Fundamentals of Electric Vehicles
Technology and Economics
Professor Ashok Jhunjhunwala
Indian Institute of Technology, Madras
Lecture 12

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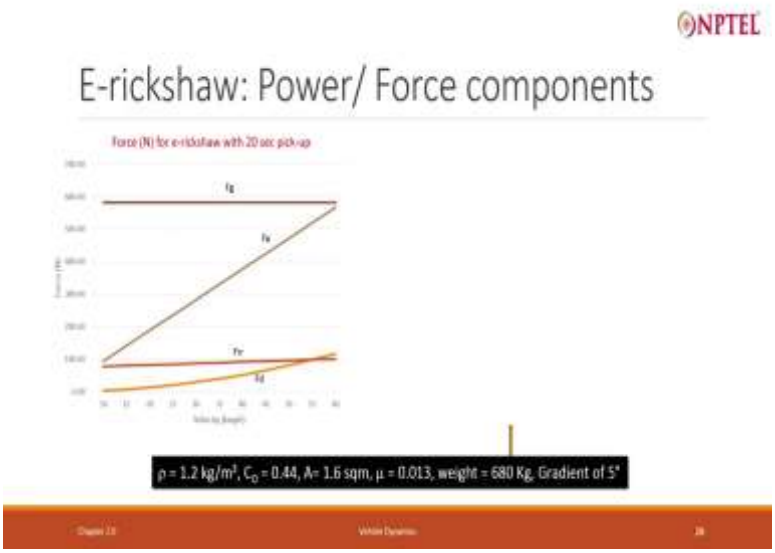

Let us move from two wheeler now to something else, a e-rickshaw, very similar vehicle rho is same, c d change is slightly 0.44, area changes 3 the e-rickshaw area amount of area that the air will cut will become larger. Mu is same, weight increases like anything because suddenly you are talking about 5, 6 people.

So, instead of 200 kg you are talking closer to 700 kg, 680 kg that will make a very-very big difference I am taking the same gradient of 5 degrees and for sake of calculation I am saying the same pickup 20 second for a specific speed.

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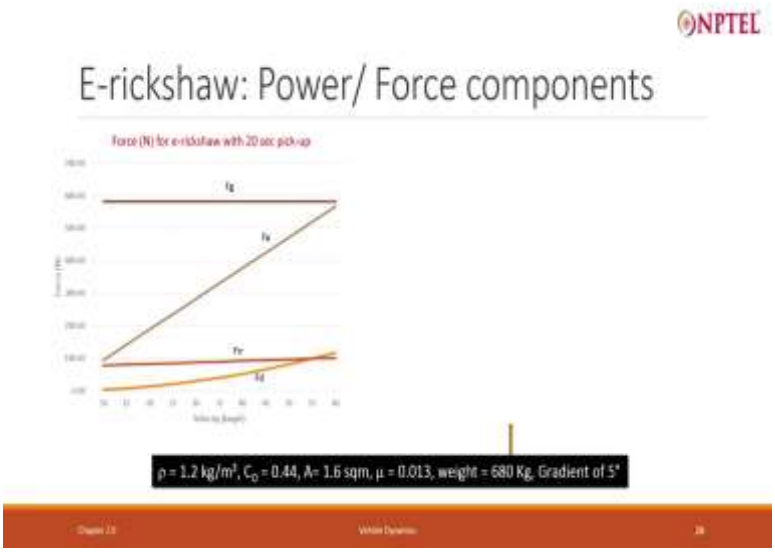

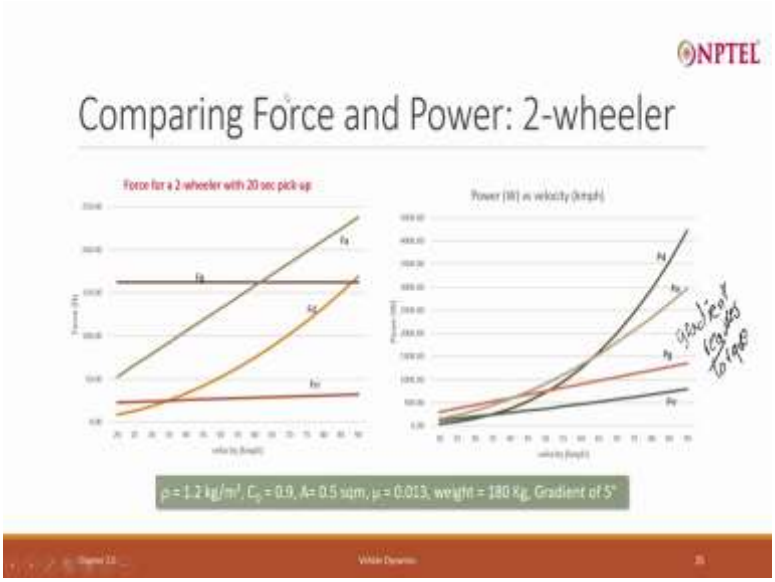

Look at the force, if you see the gradient force is now very-very large, compare it with the graded force that was required here gradient force required here you can see it on this screen it is more like 160 Newton, gradient force required in this is 600 Newtons, why? Weight has gone from 200 to 700 kilo newton, little bit of drag also has gone because the area that it cuts becomes larger.

Acceleration, again plays a very-very important role particularly if you want to do fast pickup up to 60 kilometre it goes up like anything, it just keeps on increasing depends on in 20 second what is the speed that you want to reach, if you want to reach only about 25 kilometre is not that bad, but if you want to reach 60 kilometre it again requires a 600 Newton force.

Here, even at 90 kilometre you require only 250 Newtons, here you require much more because again mass comes in mass plays a major role. What about drag and rolling resistance? Rolling resistance is about 100, but if you see rolling resistance is still higher compared to this because once again mass comes in, mass plays important role.

Drag is basically the same between the curve that I am showing here for e-rickshaw and the curve that I am showing here for a 2-wheeler, why is the 2-wheeler curve showing as if it increases rapidly? Because the scale is that it actually goes even at 60 kilometre per hour it will go to around 100 Newtons, not even 100 Newtons 60, 70 Newtons.

Here, it is only up to 60 kilometre and you see it goes to up to nearly around 100 kilometre, it is not a function of mass, it does go up a bit because of the area going up but not considerable.

Student: C d also changes.

Professor: c d also changes. So, this is the force for e-rickshaw, so now I will actually look at that. What about the power?

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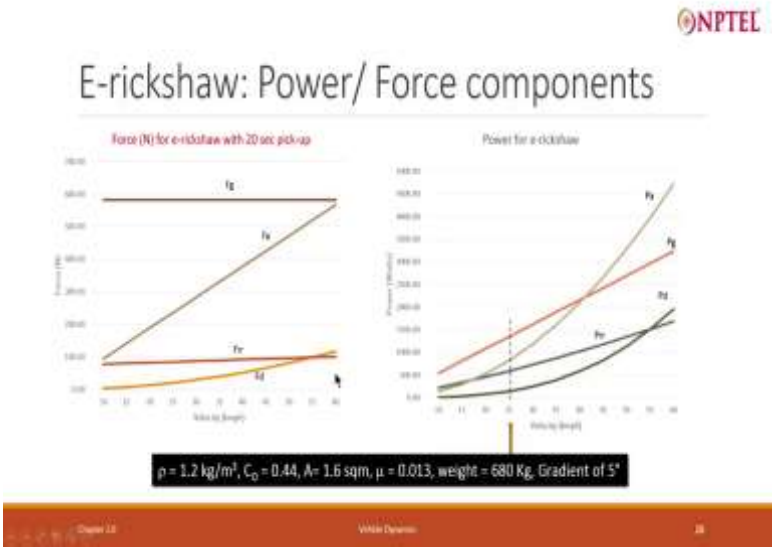

So, as a result now you multiply it by velocity all these curves and what happens and if you see this the gradient power now is ofcourse a function of velocity and gradient power can be quite large, gradient force was large you multiplied by velocity and at 60 kilometre per hour it exceeds 3000 watts 3.5 kilowatts.

But at 25 kilometre per hour still manageable, what happens to drag? Drag which in the force did not look like at all anything considerable, here the drag force does increase thus the (grad rate) drag force is going up because velocity component has come up but still not like that large, rolling resistance was low now it is dependent on the velocity, so it is going up; up to 60 kilometre.

At 60 kilometre drag and rolling resistance are between 1500 watts to 2000 watts but at 25 kilometre if you see rolling resistance is 500, drag is practically negligible that is a big advantage e-rickshaw is normally designed to work only up to 25 kilometre per hour and at 25 kilometre per hour drag plays practically no role.

Acceleration plays some but acceleration depends, are you going to accelerate in 20 second, in e-rickshaw it is not that important given this as compared to 2-wheeler.

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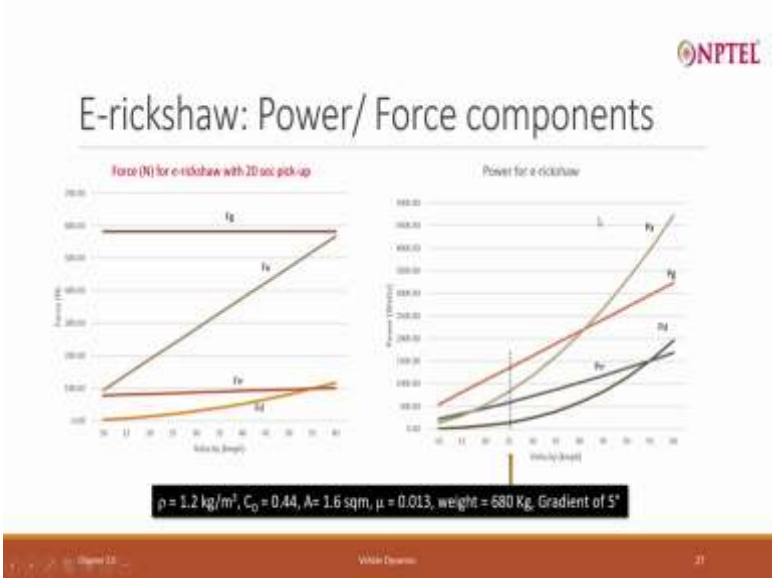

Now let us look at, so the same curve I am showing out here, let us look at what is the implication. Let us look at the power.

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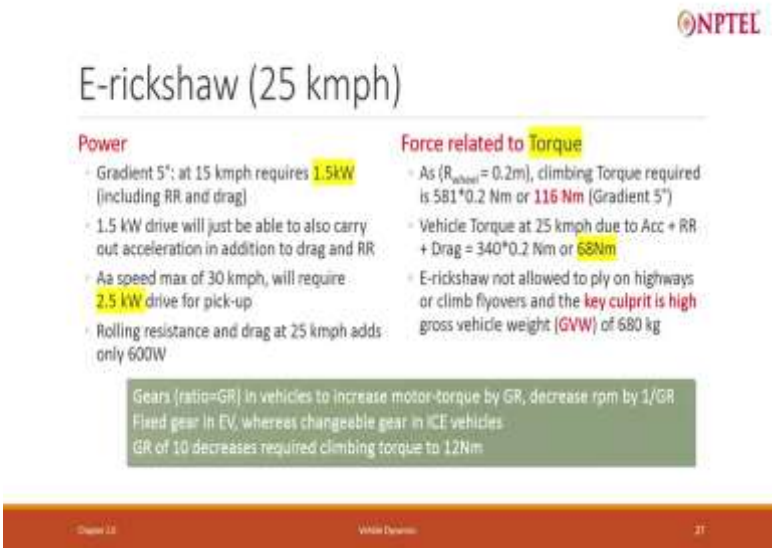

A gradient at 5 degrees at 15 kilometre per hour 15 kilometre per hour I require approximately 1.5 kilowatt, 1.5 kilowatt if I really travel at 15 kilometre per hour because I have done here at the curve is done at 3 times the velocity you will have to actually see the 45 kilometre barrier, this is 1.5 kilowatt including rolling resistance and drag.

So, 1.5 kilo e-rickshaw motor if you make it go up to 1.5 kilometre, kilowatt then it will be able to traverse slow but normally slope is not allowed, we will take from torque point of view it will become a problem, power it does not become problem and 1.5 kilowatt will just be able to carry out acceleration in addition to drag.

So 1.5 kilo watt if I have if I look at the acceleration power is 700 watts there is the drag power and rolling resistance together all of them is around 1.2, 1.3 kilowatt. So 1.5 kilowatt motor is good I do not require more than that. In fact the motor that is used is around 1.2 kilowatt. As speed goes up from 25 kilometre to 30 kilometre your things start getting worse, you will suddenly require around 2.5 kilowatt, why?

Because your gradient force also will be have gone up more important if you look at the acceleration force has gone up and both these at 30 kilometres both these points actually go up. Rolling resistance and drag at 25 kilometre adds only 600 watts, so 600 watt is what you have to do up to 25 kilometre per hour it is fairly safe.

I want to again point out force is related to torque and this is where you will find problem. Force on the other hand if you see in e-rickshaw the grating force is very large because

gradient force is very large if I take climbing torque requirement goes to approximately this is 580 Newton multiplied by the wheel radius, wheel radius is smaller 0.2 meters it comes to 116 Newton meter 116 Newton meter from a motor for a three wheeler low end motor which is about 1.2, 1.3 kilo watt will be very difficult.

So even a 5 degree slope it will not be able to climb up, 8 degrees is impossible. E-rickshaw by the way is common only in India, they are not there in many other most other parts of the world but they play a very important role in the country probably the electric vehicles if you see maximum number of vehicles are only e-rickshaw in the country. So what does regulator do government do?

E-rickshaws are not allowed to climb a flyover and e-rickshaw is not allowed to travel on a highways they just do not have the torque. So if you start trying to go over a flyover it will get stuck, and if it gets stuck it will block all the traffic below behind and therefore they are not allowed.

Even on a highway it cannot speed up 25 kilometre per hour, which means it will be actually all the time vehicles has to keep on passing unless there are multiple lanes it is going to be difficult, overtaking always requires extra lanes and you do not want the traffic to be slowed down in highways.

So, on the flyovers and highways e-rickshaws are not allowed. So, if you see one is a limit of 25 kilometre the second is a limit of the force the torque vehicle torque at 25 kilometre per hour due to if I take all the three into account acceleration plus rolling distance plus drag is a slightly better value if I combine all the three at 25 kilometre per hour it is about 225 or 230 Newtons here plus about 100 Newtons plus about 20, 30 Newtons.

So you are talking about 340 Newtons multiplied by 0.2 68 Newton meter, 68 newton meter then therefore becomes a target for your motor, if you look at it 116 Newton meter you would not be able to handle, 68 Newton meter you may be able to handle with the right gear we will talk about gear playing a important role.

And therefore, for flat road this is a flat road up to 25 kilometre you can go for a flyover you cannot do it, therefore as I pointed out e-rickshaw are not allowed to ply on highways or climb. The key culprit is a large weight 680 watts is what we have taken kg 680 kg we have taken, this much of thing climbing up is very difficult highways is very difficult.

Now, are you going to design a 1.2 kilowatt motor with 68 Newton meter? No, even that is not possible even torque of this size is not possible. So all these vehicles will have gear, now gear is there in IC engine also gears will always be there in electric vehicles also we will discuss this gear in detail later on.

The gear in IC engine in a petrol engine is a gear where gear ratio can be changed its a changeable gear, you move gear from one point to another because petrol engine or IC engine can only allow the so much variation in speed and so much variation in the force. So you make a changeable gear, now changeable gear what it will require? It will require a clutch, then gears has to be changed gearbox has to be there that whole thing becomes complex.

Electric vehicle on the other motor can actually take whole range of velocity and still RPM and still try have a fairly good efficiency and it is possible therefore to also get the fairly large differential torque. So generally electric vehicles is used uses only fixed gear. Now fixed gear ofcourse is a big advantage I do not require clutch, I do not require changeable gear, changeable gear is much more complex as compared to fixed gear but it means that I have to design one gear, and what does a gear do?

The role of gear is very simple, it multiplies force or a torque and it divides the RPM or the velocity, it multiplies torque divides by the same extent. So if I take a gear ratio of 10 my torque available from a motor will go up by 10 but my RPM will go down by a factor of 10. Now I can design a motor with large variation of RPM and therefore even if it goes down I still can drive at a decent speed.

So for example, in a vehicle like a e-rickshaw and we will talk about this again and again and again. The gear ratio typically uses 10 newton meter. Now for 10 newton meter the slope time instead of 116 Newton meter how now require only 12 newton meter to climb, even that is tough from a 1.5 kilowatt motor but if I look at travelling at 25 kilometre constant speed 68 newton meter you divide it by 10, 6.8 newton meter that is easily doable.

So in fact, electric vehicle e-rickshaw motors are designed approximately 1.2 1200 watt normal power, peak power can go up to closer to 1.7, 1.8 so it will take care of all these requirement torque, peak torque can go up to 7 kilo Newton meter and with the gear it will give you 70 newton meter, so that is how it is designed.

We will talk about gears more in a another chapter we will specifically talk about gear, so the term used for gear gearbox clutch everything is in a petrol engine, IC engine is transmission because you have a fixed gear electric vehicle your transmission is very simple. A simple gear with a fixed ratio, you know in a other vehicle in a petrol vehicle is far complicated.

Now this however means that motor has to be appropriately designed for wide range of torque and RPM and that is what we are going to focus on.

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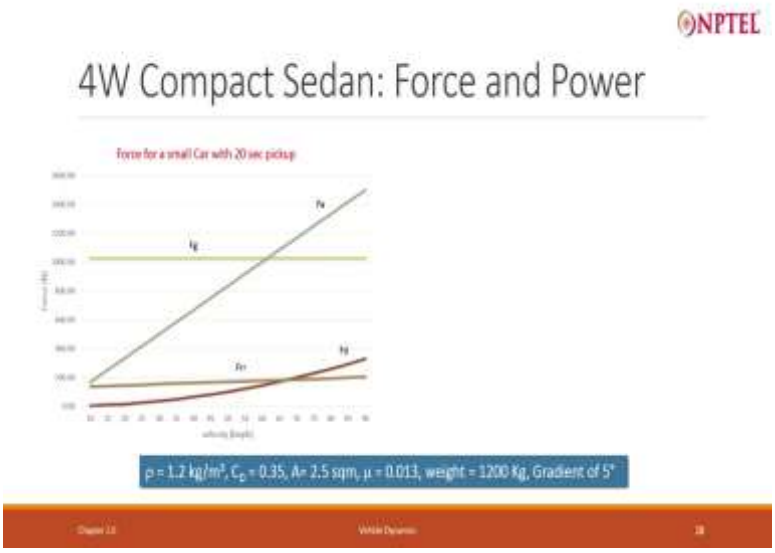

Now having done this, let me come to a small sedan, small 4-wheeler kind of vehicle is like Mahindra E-Verito, I think you must have heard of Mahindra came about 4-5 years back one of the first vehicle electric vehicle that came into India is E-Verito, in fact I own one such vehicle I have been driving that for almost 4 and a half years.

It is a vehicle where 4 people sit comfortably 5 people can sit, no problem back seat 3 people can sit 5 people. It is a vehicle with not very powerful motor is designed to only travel at certain speed maximum speed that it travels about 70-80 kilometre per hour 80 kilometre per hour above that becomes very difficult, it does not go to 120, 130 kilometre that many other vehicles go it has a certain torque, so climbing becomes slow.

So this is the vehicle I have taken the motor weight to be 1200 kg, this weight includes passenger weight which is little small, if I put 5 people then it cannot be 1200 kg it has it will go up, so one has to take that into account but I still do the calculation at 1200 kg gradient is

5 degrees. So it is about 8-900 kg vehicle with 5-3 people normally it will be 1200 kg, all 4 people will be 1200 kg, 5 people will become extra.

The air density remains same, the drag coefficient is 0.35 if you look at the drag coefficient that I yesterday talked about, you will see the 0.35 for a sedan kind of vehicle compact sedan it is a combined not very large vehicle it is like your little bit like your ambassador vehicle of yesterday years.

Area is larger 2.5 square meter even larger than the 3-wheeler, what happens to all these forces? Look at the forces gradient of even 5 degrees is about 1000 Newtons, force is of course constant with velocity if I want to accelerate in 20 second suppose I want to go to 50 kilo 60 kilometres well it is again 1000 Newtons but if I want to go to 90 kilometre, it is about 1450, 1500 Newtons force goes up quite a bit.

Look at the other two components, compared to these two component they look very small look at the rolling resistance just under 200 to begin with as speed goes up it goes to up to 200 Newton. What about drag? Well, even 50-60 kilometre per hour it is still under 200 at 90 it goes up slightly to around 300, 350.

So in a normal operation it is only going to be rolling resistance and drag I would not accelerate I would not go to slope, so the force requirement is not that high even if I add everything up its about 500, 300, 500 Newtons but if I take the gradient it is large. So it has to be designed to take that into account and if I want acceleration that is going to be large.

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Let us look at the power, look at the power curve as I told you everywhere a v term gets added rolling resistance therefore continues to increase at 60 kilometre per hour rolling resistance is still going to be around 3500 watts 3.5 kilowatts drag is going to even less at 60 kilometre look at 60 kilometre at 60 kilometre what happens, gradient power I require well 60 kilometre is actually 20 kilometre I require about 5-6 kilowatt acceleration requires about 8 kilowatt plus I have to add the other two.

So look at it, if I mean take and if I want to travel at 60 kilometre and I want this acceleration plus rolling resistance and drag, it will be 6 plus 2 plus 2 I require 10 kilowatt even for gradient I have 6 kilowatt plus 2 plus 2 so 10. For acceleration at I require plus 8 plus 2 plus 2 so 12 kilowatts, so 12 kilowatt motor can make it comfortable up to 60 kilometre per hour.

On the other hand if I want 90 kilometre per hour things change, first of all if I want a fast pickup I require almost 18 kilowatt and my gradient also requires 8 kilowatt plus drag and rolling resistance is also increased to about 5 to 8 kilowatt, so I will require even if I do not want to accelerate that fast, I will require 8 plus 5 plus 5 about 18 to 20 kilowatt motor. Ofcourse, I still will not be able to accelerate fast enough.

Now when do you need acceleration? Ofcourse during the pickup right in the beginning you also need to when you try to overtake. So if you want to travel comfortably at some 80 kilometre on highway and want to be able to overtake then you require 18 to 20 kilowatt motor, otherwise 14-15 kilowatt motor may be enough.

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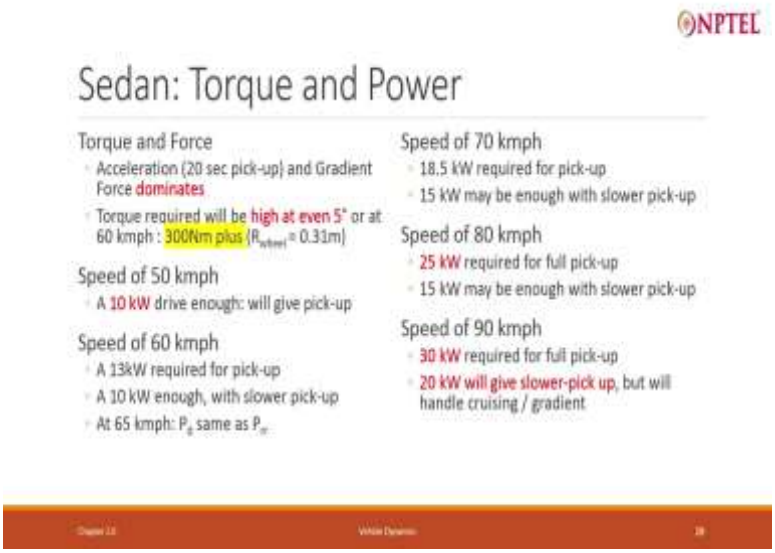

Now so that is what you must keep in mind and I look at therefore again torque and force acceleration 20 second pickup gradient and gradient dominates, that is what it is, it is the pickup for the torque both things dominate both these dominate. Fortunately both of them do not to come up together, so one of the two will be there. So for the torque that you require, torque required at 5 degree slope at 60 kilometre per hour one I have computed it is 300 Newton meter it is a 1000 radius is about 0.3 meters so what 300 Newton meter.

So you require 300 newton meter you have to choose the appropriate gear ratio to get 300 Newton meter. Of course you have to also require at that point some force due to the rolling resistance and drag you have to add that but this is 2-300 so okay you may want to go 330

340 Newton meter, that is a kind of thing that you require and if you choose a good gear ratio you require only that much, that is the torque and force.

And by and large at 60 kilometre that will also give you sufficient acceleration, if on the other hand if I take a speed of 250 kilometre or 10 up to 50 kilometre 10 kilowatt drive is enough, I just shown you for 60 kilometre you require about 13 kilowatt for pickup 10 kilowatt is enough is slower pickup so 10 to 13 kilowatt is required and in fact E-Verito I think has a motor which is about 12 kilowatt or something like that not much more than that

But if you want to travel at high speed and do all kinds of things at 70 kilometre per hour you require about 18.5 kilowatt at 70 kilometre per hour, let us look at 70 kilometre per hour. At 70 kilometre per hour you require higher, higher at 70 kilometre per hour you require higher both for acceleration gradient.

So you require about 15 to 18 kilowatt at 80 kilometre required you suddenly are requiring 25 kilometre per hour for 80 kilometre you require almost 15 for acceleration plus drag and rolling resistance you require 25 kilowatt motor 15 kilowatt may be enough if you are not willing to have very fast pickup.

So the new E-Verito are about 25 kilometre watt motors it all comes from these numbers and what are these three numbers there are only 4 quantities, first is rolling resistance, gradient, slope and acceleration and the parameters that you need is only rho, rho c d, area, mu, weight, weight plays important role and ofcourse gradient can play an important role.

Speed up to 90 kilometre per hour you suddenly require 30 kilowatt for pickup, 20 kilowatt may be enough including for slope, slope ofcourse you will not go at 30, 90 kilometre you will go at 30 kilometre per hour, so if you have a 20 kilowatt motor it will give you a slower pickup but rest it will work. But 90 kilo watt kilometre per hour this kind of stable storm, what about if you want to go to 150 kilometre per hour like in Europe?

Whole thing will shoot up more like 60 kilowatts, 70 kilowatt, 80 kilowatt you may be requiring. In fact it will be a good homework problem you take the same sedan make it work till 150 kilometre per hour calculate each of the four components, please note down and send it to me add this as a homework problem, that each of the rolling resistance drag pick up suppose you want at 90 kilometre gradient you want to travel 5 degrees alone but at 30 kilometre per hour because 90 kilometre resort maximum speed.

What is the forces and what is the torque required you will say torque also will significantly increase at 90 kilometre per hour. Gradient torque will not increase much gradient torque is flat but at 90 kilometre hour if you see this force at 90 kilometre per hour it is 1500 plus 200 plus 300 you require almost 2000 multiplied by 0.3 you require almost 60 Newton meter 600 Newton meter. So it is actually much more, so you have to design your motor appropriately.

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So I think I come to a very important part a drive train is to be designed to provide adequate force and torque force and torque is very important at different speeds to overcome drag rolling resistance gradient resistance also provide the right acceleration pick up. If you cannot have sufficient torque, you cannot speed up, you cannot go up to the gradient torque plays a very important role.

Similarly adequate power at different speed torque and power are two different things they are related in to all force the force is multiplied by the wheel radius to give you torque force is multiplied by another velocity term. So power speeds become very important torque is somewhat independent of speed for the different kind of drive having done this much we have actually done for three vehicles.

We can do for more vehicles we can do it for a truck, we can do it for a larger vehicle but its a pretty much similar and there are some homework problems and other things where I will be actually talking about this but there is a new task that I want to define for our next set of lectures. So far we talked about force, torque, power and speed four important parameters

force, torque, power and speed force versus speed, torque versus speed, power versus speed four parameters we talked about, next we are going to talk about energy.