 percent. Now you will take it to 85 percent and redo the calculation. So, that is what the last point will like you to do. Any question? So, I should have brought that from chapter 1 that approximation out here. Well it is there in your notes. Please look at it. I could have given you a slightly more realistic picture. This 10000 rupee is very aggressive. You would not be able to do that but that is a target that I give it to Kaushal.

Cells have come down for 1000 cycles has come down to 100 dollars per kilowatt hour, 102 dollars but that still by the time it lands up in India it will be 8000 rupees. So, very difficult to make a battery and sell at 10000. It will be more like I think 12 13000 could be the aim. So, it was a little underestimated but it does not matter.