Fundamentals of Electric vehicles: Technology & Economics
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Lecture 17
EV Subsystem- Design of EV Drive Train- Part I

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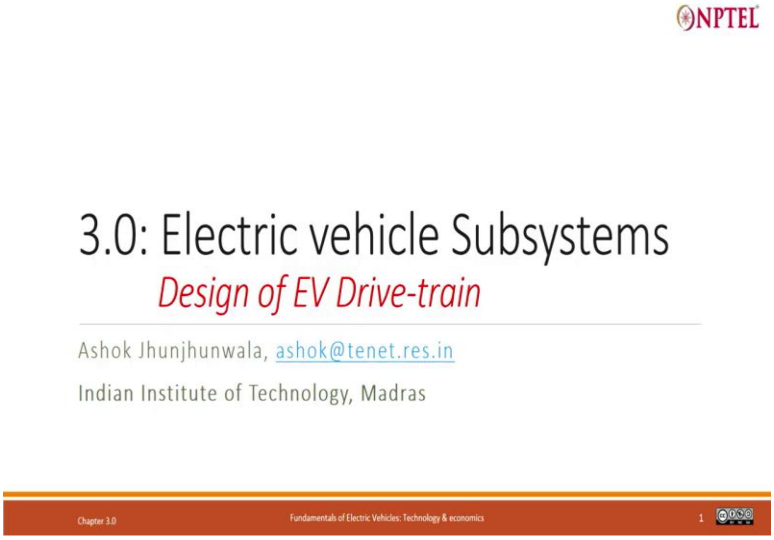

We are now coming to the third chapter, Electric Vehicle Subsystem Design. We can also call it a design of electric vehicle drive train because it is primarily the drive train that we will drive design, rest is common to a ICE or a petrol vehicle.

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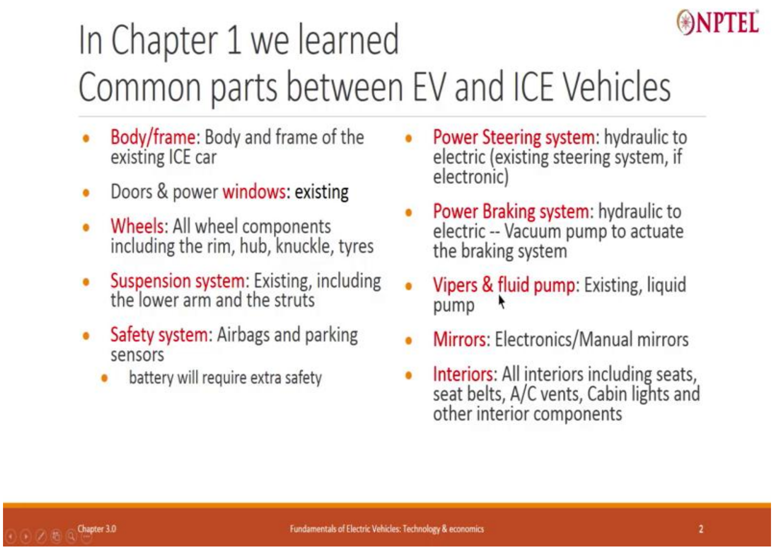

So I start this by saying what are the common parts, we actually did this in chapter one I am repeating it because now you have a better understanding of few things. So what are the parts which are common between EV and a petrol vehicle ICE vehicle. Body and frame, well you can use body and frame of the existing cars, of course the fact that you will have electric vehicle you have to look at the number of moving parts will be small, vibrations due to the moving parts will be small, can you change the material used for body? Well, that is just something that work is just started and it is a future thing.

Similarly, doors and power windows pretty much existing, of course you will probably not have manual you will have all with motors and which requires electricity which a separate battery was used in a petrol vehicle, today you do not need this separate vehicle battery you will take the existing battery convert it to the right voltage and drive all these motors for windows and doors and things like that.

Wheels, pretty much the same except remember that if you do wheels with better material rolling resistance, improves its significantly makes a difference to the car. In fact, the extra cost that you put in the wheel is more than recovered when you look at the cost reduced cost of the battery. So I will really spend time on making the wheels better. Suspension system again existing can be included.

Safety systems, airbags, parking sensors all those things will be similar, except now you have to worry about battery safety. Well, in early days as I told you you had to worry about petrol safety but now you have developed good tanks the way the petrol moves its well protected petrol getting lighted up and creating fire is unlikely.

So that the learning took place I do not know from when from early probably 20s 1920s to all the time till 70, 80, 60, 70, 1960, 1970 where you do a similar learning electronic vehicle because battery per se has to be made safe and then current is being drawn out but you have to worry today you have to worry because if a battery catches fire it can be disastrous it has a lot of energy.

Power steering system, again similar except you know earlier you used to use hydraulic power steering system already in many cars it has been changed to electric there is no reason for us to use hydraulic, we will of course work with electric driven by not auxiliary battery but the current battery.

See in a petrol vehicle you also have a what is called dynamometer which converts the motion into electricity its called what, dynamometer? Dynamo alternator or dynamo now you do not require that out here I should have told you that it goes away here directly use electric current.

Similar thing with power braking system it is not going to be hydraulic it is going to be electric but as I pointed out many of the modern vehicles already have electric power steering, electric power braking. Wipers and fluid pumps, mirrors pretty much the existing meters measures can produce they can be electronically controlled new ones are electronically controlled, manual mirrors. Interiors I do not see any major reason to change that interiors.

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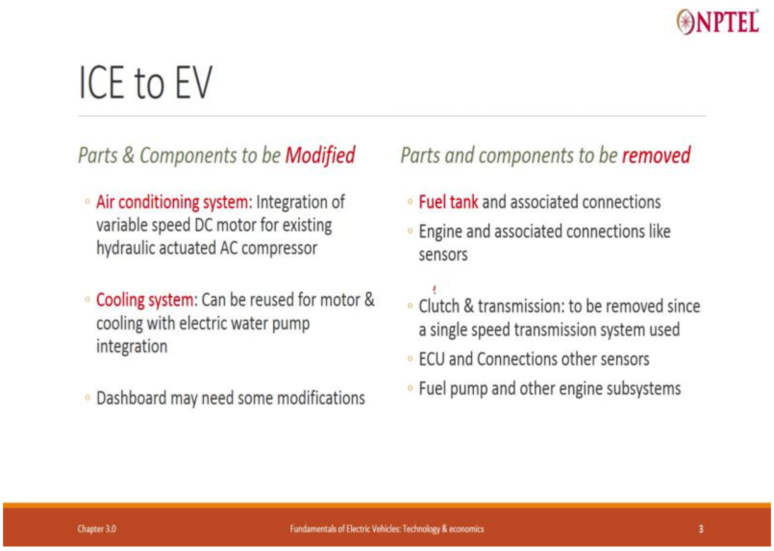

So these are the common parts. What are the parts which needs to modification? Air conditioning system, air conditioning systems again driven by hydraulic it is not driven by battery that auxiliary battery that it is there because actually consume a lot of energy. So actually the petrol which is burning and driving the air conditioner, here can directly be driven by electrically.

So you require motors, motors for air conditioning systems pretty much the kind of things that are used in a home air conditioning system, office air conditioning system, cooling systems all kind of cooling systems which will require, we have to cool the batteries, we will have to cool the motors and controllers and you will require these to be electrically driven rather than again petrol driven.

Dashboard may need a few modification you have to add a few parameters and you can today make it more intelligent. Parts which can go away completely, fuel tank can go away completely, in fact, battery comes instead of fuel tank. Engine and associated connections like sensors several of them they will go away. Clutch and transmission system should go away unless you make motor also which is requires multiple gear. ECU and connections to other sensors again can be removed you may require something different for electric vehicle, fuel pump and other engine subsystems will also go away, there are things that are removed.

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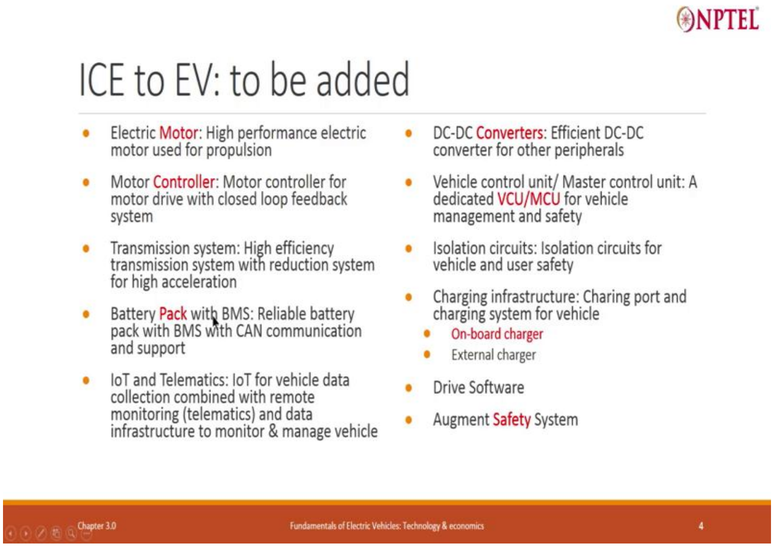

What are to be added? Most important is electric motor and controller, high performance electric motor used for propulsion for movement controller which controls the motor. Transmission system require very limited amount of gear and yet you may require some transmissions, gear is of course there, single gear is absolutely required, battery pack with BMS that is a very important component, all of them will have a CAN communication everything will be communicating to vehicle controller through CAN motor electric motor control battery pack everything will be communicating.

IOT and telematics more or less everything has become electronics today communication is so common so this is something invariably gets added this is getting added in a conventional petrol vehicles also but today you can remotely monitor the motor, controller, the battery every single thing you can remotely monitor, what is period is being driven, how long it is driven at what speeds the various converters will require DC-DC converter you may have a 350 volt battery or a 48 volt battery then you will need lights which are maybe 12 volt.

So you will require different DC-DC converters. A vehicle control unit sometime also called master control unit it will communicate with everything, motor, controller, battery pack, pass some messages may communicate to the outside world, can even get controlled a new parameter can get added, very often certain parameters software parameters in motors, controllers and in battery can be updated through a VCU, you do not have to bring all these things to a factory to update the software, you will invariably need now isolation circuits. Particularly you, if you are going for 350 volt and 750 volt drive train because they are high voltage you do not want human being to ever touch that.

So you want isolation circuit which will isolate anything at that voltage to lower and lower voltage and the rest of the parts, so safety becomes very important. You require charger infrastructure, now charging infrastructure is outside the vehicle not really it is like a petrol pump but there will be also on board charger I will talk about it what the difference is strictly speaking both things these things are not part of the vehicle but part of EV ecosystem.

You will require some drive software, of course drive software a lot of it will be there in motor controller and in battery in the (batt), but there is a in VCU also certain software will be there could be there. So you may have augmented safety systems those things may actually get added.

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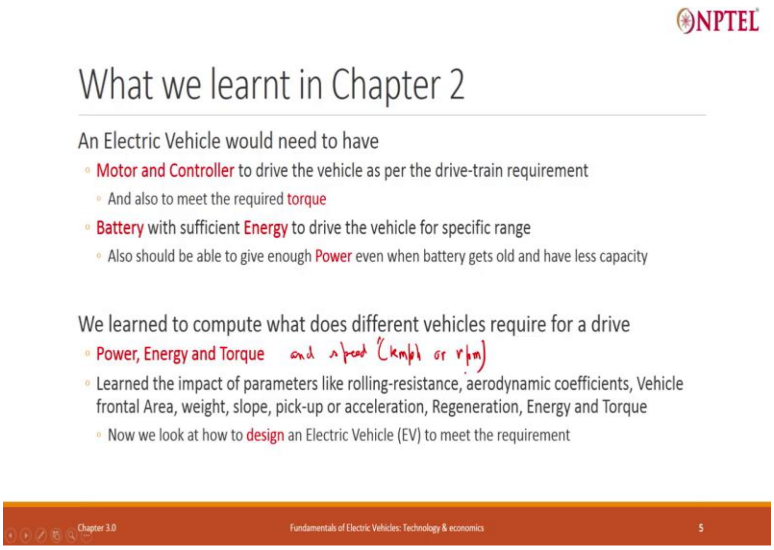

Having done that, let us recollect what we learned in chapter 2. We had learned in chapter 2, that electric vehicle would need a motor and controller to drive a vehicle as per the drive train requirement I strictly speaking not as per the drive train requirement as per whatever user wants but performance will be measured as per the drive train requirement. So velocity and what I meant velocity and acceleration at least as per the drive train requirement probably higher.

What the drive train requirement does not give you is a torque requirement, so it has to also meet the torque all the time, we have learnt to compute torque so far we have not used it. We did in one little bit when we talked about the truck say you require so much torque to to go up a slope, to start on a slope so we did that so there is some thing that we learned in chapter 2.

You also need a battery with sufficient energy to give your vehicle with specific range, otherwise you will have range anxiety but not just the energy, battery should give you also sufficient power at every instant even as it gets older. Remember the vehicle the battery capacity will go down, your power cannot go down, energy will go down, power is important because power is linked to the force that you can give, so very important.

We learn to compute what different vehicles require for a drive power energy and torque learn the impact of parameters like rolling resistance, aerodynamic coefficient, vehicle frontal area, weight, slope, pickup acceleration, regeneration. Now we will look at the design of electric vehicle I keep on missing that all this is a function of certain speed kilometer per hour or RPM that is also equally important, so you can either call it kilometre per hour or RPM, this is equally important.

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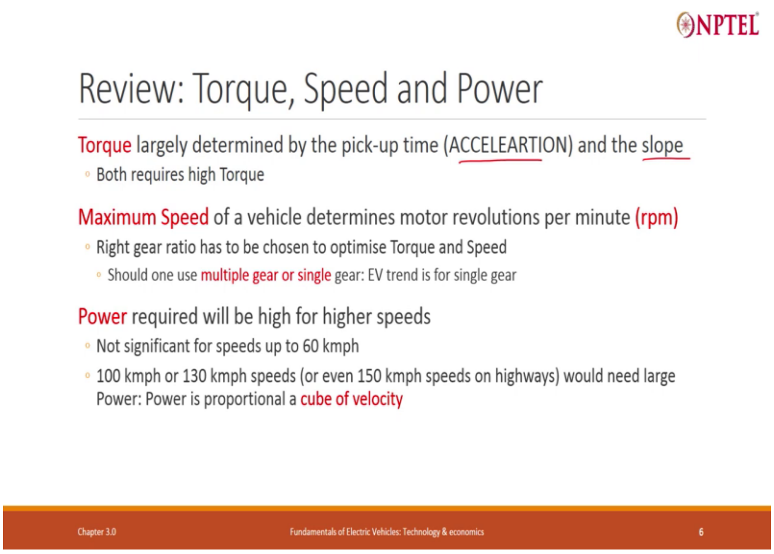

Let us look again little more deeper at torque, speed and power. If you remember, we talked about torque, large torque comes from two things, one is acceleration and number two slope two things acceleration, pickup time or acceleration and the slope both requires high torque. Maximum speed of the vehicle determines revolutions per minute or RPM of the vehicle, torque. And right gear ratio is to be chosen to optimize now the torque and speed, this is not what we, we did mention it did not learn this and we also raised whether should we use a multiple gear or a single gear EV trend is single gear as far as possible, we will talk more about it as we go on.

Power requirement goes very high during high speeds, somebody asked me belief was on the last gear you use very little power, not so as the speed goes up power the last gear essentially basically means that velocity is not being reduced, RPM is not being reduced significantly you do not require large torque at that time but you do require large power, last gear will give you less torque therefore if you want to climb up you cannot use last gear.

Anyway this gear, last gear, first gear is all petrol engine. So power requirement is very low at speeds less than 60 kilometer per hour and then it shoots up and I pointed out 100 kilometer per hour, 130 kilometer, 150 kilometer it can become very large because it is going cube of the velocity. So from 60 if I go to 120, my power requirement goes up by 8 times. If I go to 180 kilometer per hour from 60 it will go by 27 times and corresponding energy requirement will go up.

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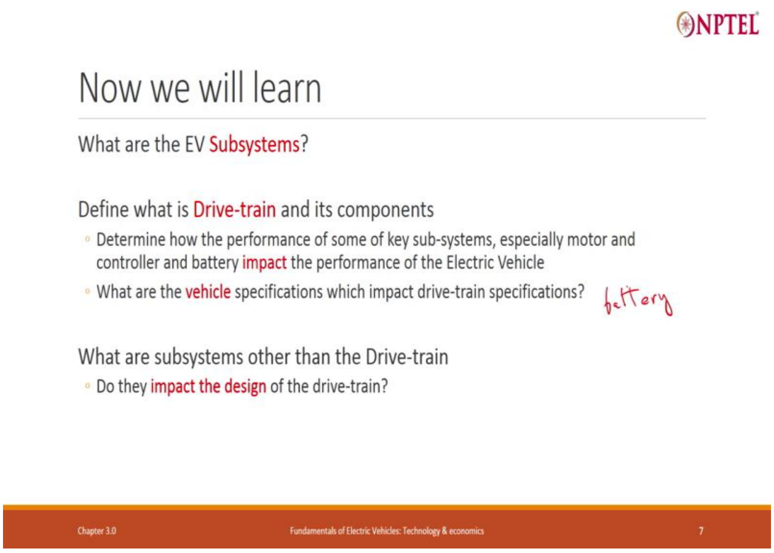

What will we learn in this chapter? What are the EV subsystems, define what is called drive train and its components and determine the performance of the key subsystems especially motor and controller and impact on the performance of electric vehicle and what are the vehicle specification which will impact the drive train specifications.

And finally what are the battery specifications, I did not write what are the battery specifications, what are the other subsystems that other than drive train, drive train is a major subsystems and do they impact the design of the drive train I have to take that into account.

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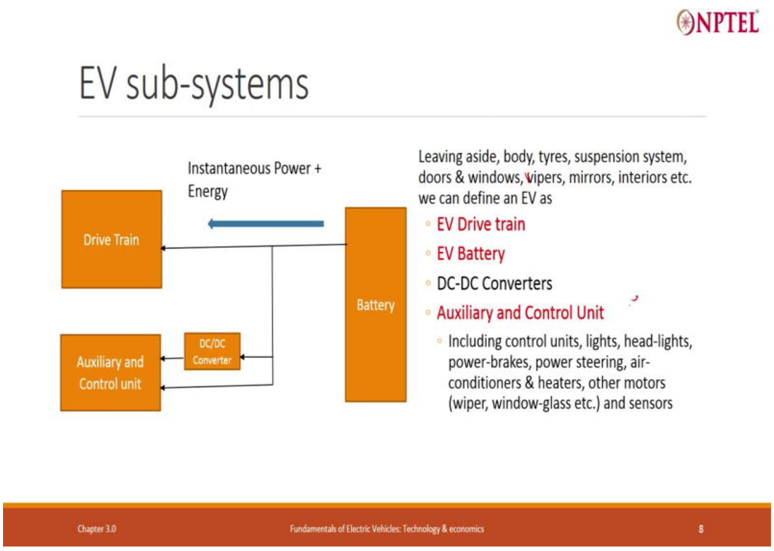

Having done this introduction let us look at the EV subsystems and remember right in the beginning I am leaving asides body, tyre, suspension system, doors and windows, wipers again I am very fond of the snakes, mirrors, interiors if you leave aside this, EV consists of first a drive train this is the drive train sometime battery is included in the drive train strictly spring battery is connected to the drive train, it is outside a drive train EV battery various DC-DC converters an auxiliary and control unit, air conditioning system your things like power brakes, power steering, your lights all kinds of lights all these are auxiliary and drive control.

In fact, even this your opening of doors nowadays electrically you open door the that is also auxiliary and control systems. So, it is primarily a drive train and EV battery these are the two most important thing, then there is a DC-DC converter this basically a converters so that the voltages you can get and auxiliary control unit. So essentially power is required by these three parameters drive train, battery and auxiliary control units. The control units as I pointed out includes actually control the VCU, lights, headlights, power brakes, power steering, air conditioners, heaters other motors here I got my wiper right, window glass, sensors variety of sensors, whole lot of sensors are put.

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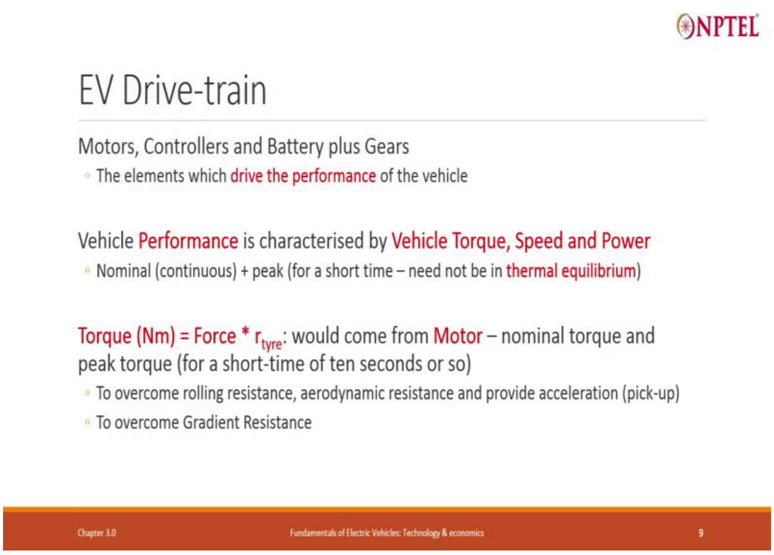

What is the EV drive train? Essentially, motors, controllers, battery plus gears. Gears is a very much part of it, these elements will drive the performance of the vehicle. The auxiliary elements, their converters will not drive the performance, performance of the vehicle will be driven by motor controller battery plus gears. So, vehicle performance how do you characterize the vehicle performance? Vehicle performance is characterized by vehicle torque, vehicle speed, vehicle power these three, are you getting sufficient torque at the speed that you want? And the power that you require.

These are three most important parameters and for all of them there is a term used continuous and peak. So you talk about continuous torque and peak torque, continuous power and peak power particularly for power, why are you using continuous and peak? Peak is for a short time 10 seconds, 20 seconds and primary difference between peak and continuous is the thermal design, for example a motor may have a certain power in a continuous manner for a short time you can go to higher power, when you go to higher power your heat dissipation may be more.

So the temperature will start rising, if you keep on driving at higher power the motor will become too hot and will fail but 10, 20 second let it heat up it will cool down. So the primary difference between nominal and Kanan will actually talk to you more about it and the peak is the thermal equilibrium the heat dissipation, you have to design to have heat dissipation for normal, for peak your objective is during normal temperature will not go up it will reach a certain state maximum number and it will stay there peak it can go up slightly and it will go down because this peaks are always short term.

So this you must understand this is the, and really I do not think any difference is there other than thermal, well in the motors and controllers in battery there is a difference battery high peak again it has a impact on the life of the battery but normally you can do this. Remember something that I had done it and I will again talk about torque is force into the radius of the tower would come from the motor nominal torque and peak torque peak torque for a few seconds.

Peak torque is normally required if you suddenly have to go for a big slope, suddenly for a short period of time you go to that and then come down. Similarly, peak torque may be required if you want to suddenly accelerate you have you are actually behind a vehicle and you suddenly accelerate to go ahead very short time it is not a sustained torque.

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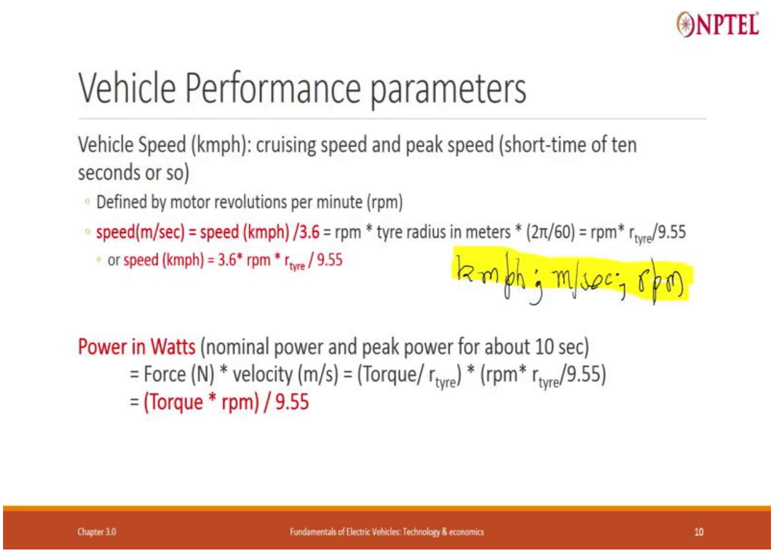

This vehicle speed I had done this it is a cruising speed and peak speed. Peak speed again for a short period of time, 10, 20 seconds. Cruising speed can be there all the time this may be defined by motor revolutions per minute RPM is used and please look at this very important speed should be defined in meter per second but most of the time it is defined in terms of RPM revolutions per minute, of course speed can be defined in terms of kilometer per hour you often talk about vehicle speed in kilometer per hour, kilometer per hour if you convert kilometer per hour it is 3 kilometer per hour speed divided by 3.6 because kilometer is 1000, hour is 3600.

So 1000 by 3600 seconds is kilometer per hour divided by 3.6 and that is a meter per second. If you want to compute that as in RPM, RPM into 2 pi into r 2 pi r but it is a revolution per minute, so convert it to second is divide by 60 this is the RPS or not RPS this is the speed in meters per second speed in meters per second is RPM multiplied by 2 pi r divided by 60 and if I take 2 pi by r and look at it it is actually RPM into r tyre divided by 9.55.

So this 9.55 number comes very often keep that in mind most of the time it is approximated as 10 you multiply RPM with r radius of the tower divide by 10 you get meter per second. So if you have 60 if you have 3000 RPM your tyre radius is 0.2, so you get 600 divided by 10 60 meter per second or 60 divided by 3.6 or 60 multiplied by 3.6 to get you in kilometer per hour.

So speed is 3.6 into RPM into r tyre divided by 10 this is something that you should use and should be able to convert that all the time I am going to give you an assignment without gear and of course after that you have to take the gear into account. Similarly, power in watts, how is power in watts defined?

Nominal power and peak power I remember for 10 seconds it is force into velocity which is same as torque by for the force is torque divided by radius of the tower into a velocity in meter per second is RPM into r tyre by 9.55 you see in here it comes division by r tyre here it comes multiplication by r tyre, so r tyre does not matter you can actually write this as torque into RPM by 9.55 this is another very simple important thing you know the torque and you know the RPM you know your power consumption.

So if you have a 3000 RPM and torque is 20 Newton meter 3000 into 20 divided by 9.55 it gives you 6000 watts 6 kilowatts very simple, these two you must remember and conversion RPM to meter per second to kilometer per hour power in watts to torque into RPM by 10 you must remember this this something that you will use it again.

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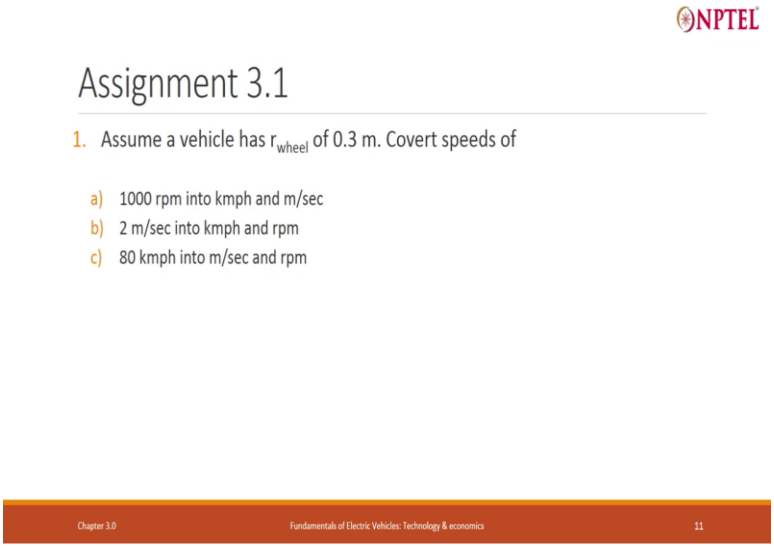

And again and I am giving you an assignment assume vehicle radius is 0.3 meter, convert speeds of 1000 RPM into kilometer per hour and meter per second and 2 meter per second into kilometre per hour and RPM and 80 kilometer per hour into meter per second and RPM, all right? Do this as an assignment.

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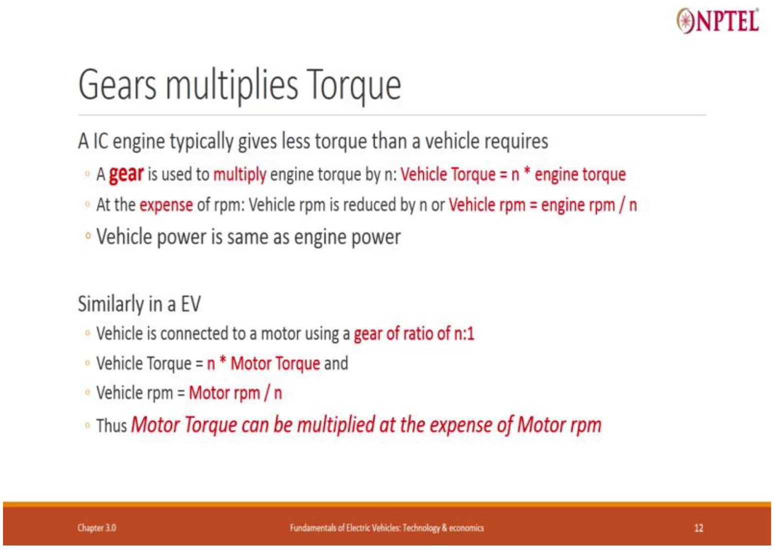

The next very important this is the critical thing, so far we are not assumed gears though I have been talking about gears, an IC engine does not give you enough torque that a vehicle require. So you put a gear to multiply the torque, a gear just multiplies the torque so vehicle torque becomes n times engine torque where n is the gear ratio.

Now whenever you multiply torque, you will multiply torque so you multiply torque your speed go RPM goes down, RPM goes down by a factor of n. So the vehicle RPM is engine RPM divided by n and vehicle torque is n into engine torque if you have a single here of a n this is what is used if you are multiple gears as the gear ratio changes your multiplication and division factor will change.

Vehicle power is engine power, so it is a vehicle power and engine power there is no difference. Torque gets multiplied, RPM gets reduced by the same factor, so the vehicle power and engine power is same. You will see the same thing in electric vehicle, the well there is always a gearbox sufficiency I have not taken into account, which I will leave it to you to leave it to motor people.

EV is normally use a single gear n is to 1 as I pointed out there is a certain efficiency, efficiency can be 98 percent so very close to 1 we normally will assume one unless it is required if there are multiple gears the efficiency gets worse but then it is not as easy, single gear is kind of almost fully attached you can get very high efficiency 0.99 close to that.

Here also vehicle torque is motor torque multiplied by n, so if I am getting a certain motor torque and I require more torque, well remember that vehicle torque and requirement can go very high remember in a truck we talked about 1700 Newtons meter Newton meter now motor will not give you you have to multiply by n. We even talked about 3000 or 3500 Newton meter, you have to have a gear ratio of n maybe n can be 10, 12, 14 and then your motor torque becomes more reasonable.

In a similar manner vehicle RPM is motor RPM divided by n same thing same thing that you see instead of engine now we are talking about motor. Thus, motor torque can be multiplied at the expense of motor RPM, this is an important factor that you want to take it is pretty much the same, of course as was pointed out that if gear has certain efficiency it is not one to the extent it is there that much is a power loss. This is something I am just wondering whether power loss will come well power loss will come as square or no multiplied and this there is a single power loss efficiency, efficiency speed as calculated.

So this is something that we will be using all the time, so in fact it helps us design motors otherwise motor torque requirement will become very large, we actually are able to design motor with higher speed electric motor you learn when you design particularly PMSM motor, how do you increase the speed of the motor? By simply increasing the frequency as you increase the frequency the speed increases.

So that is possible you rotate it faster, that will that is easier to do, getting a torque is a tougher job, torque requires your more current, more magnetic, magnet has to be more powerful so it becomes more difficult, anyway we will learn this but this is an important thing that I actually wanted to point.

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So a very important question comes, in electric vehicle do you use multiple gear changeable gear or a single gear? Now I know early electric vehicles were designed with multiple gears they are more or less copying the petrol vehicle, today the trend is to move design a motor which can take the whole range of speed and the torque with the right gear ratio and not have multiple gear, far more efficient, no clutch requirement, no changing gear makes things far more efficient.

You are not always able to do that particularly like example if a heavy truck is there and suddenly you say, well I also want it to climb 90 degrees, that is the kind of requirement these people will come up with, you will then have to worry about gears. Generally, fixed gear in my own vehicle there is its a fixed gear but there is extra gear that I can use for reversal of course you have to turn the motor in reverse direction you have to have indications not gear but there is a extra gear that is put in my vehicle but thats it is if I redesign that vehicle I will not put that.

Single gear will be preferred but sometime vehicle requirement forces you to but as motors become more and more powerful you will see single gear will actually come up I have repeatedly pointed out power does not change except the efficiency factor is there to the extent power will get lost, we will take that into account.