Fundamentals of Electric Vehicles: Technology and Economics
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Lecture 18
EV Subsystem: Design of EV Drive Train - Part 2

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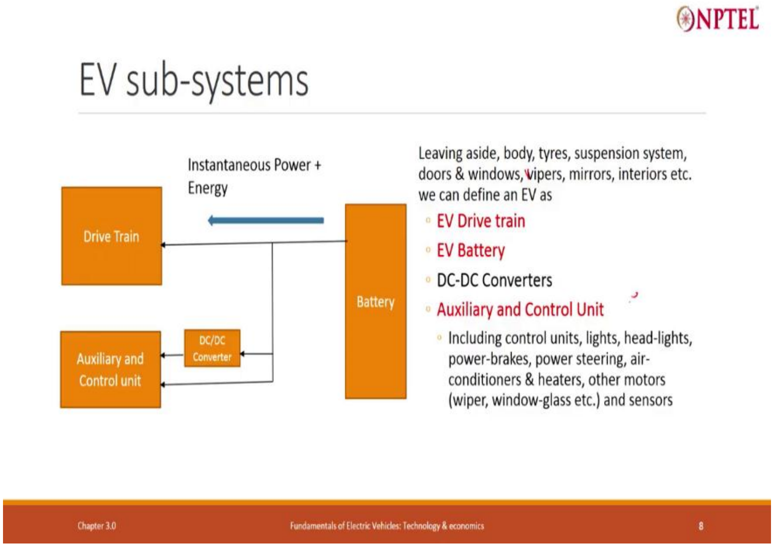

Welcome again, if you recall in the last class, we had defined all the EV subsystems and we have said the primary part that we really need to work worry about is one is this drive train and another is the battery. Of course, there is a DC-DC converter and auxiliary in control units. And I had defined each one of this having defined that and said that the most important thing is the drivetrain and the battery and we are going to get into details of the drivetrain and a battery.

DC-DC converters are important simply because we may actually be working at 350 volts. And finally, we may require lights at 12 volts. So, it is may be required but something more standard and various axillary and control unit are there we have talked about it. We will talk a little bit more about it control unit slides headlines power brakes, power steering, air conditioners and heaters. But we are not going to get into details of this.

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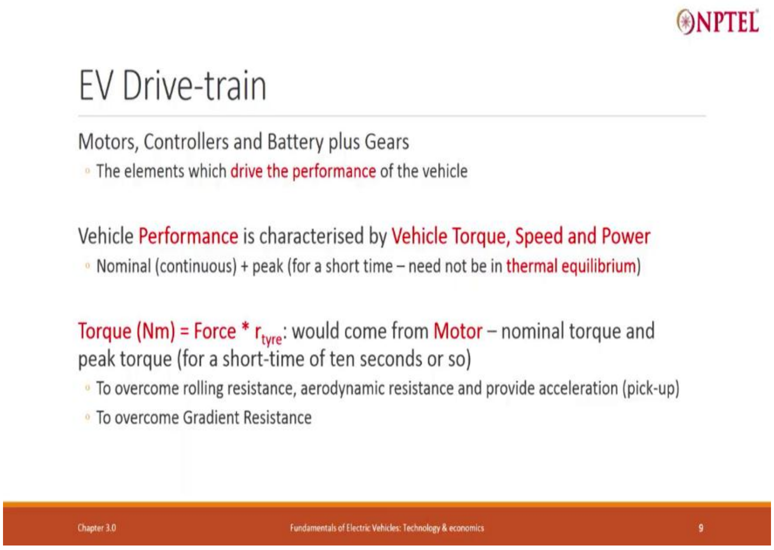

So, the most important thing is motors and controllers and battery. The very important component that we pointed out was the gears because while the motor can give you the speed and a torque, the speed and the torque that the vehicle may want is different from the speed and the torque that motor can give and we basically pointed out that you can multiply the torque of the motor, you can multiply it for the vehicles by through gears by a certain amount through the gears, and which is torque that is required for climbing up and for acceleration.

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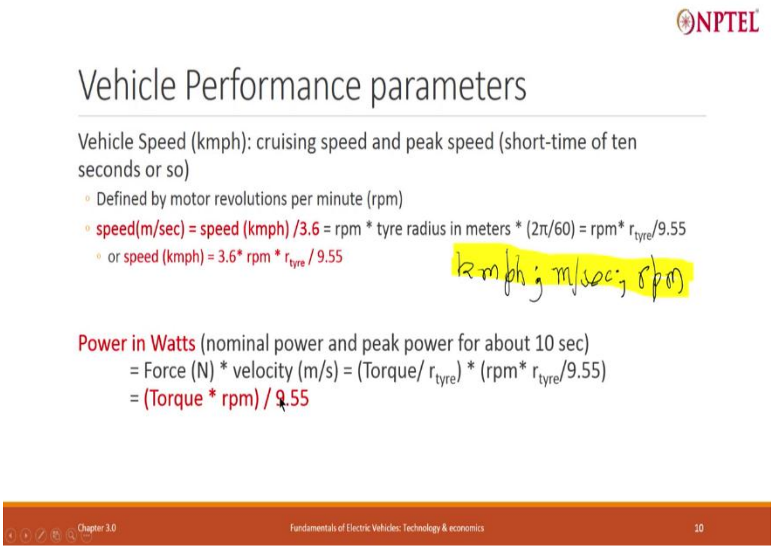

Whenever you multiply the torque by a ratio to the same extent the speed will come down by the same extent. So, we covered this we did this in the last class. I am just pointing out that we that both torque and speed we can play with by using a gear. I also talked about that while multi-staged gears are used in IC engine. The trend is to try to use a single stage here in electric vehicles. We also did various conversion speed for example, as a user will talk about kilometer per hour, the speed that motor people are used to is RPM and then there is a meter per second that will come and we have done all these conversion and everything and we had even talked about the power is torque into RPM divided by the 9.55, that is the important ratio that we will talk about.

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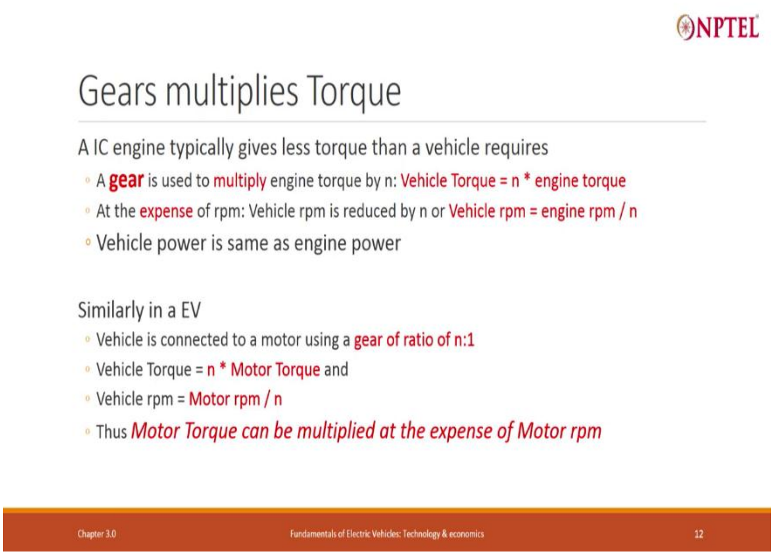

So, this is what where we did the gears, the gears multiply the torque and at the expense of the RPM, this is what we talked about.

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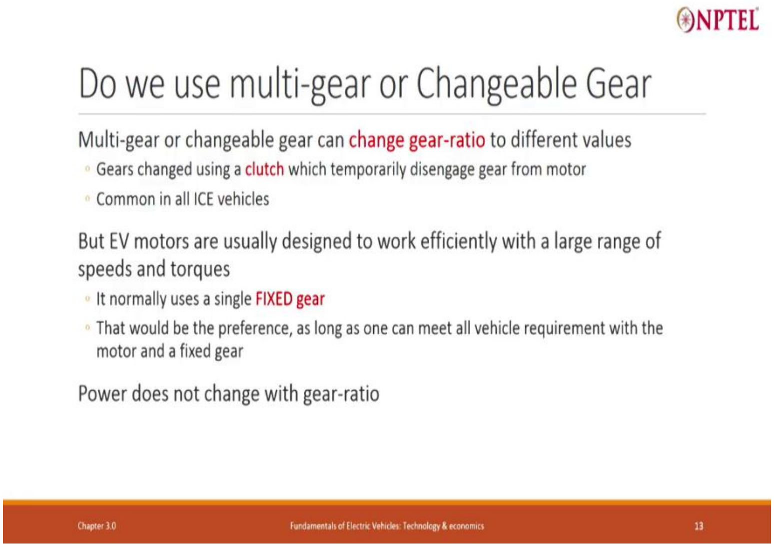

And we saw shift while multistage gear can be used EV train to use fixed gear.

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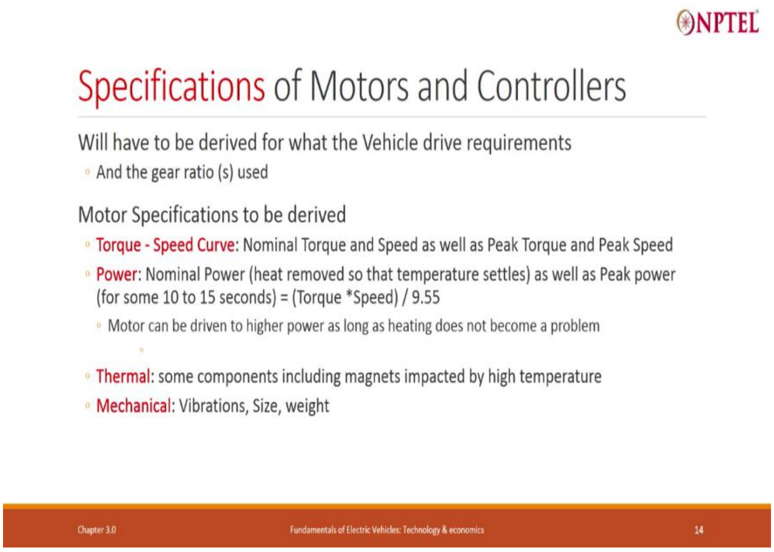

What we will start today? That from the vehicle drive requirement we come with the motor specification, we of course have to choose a gear. But once a gear has been chosen gear ratios and gear then from the motor requirement. We straight away come to the, from the vehicle requirement we come straight away to the motor specification.

And torques speed curve, torque and speed, different speed what is a torque? Becomes a important parameter for the motor, motor has to deliver a specific torque at a certain speed. There is a one more term that will keep on coming up sometime we talk about nominal torque or nominal speed and then we talk about peak torque speed. As I discussed that in the class this nominal and peak, we also taught say the same thing about power a motor has 5 kilowatt nominal but peak can go to 8 Kilowatt.

Now, what does this nominal and peak actually imply, the key thing is that the motor is designed to actually give everything peak. It should give you peak torque, it should give you peak speed. It should give you that peak power. If it is not designed for this peak. You will you will never get it. So, it is always designed. But at when any of these things are at peak particularly the power is at the peak, the heat dissipation may be much, much larger than when it is at nominal.

So, the difference between nominal values and the peak values is the heat dissipation, generally the motor is not designed to do heat dissipation at peak values. Motor and controller is designed to dissipate it at nominal values, what does it mean, that if you use the motor any of the whether the torque use at peak or you use power at peak for few seconds 10, 15, 20 seconds the temperature will shoot up. But since we will stop using peak values that temperature will start eventually falling down.

What do you have to do if you have to continuously use peak value any of these peak value. Well you have to do make sure that the heat dissipation is sufficient such that the temperature does not go about a certain value. Why because every component that we used in the motor controller will have a specification for peak temperature, beyond which the likelihood of that component failing is high.

For example, if you are talking about controller, which is electronics, you may design it to have a peak value of 75 degrees centigrade or 90 degrees centigrade. But if it is exceeded, then the component can fail. Similarly, in the motor particularly they are permanent magnets. They are designed to handle a certain maximum temperature if you go above that temperature, it tends to demagnetize.

So, essentially you cannot let the motor or controller temperature exceed a certain threshold, at nominal power nominal torque you actually operate at lower thermal dissipation and that time therefore we will ())(08:14) at let us says 55 degrees or 60 degree Centigrade everything settles down temperature of motor control is not going above 60 degrees.

That is fine, peak will take it higher, but before peak impacts you. The people go and it will tend to dissipate heat and you bring you back to the nominal temperature. That is the only difference between peak and nominal.

Student: (()) (08:45)

Professor: The question that is asked is the efficiency is same at peak and nominal? Of course it is different at peak the efficiency is not good. And you are not bothered why because peak is for 10, 15 seconds. Whenever you worry about efficiency you have to worry about, that in the normal drive condition how well it will work, that is where the efficiency is becomes important.

So, the thermal become very important component of both motor and controller not just motor but even the controller, heat dissipation becomes very important. For battery you will similarly see it is a heat dissipation that makes a huge difference. So, in fact a very important component of any of these design is to really understand thermal.

What we are planning to do that when we do battery in detail we are going to look at thermal, how do you do heat dissipation. Some extent we will touch upon it during motor design also, but remember that this is not a course on heat dissipation. So, you will only get a top-level idea, but tomorrow if you want to work in any of this vehicle design and you want to work in thermal aspects a person who is an expert at thermal makes a huge difference.

And that is the reason in this course we have brought in Doctor Kaushal Jha, Doctor Khausal Jha has did his PhD on thermal aspects of things and he has been working in this, so he will be able to give us a good understanding of that. So, remember that thermal is always important consideration. And very often most of us are not used to paying sufficient attention to thermal. So, this is the peak and that the gear ratio, torque, speed and RPM we have been talking about it and this is how the motor and controllers are done.

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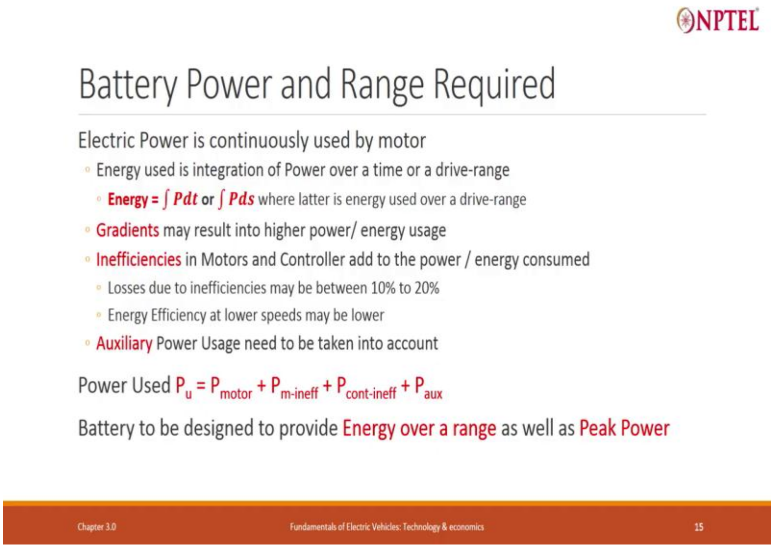

What about batteries? We will get into batteries in great detail soon, in fact next chapter is chapter 4 is on batteries, but let us look at it, electric power will be continuously used by a motor. So, what is the total energy that is taken out from the battery? What is the total energy used? It is energy is always power integrated over time or power integrated over distance, if you are figuring out power versus distance, it is power integrated over distance, or you can say power versus time in which case you integrate over time.

And this will tell you the total energy that is consumed, now this is a very important parameter because battery energy is limited, of course if you have regeneration, means some part of the energy will go back to the battery that helps, so you may talk about net energy consumed. So, the battery energy consumed becomes important parameter, battery power is also very important.

Because if you tend to draw more power than maybe energy, but if you tend to draw more power from a battery as you will talk about later on, you are using it what is called higher C rate, higher charge rate or higher discharge rate, higher C rate of a battery impacts the battery life negatively, so pretty much a battery is designed to charge and discharge at a certain rate, it tolerates for a short time higher C rate, higher charge rate or higher discharged.

But on a continuous basics, you cannot use higher charge rate and discharge rate, it is not just the temperature is more than the temperature we will get into that later on. For example, gradients will always tend to use high power and therefore also high energy. If it is a small gradient for a short time you are going on gradient it is fine, for example if you are climbing up a ramp in a city, it does not, it is for a shorter time are you do not have to worry about it.

But if you are on a mountainous road, you are climbing up the mountains, then you have to worry about the power required while the torque required in that range. In fact, some of the cities are very up and down, for example in India I drive in Thiruvananthapuram and I find that it has lots of ups and downs.

Now, there you have to worry about the torque power as you are climbing up, it more or less can happen on a continuous basis. Not continuous for fairy periodic basis, so you do not have to worry about it because these things will impact things. What we also have not so far looked that but it becomes a very important. What is the efficiency of motor and controller? What does it mean?

For a motor I put in a certain amount of energy, electrical energy I gets a certain amount of mechanical energy, all the electrical energy that I put in is it getting into mechanical energy? No, only a certain percentage is being converted. What happens to the rest of the energy? The rest of the energy is consumed in thermal that is heat some, thermal energy dissipation, which basically means that I have to give in more energy to get the same drive.

Now, this does not happen for motor it happens also for a controller, controller is electronic circuit, but remember these are high voltage circuits with lot of switching devices and as a result it consumes energy, it converts it into heat, the it has also got efficiency there is input power and there is output power and there is a efficiency. Whatever kind of efficiency that we can expect?

If I get up for motor and controller together a 90 percent efficiency is very good, for motor I may try to get 95 percent or controller I am individual try to get 95 percent, but if I get 90, 91, 92, it is very good, net efficiency, if I get below 85 percent very bad, but I have worry about efficiency it was that much multiple things happen first that much energy is wasted, so you require that much bigger size battery. Number 2, that much energy is converted to heat and dissipated as heat, so you have to do some cooling, which will require more energy.

So, you have to design things keeping these inefficiencies in mind. For a ball part calculation if you do not know, you assume 20 percent inefficiency, but in reality anything design for 20 percent inefficiency is bad, I will say depend somethings 85 percent just about be okay, but ideally you would like to get 90 percent and above and if it is a very large vehicle consuming lots of energy you try to go higher 93, 94 percent thus the amount of energy lost will become very large.

So, the efficiencies you have to worry about, we will talk a little bit about efficiencies in each case, but both for my batteries as well as motors and controllers we have to worry about inefficiencies, we want to minimize these inefficiencies. One concern that you find, I have a for example drive electric vehicle, if I drive at 55 kilometer per hour, I find that actually I am consuming very little energy per kilometer, per kilometer, I mean compared to, but if I drive at 30 kilometer per hour or 25 kilometer hour per kilometer energy consumed is much higher.

I am talking about per kilometer, I am not talking per time. Of course at higher speed I will consume more energy, at higher speed you are supposed to have higher power and high energy, I am not talking about that, the problem comes the motor that I have in my electric vehicle has high efficiency close to 90 percent at motor and controller at 55 kilometer per hour.

But once it comes to 20 kilometer per hour almost 30 to 40, 35 percent loss, 40 percent loss, 30 percent loss, so 70 percent of the energy only is utilized or even less. Now, what will happen? It depends on how you are driving, if you are driving mostly on highways it will give you very good what is called mileage, watt hour per kilometer. If you drive in IIT campus where the speed limit itself is 35 and they are lot of bumps, so you generally do not drive more than 20, 25, you get a lot more energy consumed per kilometer.

Why motors and controllers have not been designed to have flat efficiency across RPM? Now, that is a characteristics of something like an induction motor, induction motor generally tend to have a decent efficiency at say high speed at certain speed, at lower speeds it tend to have very poor efficiencies, you of course can do things for the controller to try to improve it, but still it does not work that well.

The permanent magnet synchronous motor which is very common in electric vehicle and for which we will do we do go into details the efficiencies can be roughly flat. And that is what is needed. So, efficiency will play important role and we have to worry about it. There is one more thing that we have to worry about particularly when in I talk about battery energy and the range is that it will provide me, battery power, battery energy and the range that I will provide it.

There is also auxiliary power used, lights are turned on turned off, some electronics maybe turned on, air conditioners can be turned on, that is a major auxiliary power. Now, generally in all the measurements that we do auxiliary power is not taken into account, but the auxiliary power may consume, maybe 20 percent of the energy, that time, particularly in a heat in high temperatures like in Chennai I mean temperature is 42, 43 degrees centigrade, it is actually a lot of cooling is required.

And if I park it in a sun and left it there, for some time so much cooling is required, so much of auxiliary power usage is will be done, that I actually will be able to have much smaller range. So, you have to worry about this, generally the range that is defined by the manufacturer of the vehicle is assuming that you are using a drive cycle as defined by standards, no auxiliary consumption.

Student: (()) (21:54)

Professor: And that is how it is defined. So, now you have to worry about what happens and figure out how much we will you be able to use? So, power used is power for the motor and controller plus motor inefficiency that much power is also used, the inefficiency of the due to the controller plus the auxiliary power. So, you have to take all these three are losses, not losses, auxiliary power is not losses, but that is a power used will include the auxiliary power.

That is what you have to do to compute the range that a battery will give you. Battery to design to provide energy over a range as well as peak power. You have to take the total power used to give you what the real range you will get. We will get into much more details on the battery later on.

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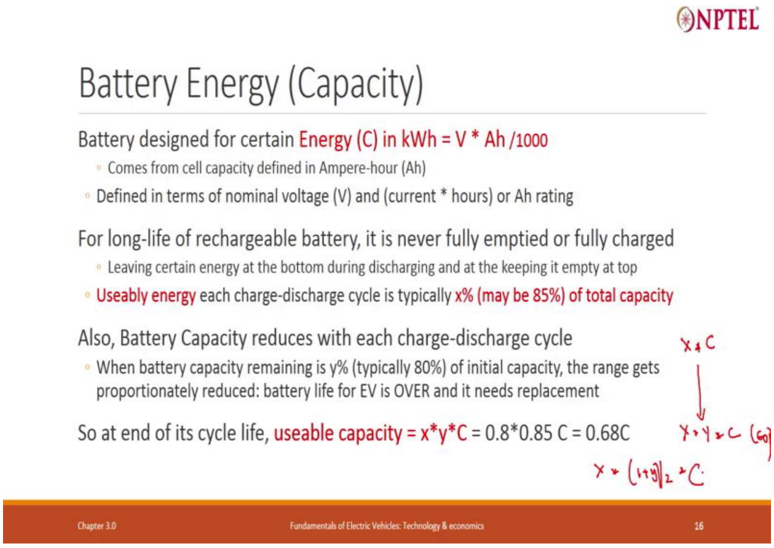

But let me just quickly introduce what how do you really define this battery. The first important thing is the batteries will be made using cells and the battery will have a certain capacity in kilowatt hour, the battery capacity in kilowatt hour of course is voltage, so what is the voltage that it will operate at? What is the at ampere-hour? Ampere-hour is what how much ampere for how much time you have to multiply that.

The energy is therefore voltage into ampere-hour that will be watt hour, now if you want in kilowatt hour you have to divide it by a 1000. So, this is important, V into Ah into 1000. Typically, you will use cells with a certain Ah, for example you may use cells with 50 Ah so that is ampere-hour that you will define.

But you may actually take different amount of ampere at different time you take that into account, so that is the capacity of the battery is defined in terms of V into Ah by 1000, multiply voltage, multiplied by current into hours, that is Ah rating. The cells are very often defined by what is called ampere-hour or Ah ratings. For long life of rechargeable battery, the other important thing is the battery is never emptied, I had mentioned that right in the beginning in the first chapter is never emptied completely and never charge fully.

If you tend to charge fully, 100 percent and if you tend to make it a 0 percent, it impacts the life of the battery, number of cycles it can support are significantly less. So, what do you do? First of all, you will never discharge it to 0 percent, you will leave some percentage below it, maybe 5 percent depends on it, 5 percent, 7 percent, you will try to leave that, you will never go below that.

Because you want do not want the cells or the battery to be completely discharged, never. So, in fact even when you use a laptop, it sometimes gives you an indication that the battery will only last for so many minutes, now what does it do? It actually computes the rate at which you have been using the energy in from a battery and it therefore says this is the current capacity left and it will last for so many minutes.

It actually when it gives you that number it assumes that whatever is below that threshold which at which you will shut down you will never use, so that energy it is not that if you say 5 percent energy is left it does not mean really 5 percent, 5 percent but the plus the lower threshold for which below which you never go.

Similarly, on the upper side you do not tend to, you tend to charge and then you stop charge, typically for example, in a NMC cell, it can go up to 4.2, 4.25 volts, but you will probably stop at 4.15 volt, why? Because you do not want to charge it fully, it is charging it fully again impacts the life of the battery.

So, very typical depending depends of the size kind of battery a very typical use of the low end battery is 85 percent, leave 10 percent on the top, 5 percent at the bottom, or could even be 80 percent, live 15 percent the top, 5 percent at the bottom, that is very good for the battery. But that means your 20 percent of capacity is never utilized, if it is 85 percent, 15 percent of capacity is never utilized.

So, if you want actual usage of 1 kilowatt hour you have to you to take a battery which is one kilowatt hour divided by 0.85, it will come to some 1.1 something 1.11 close to 1.2 kilowatt hour. But leaving that in every cycle, not charging discharging fully, gives you immense amount of benefit in terms of the number of cycles the battery can support. It is a usable energy a term that is used is, a battery may have a capacity of 1 kilowatt hour, usable energy is x percent maybe 85 percent of the total capacity.

This usable energy is also referred to as depth of discharge, we will come to that it is a depth of discharge. Depth of discharge is you are doing both on both sides it is actually combine say depth of discharge is a battery is used to DOD of 85 percent means 85 percent of capacity can be used in every cycle no more, no more than that.

The other thing that happens, you start with a new battery, let us say it has a capacity C, as you use the battery number of cycles go that C will tend to fall, I talked about it and finally you get to a value let us say 80 percent at which you sort of say I will no longer use it in vehicle. Why? Because now your range will go down to 80 percent of what you initially envisaged, you may choose y to be 75 instead of 80.

But normally I user normally a vehicle manufacturer chooses that and say well y will not be, y will be either 80 percent or 75 percent whatever, so what to that extend you get less range. So, what is the actual usable capacity? Usable capacity becomes x into y into C at the end of its life, close to the end of life, in the beginning it is x in to C at the end of life it is. So, to begin with it is x control P, so in the beginning it is x into C, over time it is x into y into C this is the end of life.

This is beginning of life, start of life, end of life, this is at EOL. So, what do you do? Well, you have to keep track of it, or you can even say that you will use average between x into C and x into y plus C. So, very often you say average usage capacity is x into 1 plus y by 2 into C. 1 plus y by 2, so if y is 0.88 you are using 90 percent. So, this is how the usable capacity is defined. In the beginning you will get slightly higher later on you get slightly lower.

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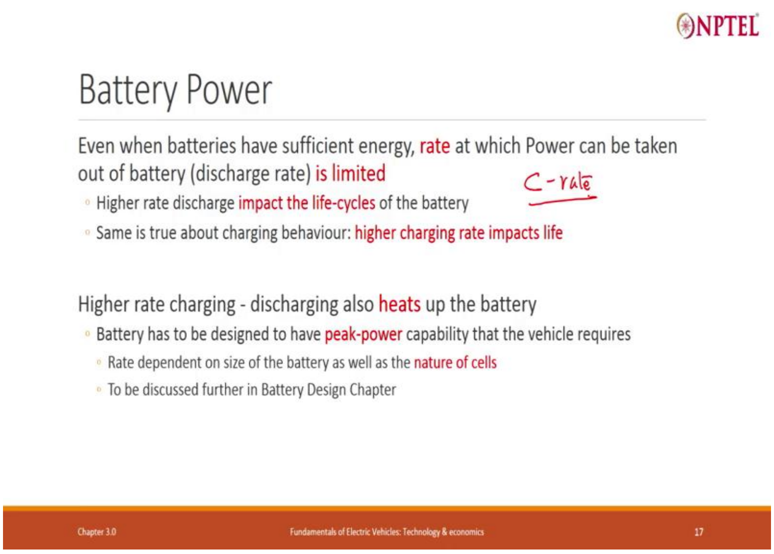

Whatever battery power as I mentioned when batteries have sufficient energy, let us say energy is not a problem, rate at which power can be put into the battery or taken out of the battery both in and out of the battery is limited, it is limited by what is called C rate, the term used is C rate, I am repeatedly pointing out we will get into details of it. Higher C rate impacts the lifecycle of the battery, either for charging or discharging.

So, you limit what C rate can you use, if you want life to be predictable. Higher rate charging and discharging also heats up the battery. We will later on see that these batteries have a internal resistance and whatever current you are putting in I square R, I where R is the internal resistance will be dissipated as heat, either during charging as well as during discharging.

So, generally therefore battery is designed for a certain peak C rate, charge rate of discharge rate or peak power capability. So, generally the vehicle requires some peak power the battery should be able to deliver than peak power, not all the time, but remember that time there will be a heating and either you are if it requires more or less close to the peak power all the time, you take away that heat, heat dissipation will have to be done.

So, the actual rate that is used is dependent not just to the size of the battery, but what is called nature of the cells, what kind of cells are you using. There are cells which will allow you to charge discharge at 2 C, we will define what is a C rate thus and it does not impact the battery life tremendously. They are cells where if you charged higher than even 1 C it will impact life the battery. So, low-cost cells generally tend to be something where you charge rate is 0.2, 0.3, C, we will get you to detail in the battery design center chapter.

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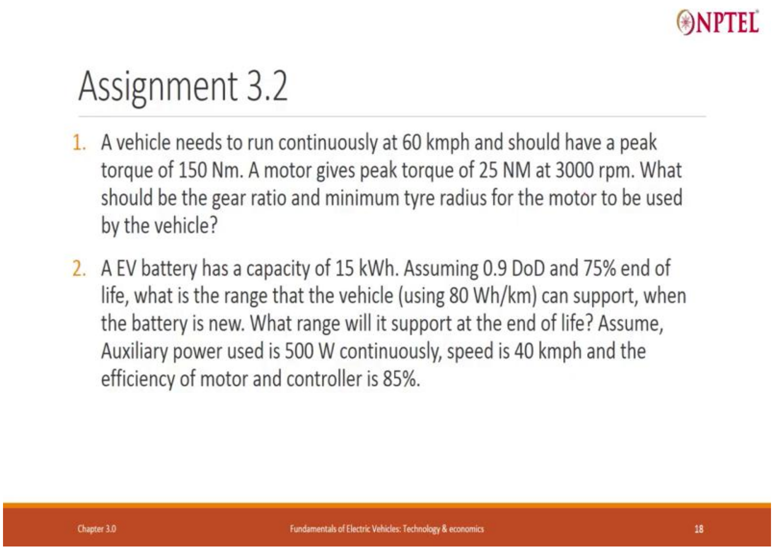

So, this is an assignment 3.2 that I am giving you. And these are assignment which will give you some good understanding. The first assignment is a vehicle is to run continuously at 60 kilometer power per hour and have a peak torque requirement of 150 Newton meter. A motor gives a peak torque of 25 Newton meter at 3000 RPM. What should be the gear ratio and minimum tyre radius for the motor to use at the vehicle?

So, I have told you that it has to be continuously used for 60 kilometer per hour, I have given you the tyre radius you have to convert RPM and all those things motor will run at 3000 RPM at 25 Newton meter, you require a torque of 160 Newton meter. What should be the gear ratio? In the second question, I have given you a battery with a capacity of 15 kilowatt hour. But I am assuming that 0.9 DOD depth of discharge and 75 percent end of life.

Assuming that it vehicle consumes 80 watt hour per kilometer, what is the range that the vehicle can support on the average, when the battery is new, when the battery is near the end of the life and therefore of this average? Now, I also assume that there is an auxiliary power of 500 watt continuously use, their air conditioner use, speed is 40 kilometer per hour and the efficiency of the motor and controller is 85 percent.

Compute this, it will be interesting, all that many things that you have learnt so far, will actually come into the picture. I come towards the end of this chapter by looking at auxiliary unit (()) (36:32), what is the auxiliary power consumption? What is auxiliaries? Vehicle control unit. What is the role of a vehicle control unit? Actually vehicle control unit is a misnomer, it does not control too many things.

Because motor has its own controller, battery has its own BMS, at what speed is driven vehicle is driven depends on your accelerator and brake, not by the vehicle control unit, and that directly controls the motor, it does not control the vehicle control unit which in turn controls the motor, no, the brake and acceleration the acceleration particularly directly controls the motor, break of course will be a is will actually slow down the tyre of course in EV it will tend to again control the motor. What is the role of vehicle control unit? Vehicle control unit is more to coordinate everything, communicate with the world, occasionally download parameters and things like that. Not the say it is not playing the role of a driver, driver is a human driver.

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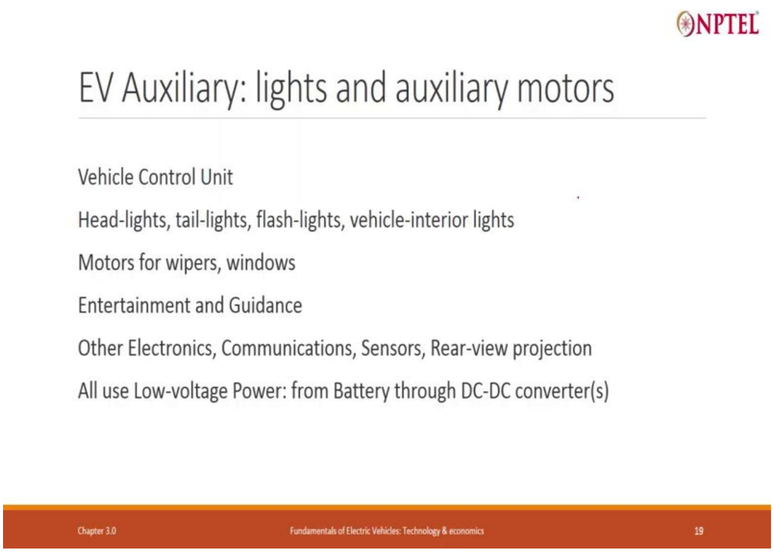

Then of course, there are all kinds of lights, headlights, taillights, flashlight vehicle interior lights, all of these are auxiliary and will consume energy. Motors for wipers, windows, the whole lot of motors in the vehicle nowadays, even to lock it or unlock it, they are actuators not motors and they have to be electrically driven, then of course there is entertainment, there is a guidance tells you gives you the map of the way, route and things like that.

There are other electronics, communications, sensors, rear-view projection, all those things are there, they all may consume small solar energy most of it is electron is consumed little bit of energy, always low voltage power, so it is typically most of the electronics actually today work at 3.3 volts or even lower. So, you tend to use a 5 volt, there are electronics which uses even lower than 3.3 volts. So, of course you will have to go through DC-DC converter, get the right voltage and from the battery to get that.

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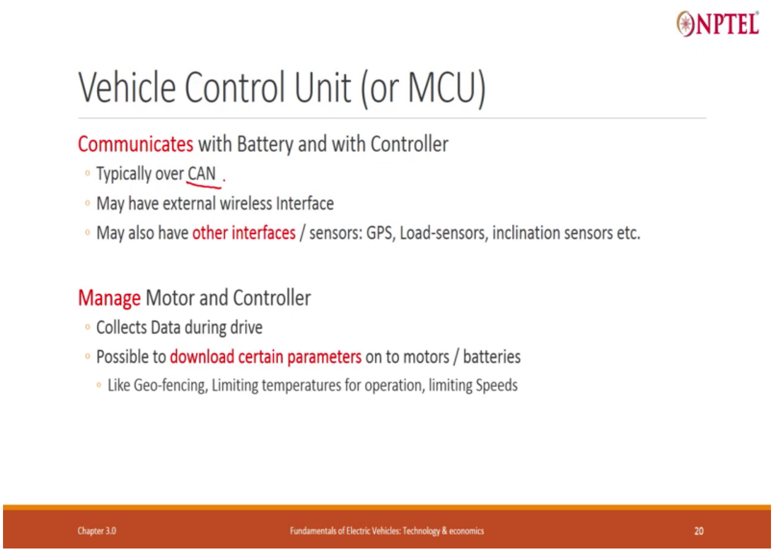

Vehicle control unit, as I told you it communicates with battery and controller typically over a standard can bus, can bus is a more or less adopted throughout the world as a standard for in vehicle communication. It may have external wireless interface, may not have but at nowadays it increasingly have it. It may have other interfaces like for example it may have a GPS, positioning, it may have load sensors, how much load is already there on the vehicle, inclination sensors, all this information may actually be fed to a server.

It manages motor and controller, these manages has to be carefully thought about. It collects the data during drive, possible to download certain parameter to motors and controllers. So, motors and batteries, motor controller will directly control the motor, but a parameter can be changed through the VCU maybe from a wireless outside through the VCU and now the VCU will communicate to the controller and now the controller communicate, control the motor.

Similarly, you can say you can download a parameter to battery BMS, now BMS will control the battery. You also use it for things like Geo fencing do not allow that use a GPS where are you, have you gone out of this place, it may control limiting temperature, if the temperature exceeds this shut of the battery or slow down the battery, temperatures for all operations limiting speed you can limit the speed, do not allow the speed to go above some speed, you measure the speed and if it is going, slow down the motor. So, these are things that are done and it is mostly the VCU or MCU that has that, so in real sense it does not control, it acts as a data communication platform.

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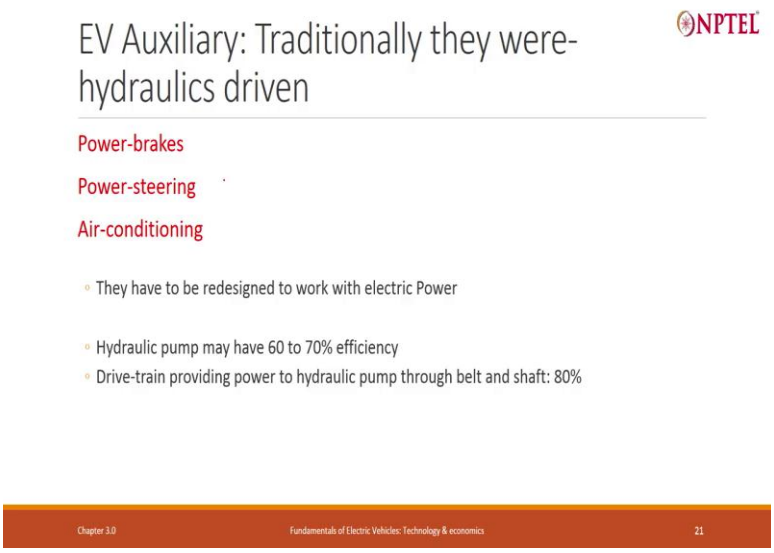

There are 3 other units I have been talking about it, power brakes, power steering and air conditioning. Generally, all these 3 things used to use hydraulics and mechanical it used to be form fuel, the engine is driven that we generate mechanical engineering and using hydraulics it will control brake, steering and air conditioning. Today all of them have to be working for electric power.

In fact, most of the current new vehicles already have that working on electrical, but in case there is not our future EV's will not first create mechanical force and use hydraulics to control them, so this has to be changed. Hydraulics does not give you a very good efficiency that is part of the reason.

So, drive train providing power to a hydraulic pump through belt and shaft will give you 80 percent efficiency, you do not want that much power to velocity. So, you directly start using electric motors, again motors and controller, so you have motors and controller design for air conditioner, you have motors and controllers designed for power steering. So, there are multiple motors and controller that are required.

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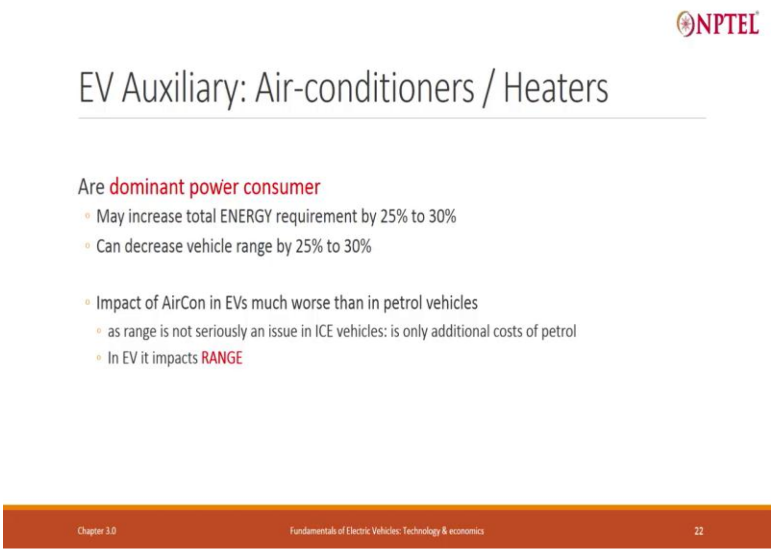

Motors and controllers that are used for example windows up and down, so air conditioners heaters are dominant power consumers, it may increase the energy requirement by 25 to 30 percent and therefore decrease the vehicle range. Now, if same thing happens with petrol vehicles also, instead of 15 kilometer per hour, now it will give you only 12 kilometer per hour and therefore the total tank will limit the range.

But you know that range tank is made large and you have 400 kilometer, 500 kilometer range, even if it comes down by 25 percent still 400 kilometer, very easy and quick to fill petrol, so you do not worry about it too much except for the cost associated. Not so far electric vehicle, the battery will anyway give you a limited range and then you take away 25 percent, 30 percent of the battery energy for using things like this, your range significantly goes down.

So, I want to point out the impact of air conditioner and heaters is felt much more on EV, energy consumption. It impacts range and range is very valuable, till we figure out a way of almost instantaneously charging battery in a few minutes like the way we fill out petrol. It will have, you have to worry about it and therefore you will rather spend money to make a air conditioner more energy efficient, it will help you reduce the battery size and save you money there.

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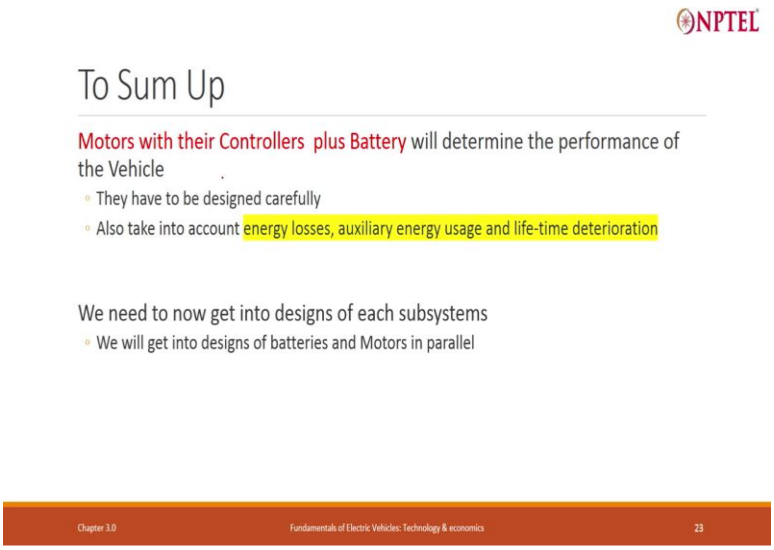

To sum up motors with their controllers plus battery will determine the performance of the vehicle, that is something, this is the key thing for the drive, they have to design very carefully and take into account energy losses, auxiliary energy usage and lifetime deterioration of battery to really figure out what can be used. What we need to is now start looking at batteries and motors and controllers. And actually we can do it in parallel. So, the next chapter I am going to start with the introduction to the batteries in detail after that as a pointed out Doctor Kaushal will start getting you the detailed design of a battery.

In parallel Kannan, Mister Kannan will start looking at motors and controller, but I think I will do a little bit of batteries in detail, which will get set for chapter 5 and 6, 5 on battery design and 6 on motors and controller. 4 will actually provide the link, 4 does not have to be completed, you can start while we are doing 4 towards the latter half of it, you can start looking at chapter 6 also. Thank you. Thank you, plan, please submit your assignments and solutions in time.