INDIAN INSTITUTE OF TECHNOLOGY DELHI

Video Course on

Electric Vehicles Part 1

by

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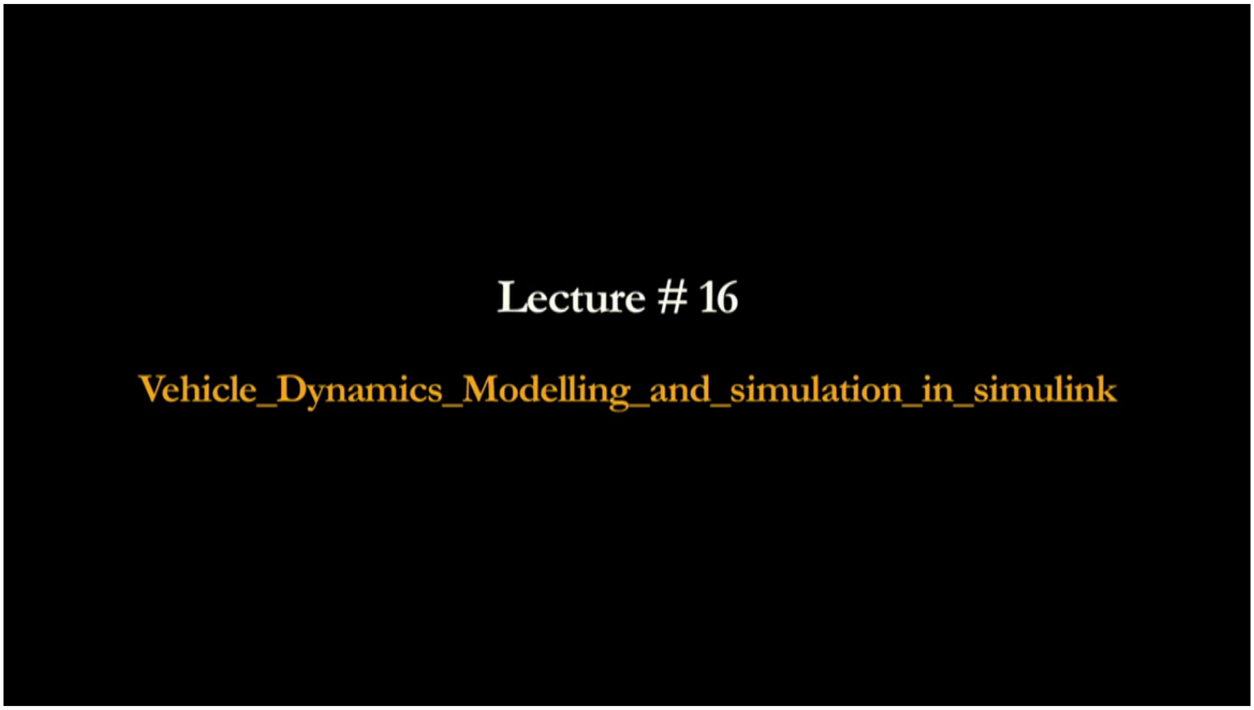
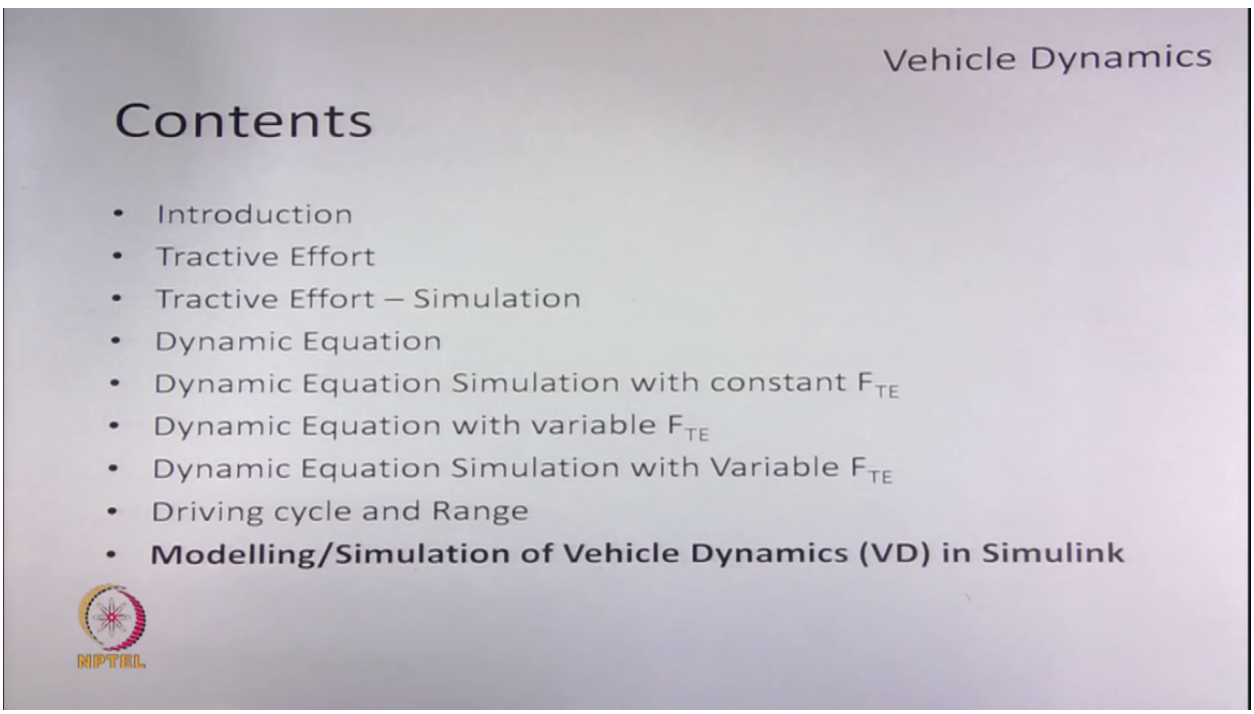
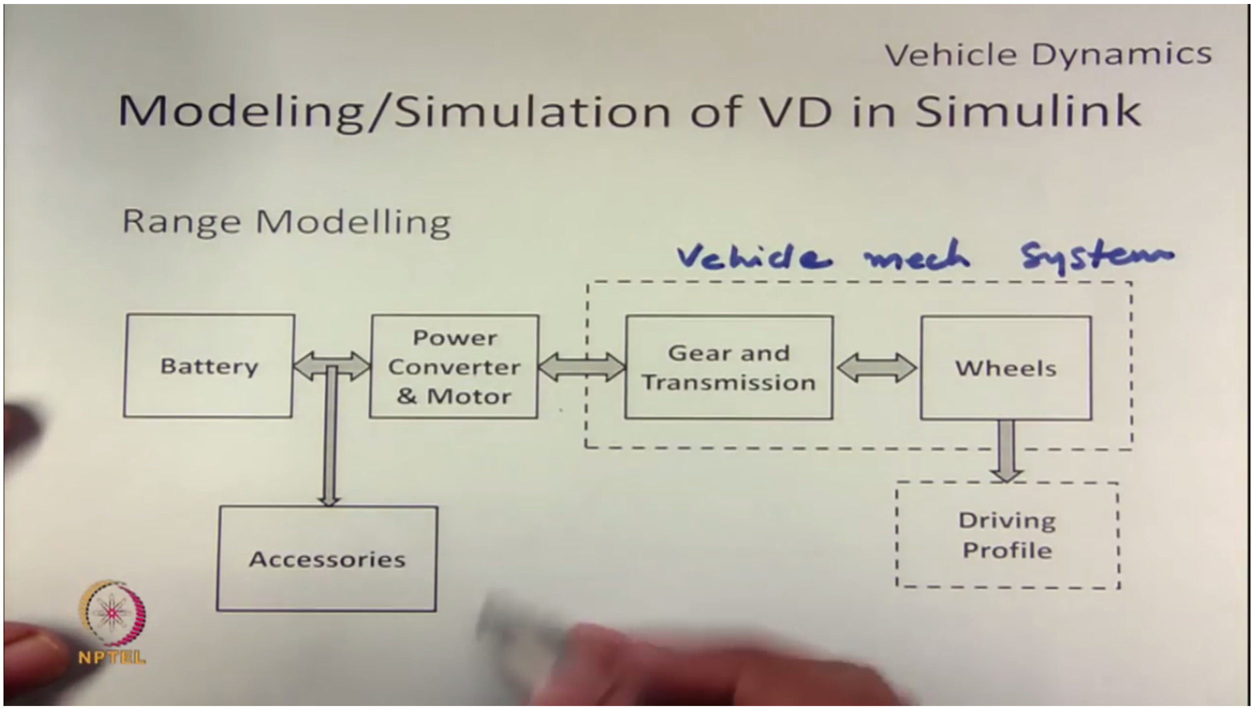




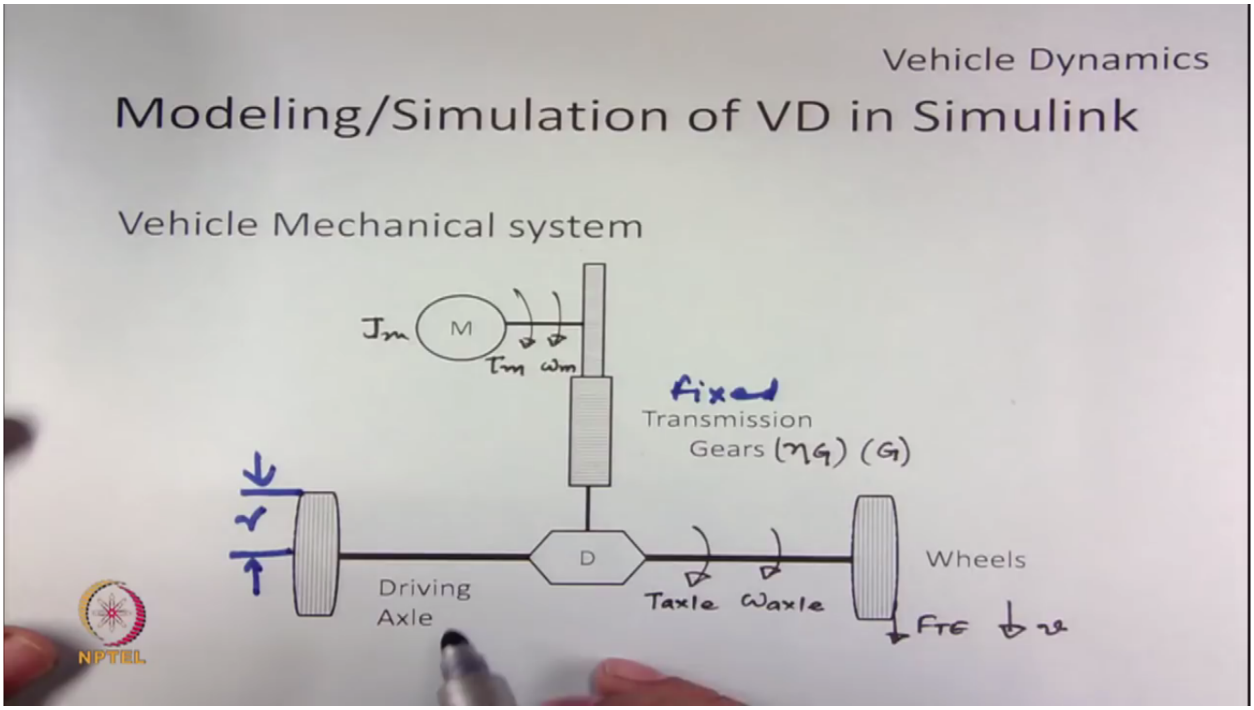
Hello everyone. Welcome to NPTEL online course on electric vehicles.

In today's interaction let us discuss the next topic under vehicle dynamics which is modeling and simulation of vehicle dynamics in simulink. So as most of you maybe knowing a simulink is a tool within Matlab which is widely used for simulation of dynamic system. So it will be nice if we can model and simulate the vehicle dynamics also in simulink. So let us see how it can be done.

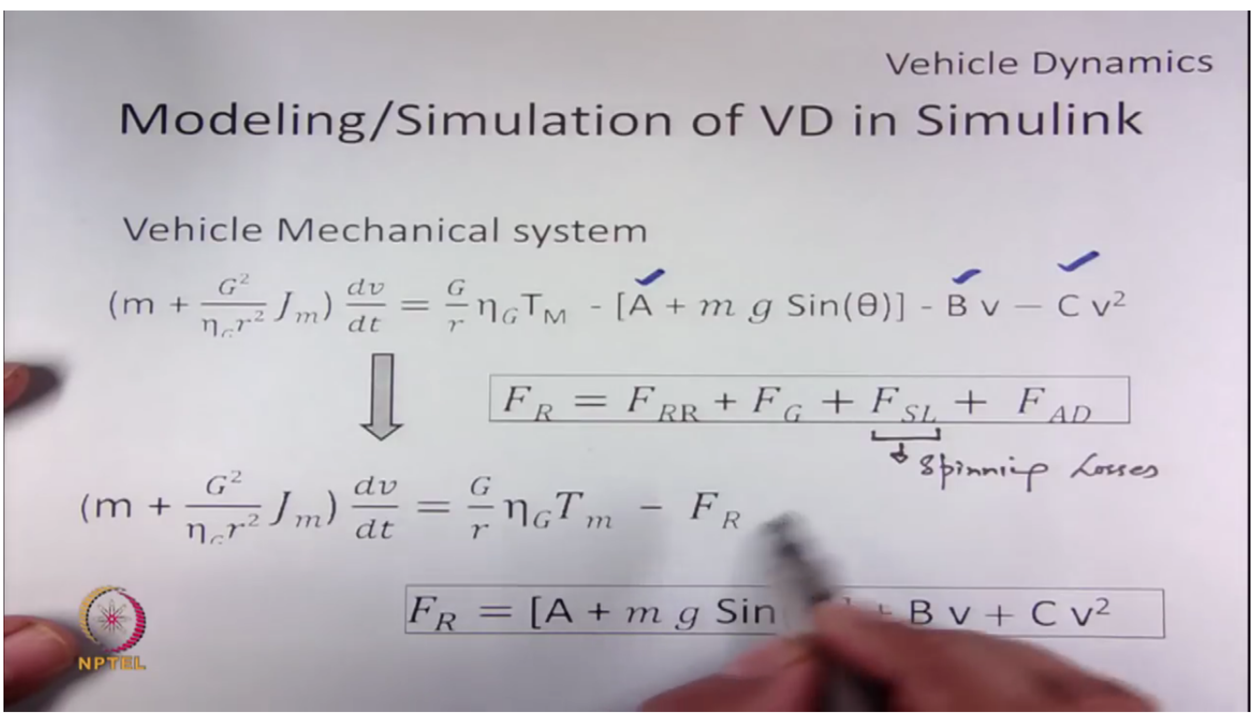


So when we see the total system of a petrol electric vehicle, it consist of battery followed by power converter and mortar gear and transmission and wheels of the vehicle. Battery also needs to support the power requirement of accessories such as air conditioner, heater, power steering, infotainments, and other things. So when we want to model the total system we have to model each of this subsystem individually. So let us try to model the vehicle dynamics within a battery electric vehicle or it can be same for even other vehicles such as fuel cell or ultracapacitor or utra-flywheel based EV or a combination of many resources combined to drive a electric vehicle.

So this is the, you can say it is a vehicle mechanical system. So you're talking of driving profile, wheels, gears and transmission. So we shouldn't be able to model all these things separately. And the models of these can be added later.

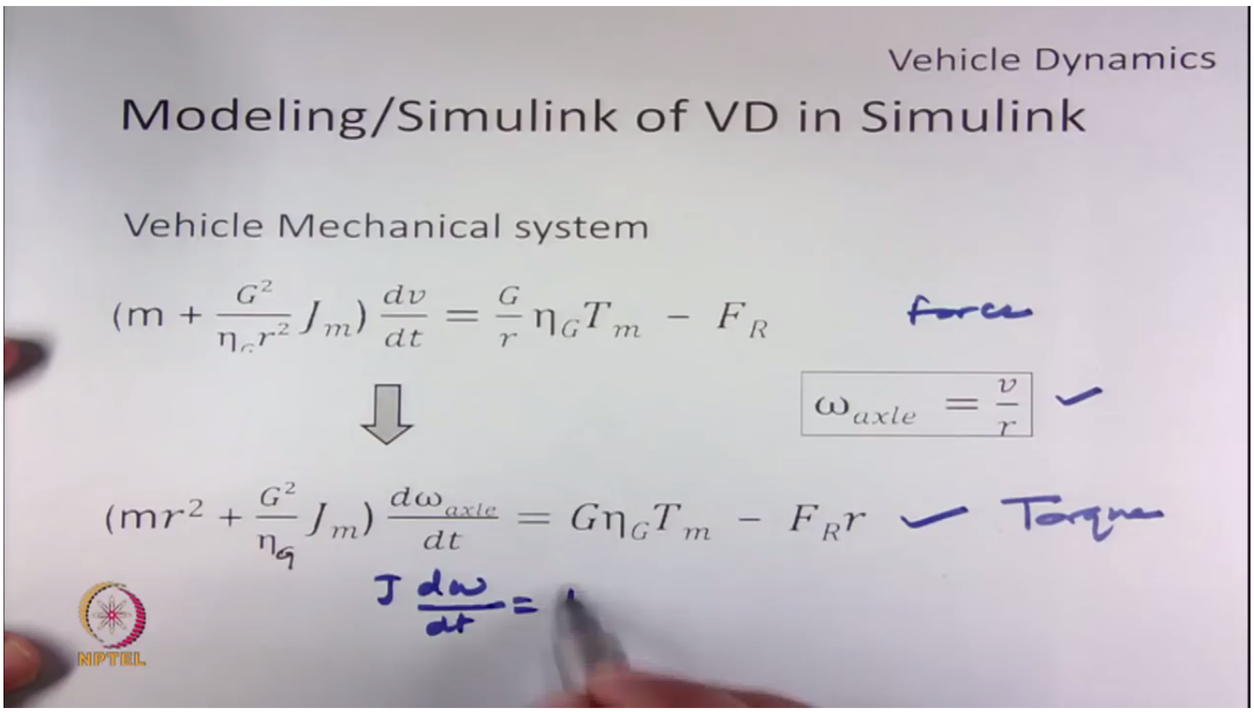


So as discussed we have seen the diagram of a vehicle mechanical system wherein electric motor drives a fixed gear system which is connected to differential and to the wheels via driving axle. So this is basically fixed gear system. So let us assume that retractive efforts on the wheels, FTE which is driven at velocity V. So if you know the basically radius of the wheels you will be able to calculate the torque and angular velocity on the driving axle.



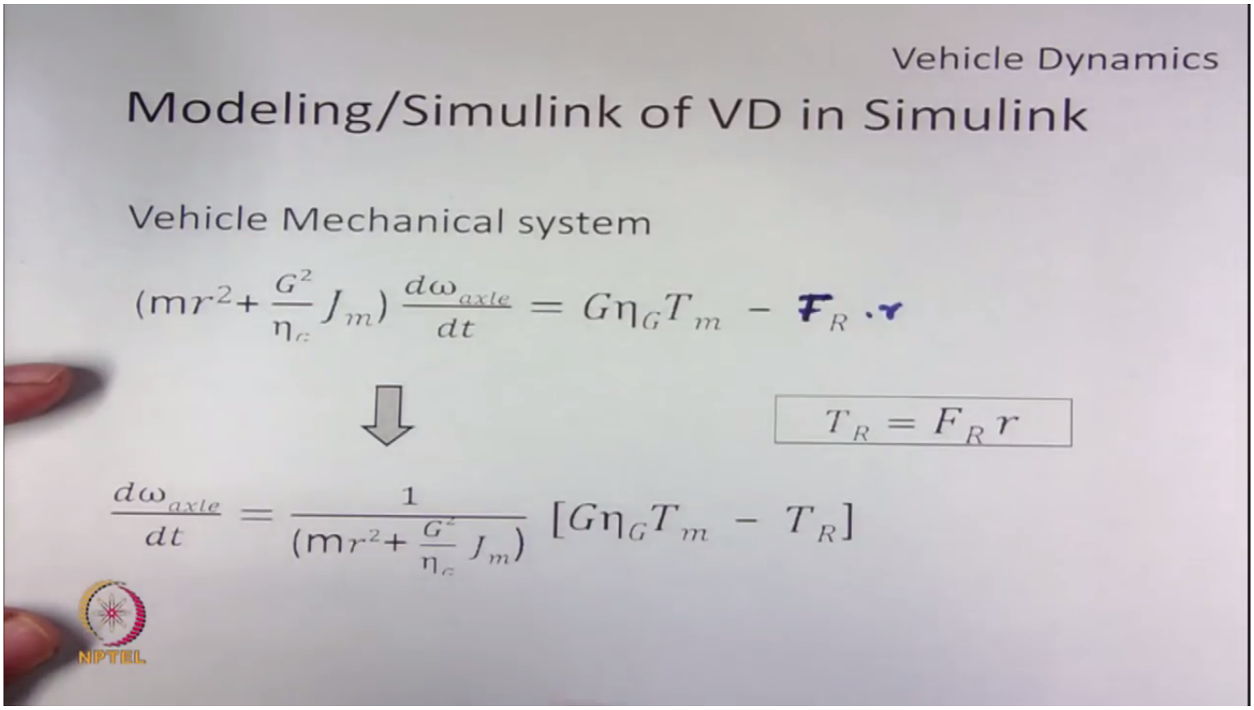
Generally if you have knowledge of the gear ratio and efficiency of gear, you can calculate the torque that is required on a motor shaft and relative velocity of the motor shaft. So using understanding of the tractive effort that is required to drive a vehicle we know that the motor has to support all resistive forces such as rolling resistive force, gradient force and aerodynamic force.

So this is the mortar torque. If the vehicle needs to accelerated it has to also support the acceleration for switches mass into dv by dt. So if we substitute the resistive forces as a FR we can rewrite this equation as this equation. We have also seen the method of representing the resistive forces by means of ABC constants. So in ABC constant in addition to rolling resistance force, gradient force and aerodynamic force we also consider the spinning losses forces as well. So in some sense these constants and force calculation using this constant is slightly more accurate compared to the previous case. So we can also use ABC constant to represent FR.

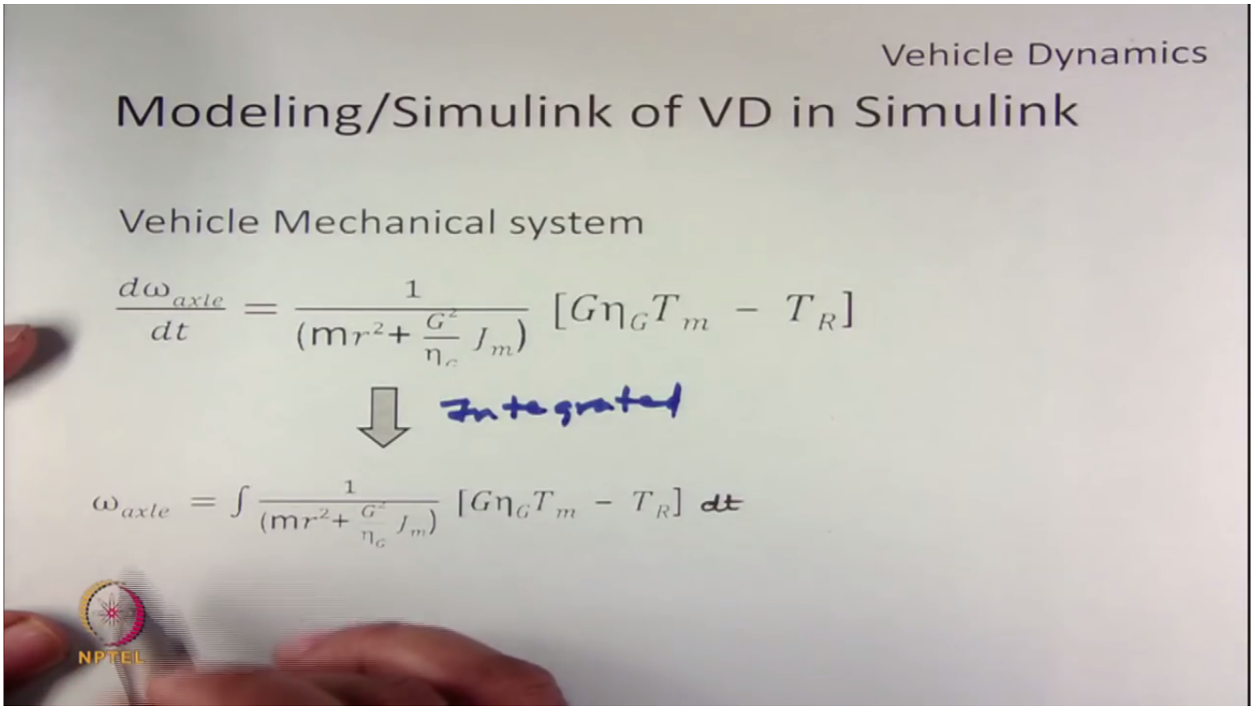


So we know the angular velocity of axle velocity of the vehicle divided by the radius of the vehicle. So if we substitute velocity equal to omega axle into r and the dv by dt we will get this equation. So we will get r term here. So this r term can be multiplied by this r term so you will get a r square term here. Basically if you do that we will get r square term here and this FR will multiply by this r. So if the r is equal multiplied by this r square will be canceled and m will be multiplied by r square. So using this substitution with slightly reconfigurating this equal we will get this kind of equation.

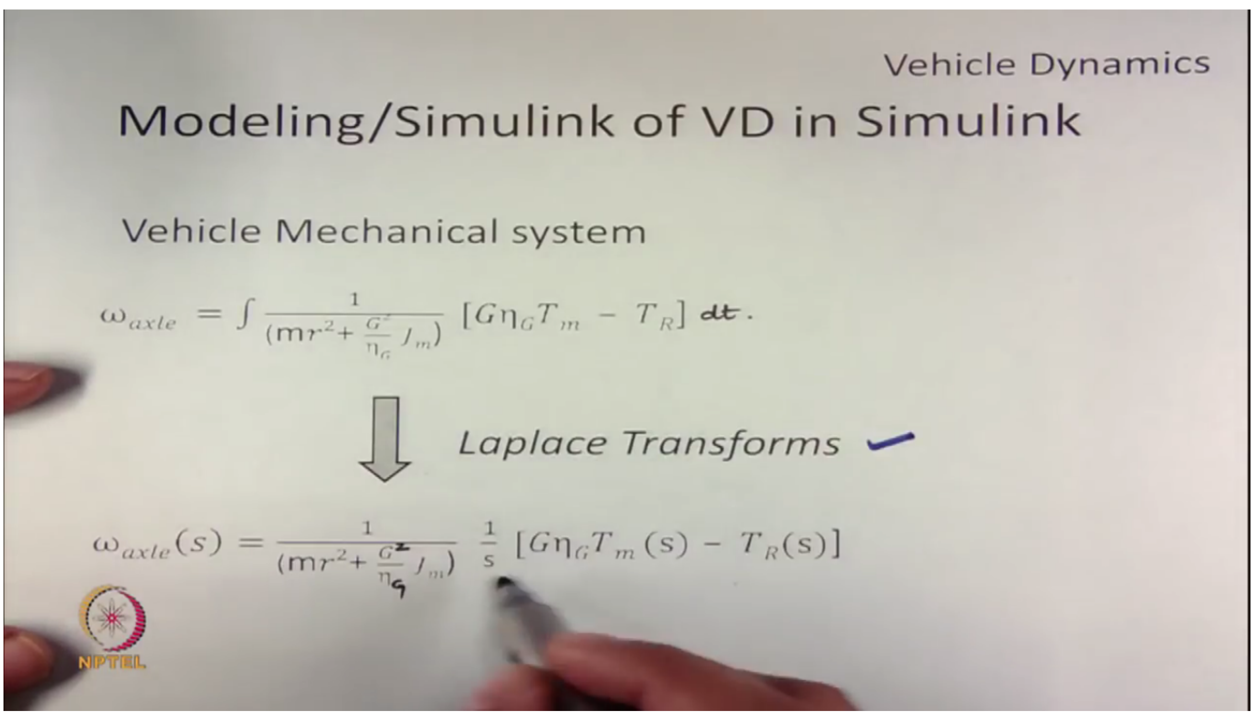
So the equation is a torque equation. So here the equation is a kind of force equation but this is a torque equation. So this mr represents inertia also. So this is inertia into d omega by dt equal to so it is very similar to that equation. J dw divided by dt equal to driving torque minus load torque. So this is equation we use for mechanical system. So it is very simple equation.



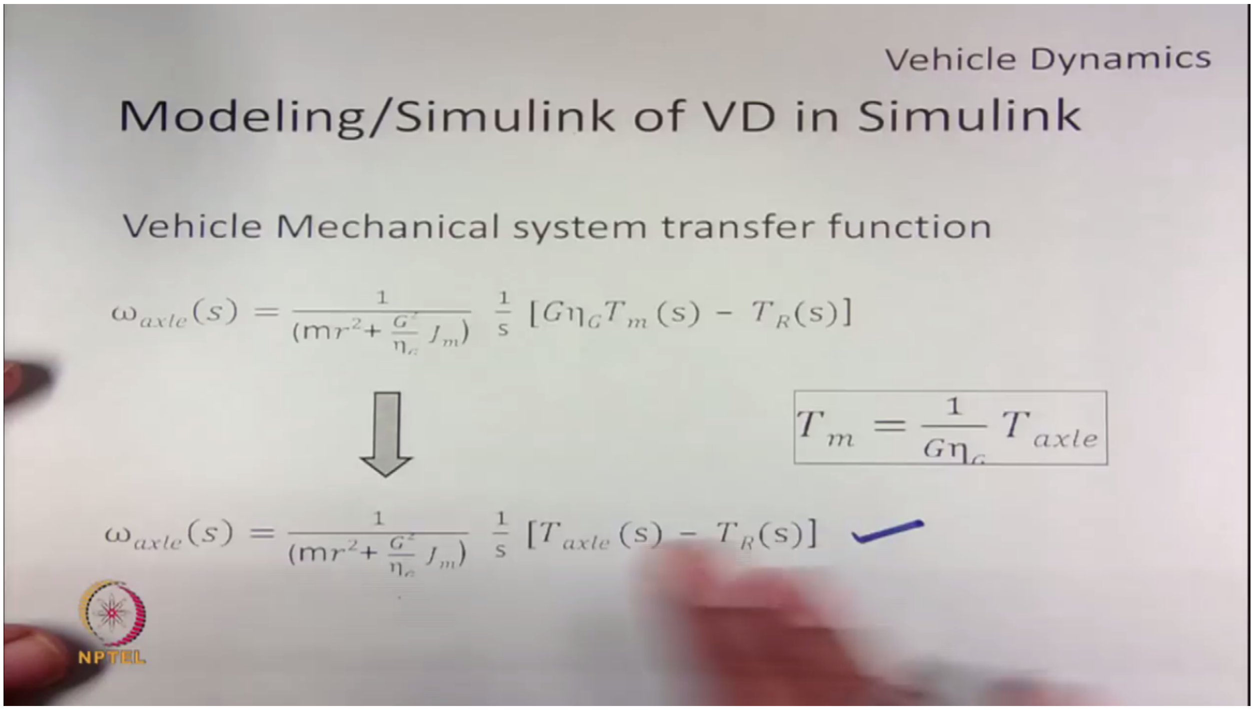
So this equation can be further modified as this so we can substitute FR into r and we will get TR. So we can say that torque due to resistive forces can be termed as TR. So this equation becomes this. So basically here it was kind of FR into r and which we will rewrite at this using this substitution. So if we add this equation in terms of discuss omega axle by dt we can move the inertia as one by inertia into difference of driving and resistive torque.



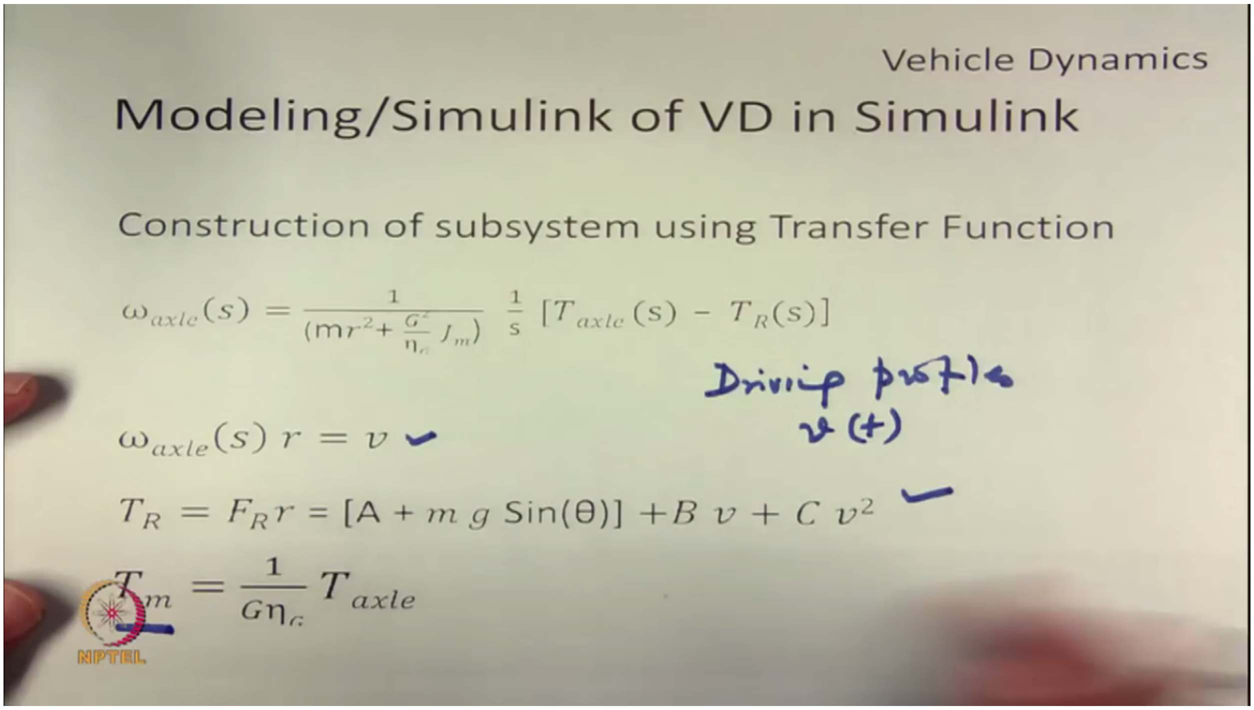
This equation can be now integrated so that we can calculate the value of Omega axle. So omega axle will be integration of this equation into dt.



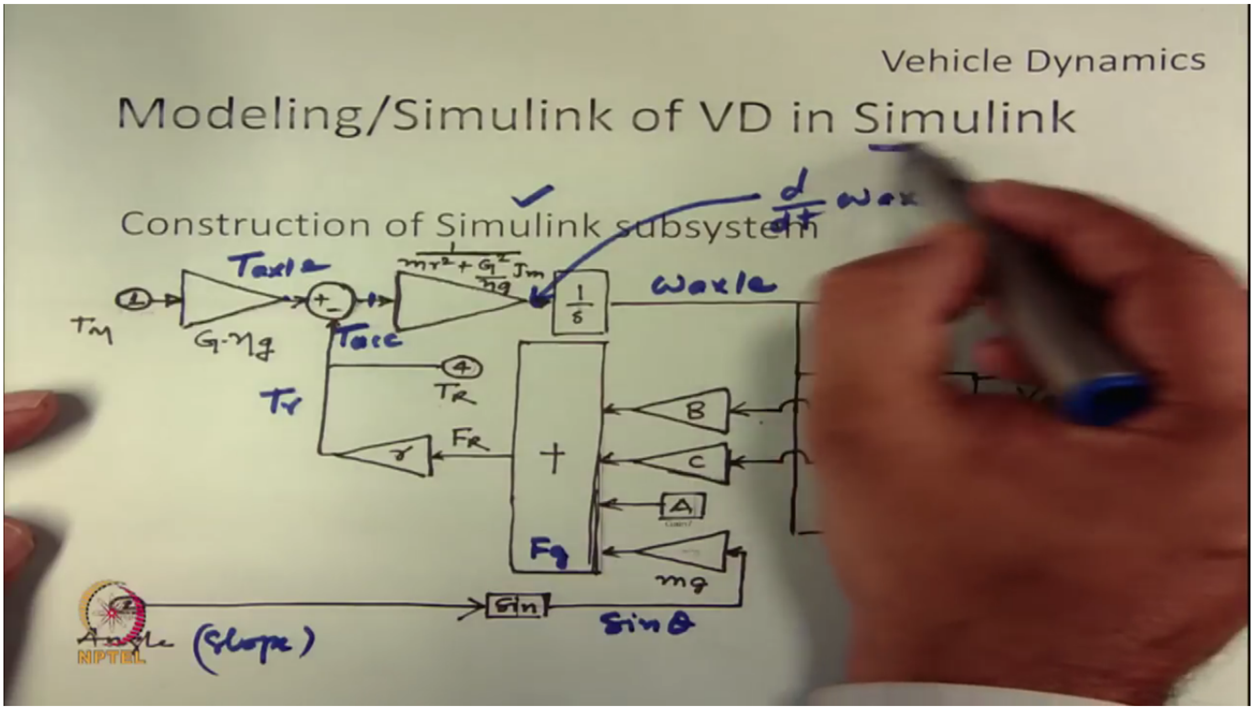
So if you want to get a transform function next domain with respect to this time equation we can do the laplace transformation and we can get a transform function with respect to this equation. So it will be so the integration of dt will be one by s. This equation will become.



So on the left hand we have omega axle. So it will be also nice if we can substitute the motoring torque also as function of T axle. So we know that Tm is one by G eta T axle. So if you substitute this here we will get this equation. So this is kind of equation in the driving axle.



So generally in a driving profile so if we look for driving profiles it's a basically curve of v of t. So let us use this transform function and all this relations so all things can related to velocity. So the more exact version can be done by using ABC constants. So we are relating here kind of the velocity profile and the – so the input to the system is torque of the motor and output is velocity. So we will be able to put all these together such that you maybe able to do the modeling the way we require.



So if some of you maybe accutom to simulink tool for Matlab it uses very simple terms such as addition, so this is addition. This is addition subtraction block. This is multiplication block and this triangle shaped is kind of gain blocks. And this kind of trigonometric blocks sine function. So using very simple blocks of simulink we can able to model this equation. So how we can do that? Let us see.

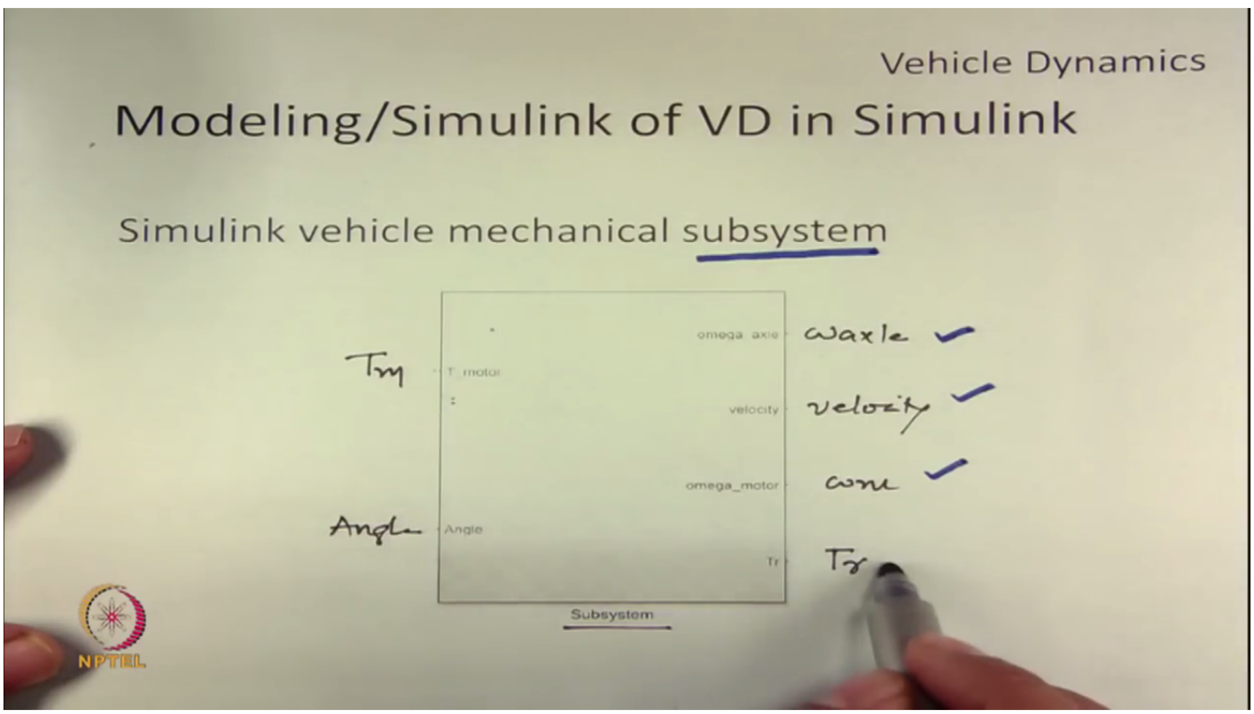
So we know that the input to the system is the motoring torque. So the motoring torque has to be first converted to the axle torque. So if we multiply G, eta G to Tm we get basically T axle and the output of it. So T axle has to be subtracted by the equivalent torque proportion to the resistive forces. So we need to calculate Tr here. So what is Tr? So Tr is a product of FR into r. And what is FR? FR is basically A plus Bv plus Cv square plus mg sine theta. So another input to this system is the slope angle. So if we know the slope we can define the angle and it can be multiplied by sine function to get basically here sine theta and if it's multiplied by mg we get basically here Fg force due to gradient and this is the force due to A constant B constant and C constant.

So for calculation of this resistive force we need velocity information. So how to get the velocity information? We can do that once we know the acceleration torque. So we know T axle minus Tr is nothing but T acceleration. So this is basically T acceleration. So once T acceleration is known we can multiply this T acceleration with the equivalent inertia of the system. So we know that it is mr square plus G square eta G by Jm. So if we divide this acceleration by this equivalent inertia basically here we will get a term which is so this term is d by dt of omega axle.

So this is angular acceleration. So once we have the angular acceleration if we integrate this angular acceleration we will get the angular velocity itself. So here the output is omega axle. So you can see that it's omega axle. So input of the system is one is Tm, two is angle. One of the outputs of the system is omega axle. So once the omega axle is known and if we have the information of the radius of the wheels we can multiply omega axle into r by means of gain and we can get velocity. So this is first output, second output. So now we have the velocity information.

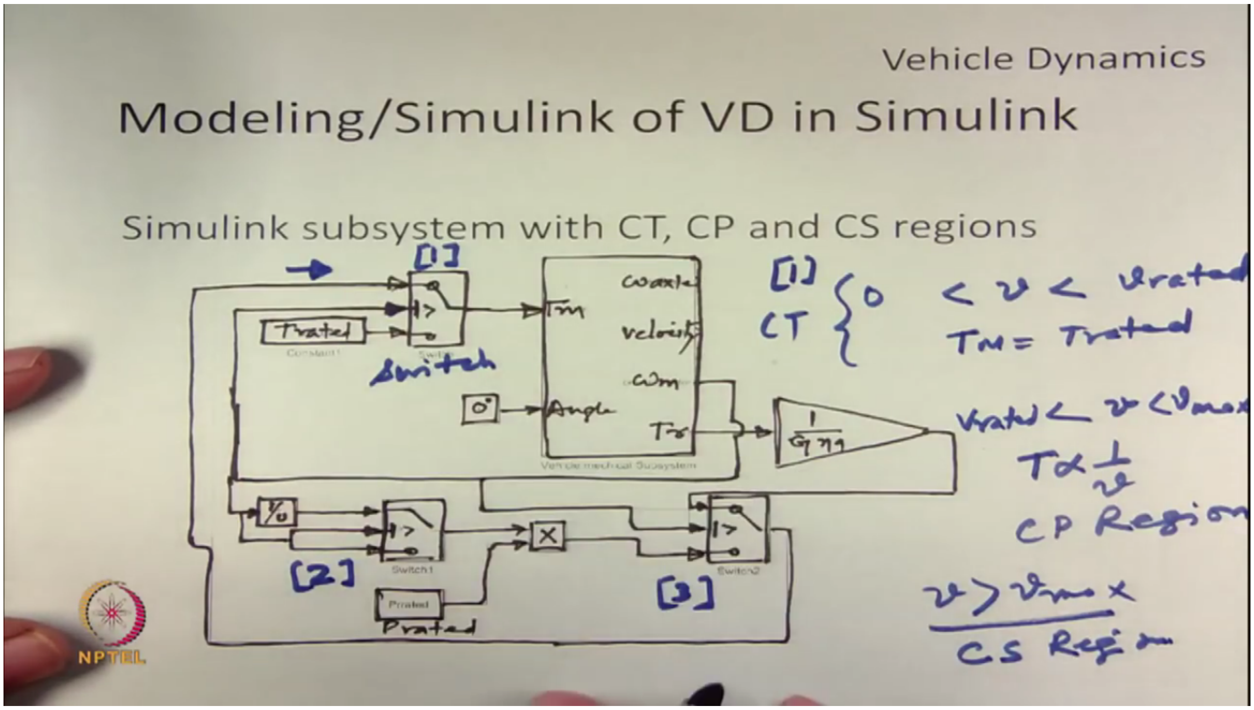
So once we have the velocity information, we can use it to calculate Bv force, Cv square force so here B into v it will create a v square. You can multiply by C to get the Cv square. On a motoring side we may like to know the angle velocity of the driving shaft. So if omega axle is multiplied by G we can get omega m which is the angular velocity of the driving shaft of the motor.

So we have three outputs. Omega axle, velocity and omega m inputs are Tm and slope angle. So you can see it's very simple way of representing the vehicle mechanical system in simulink.



So once we do this we can create a subsystem. If we combine them into a common block we will have two inputs of the block Tm and slope angle and three outputs, omega axle, velocity and omega m. So let us see how it looks. So if we do the subsystem generation for the system we have just talked we can increase the subsystem where these are the outputs and we can also take resistive torque as one of the outputs and put this motoring torque and slope angle.

So this kind of block can be used to connect with the motor control blocks. So generally electrical drives basically the control of electrical motor and the motor itself and their modeling is then simulink. And it will be very useful to connect the vehicle dynamic system to the electric drive system using this kind of blocks. So we will see and do the exercise somewhere later in the course.

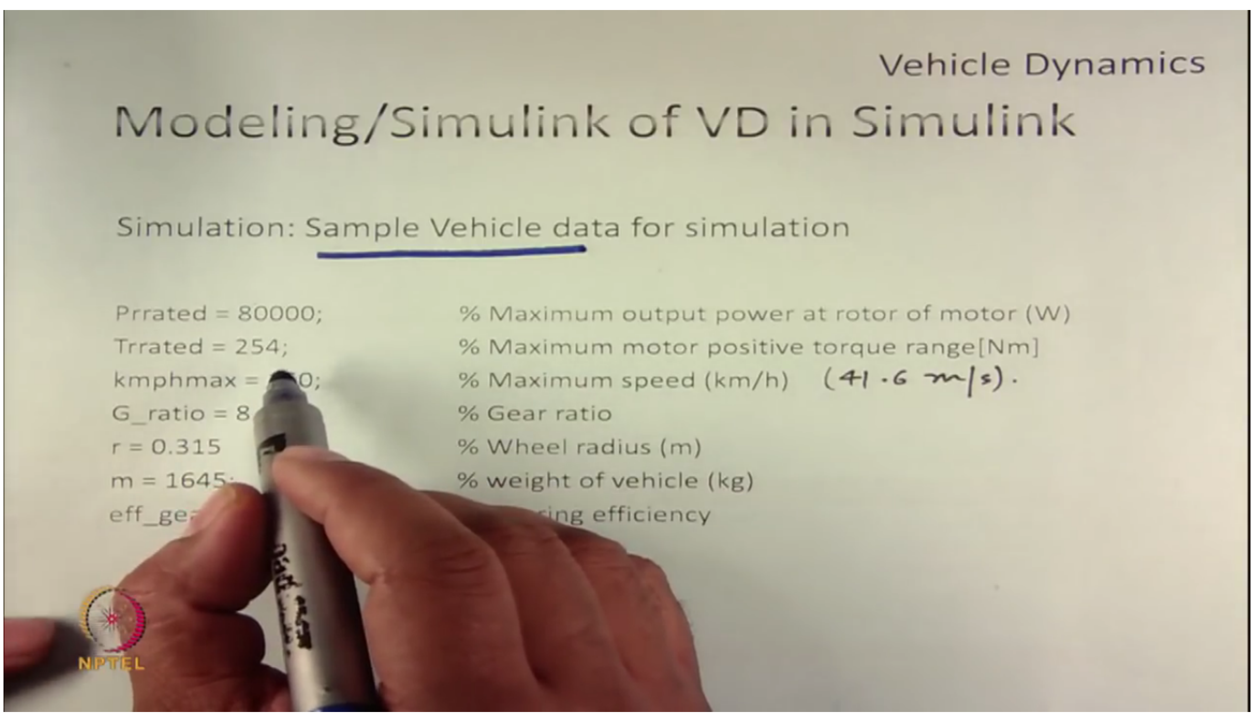


So we have seen that for a variable input tractive effort generally there are three regions of operations. So we have constant torque mode, constant power mode and constant speed mode. So these modes are based on the vehicle speed. So when the vehicle speed is between zero and v rated we say it is a constant torque region. So and together with Tm equal to T rated. So this together is constant torque region. Similarly, when the velocity is between V rated and V max and torque is equal to velocity this region is basically constant power region and when the velocity is greater than V max we say it is constant speed region. So if we want to incorporate all these features in this block we have to incorporate these conditions in the block. So we have already seen how this vehicle mechanical system can be made.

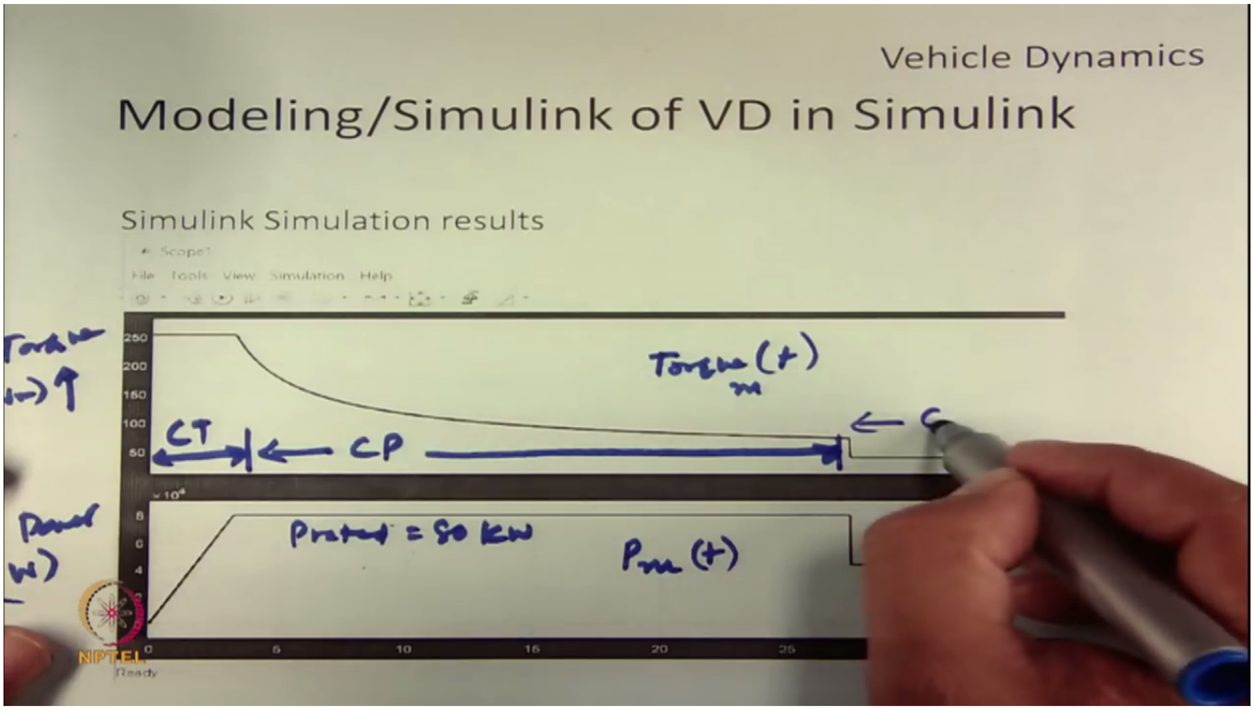
Now to incorporate this conditions and obtaining the different regions of operation we need to vary the torque input resistance. So we know that motoring torque is T rated in constant torque region. It is one by v in the constant power region and it is only equal to losses of the system when you are operating in constant speed region. So this can be done using some kind of selection or comparison of speeds.

So let us take the angular velocity of omega m for doing that comparison. So when omega m is less than omega m rated this block which is basically switch block in Matlab Simulink it will tell that if the omega so this input is coming to this block. So if omega of the system at current time simulation is less than omega m rated the torque input of the system will be T rated. So this selection is based on the current angular velocity of the motor. And this block will also tell that if the omega m is greater than omega m rated then use the value which is coming from here. So this value now we have to see how – so this value of torque maybe of constant power region or constant speed region. So these two blocks help us to do that. So again this omega input is coming to this block also. So when the omega m is greater than omega m rated this block or this switch block basically this is another switch block becomes active and it will tell the torque input to the system will be P rated into one by omega. So this is reciprocal function one by U. So P rated into one by U of omega m will now go as the torque input to the machine. So if this – the first is this block, so let's say this block will be active so this is basically block one which is this. Constant power region is basically this block or this switch block basically and this is constant speed block.

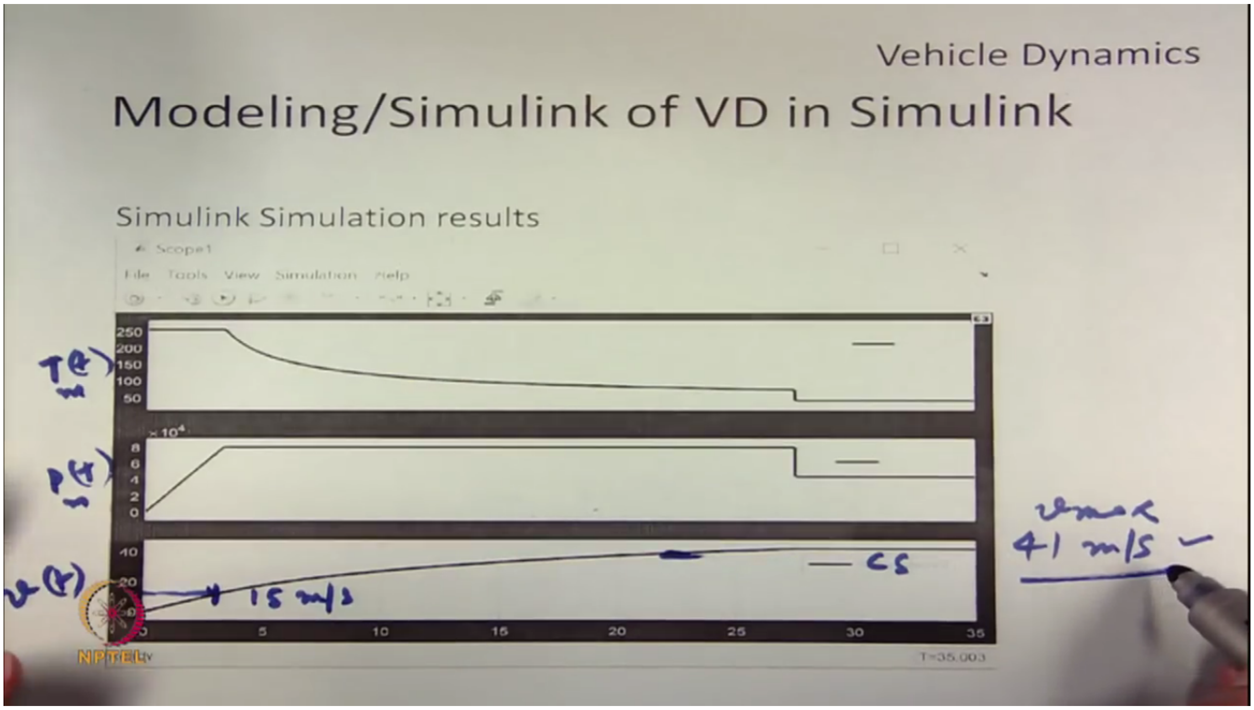
So first in constant torque mode based on speed feedback P rated will be selected when the omega m is greater than omega m rated P rated by omega m will be selected as torque input to the system and when the omega m is greater than omega m max this switch will be selected. Losses. So here we only support losses. So this can be – this kind of intelligence can be incorporated and we can get all these three regions of operation.



So let us see the results pertaining to this simulation block. So let us take a sample vehicle data. So the rating of the machine is 80 kilo watt. The torque rating of the motor is 254 Newton meter. And the maximum speed of the vehicle in kilometer per second is 150 so it will be 41.6 meter per second. Gear ratio around 8. radius 0.3l. Mass is around 1500. Efficiency of 0.97. So let us try to add this data to the Simulink blocks we have discussed and see what kind of results we get.

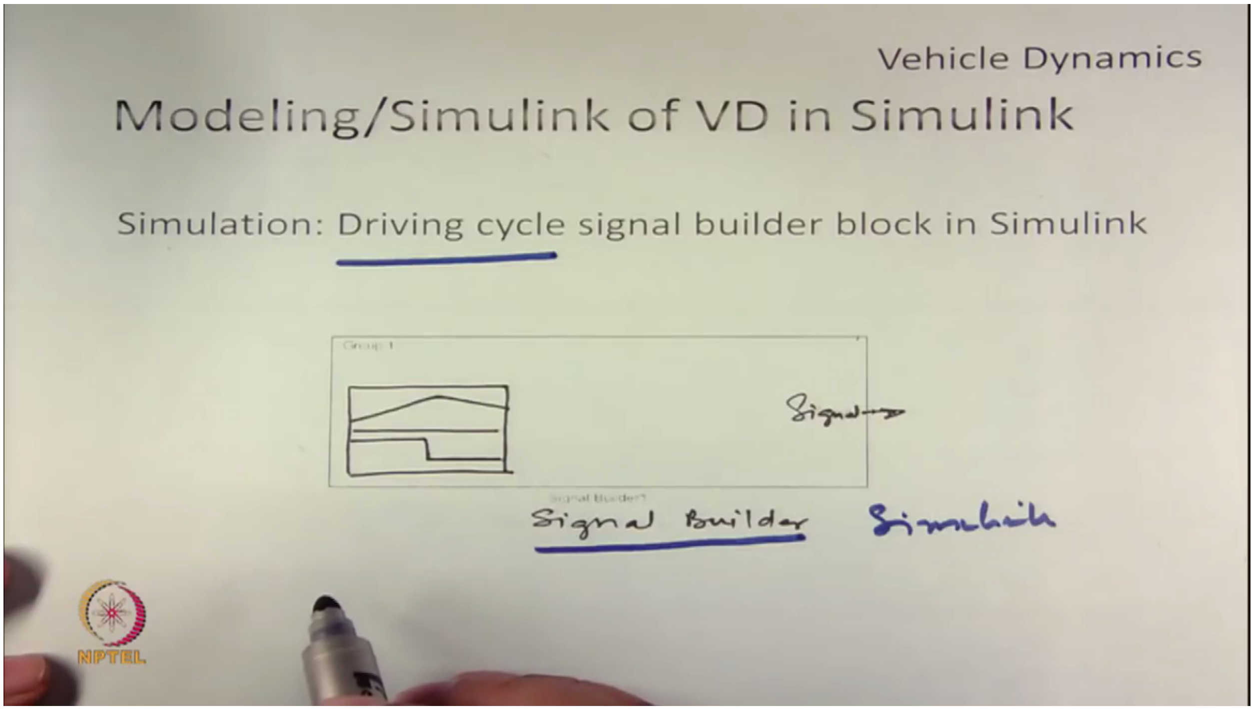


So this basically torque with respect to time. So this is Tm. Torque of the motor and this is Pm of the motor at different states of time and with respect to speed. So this is basically time and this is basically torque in Newton meter and this is basically power in watts. So we can say it is 8 into 10 is to 4 so it is roughly – so this – so we can see that we have three regions of operation. So this region is constant torque region. So here the torque is constant equal to T rated. So 254 Newton meter and constant torque region we know that the power increases linearly from 0 kilowatt to 80 kilowatts. So this is P rated equal to 80 kilowatt. You can see 8 into 10 is to 4 so. So this system has a pretty wide constant power region. So this – so in this region the torque drops as a function of speed. And when we reach the V max so torque will be reduced only to support losses. So this region is constant speed. You can see that it's very easy to do the mechanical block simulation and Simulink we can get very nice results.

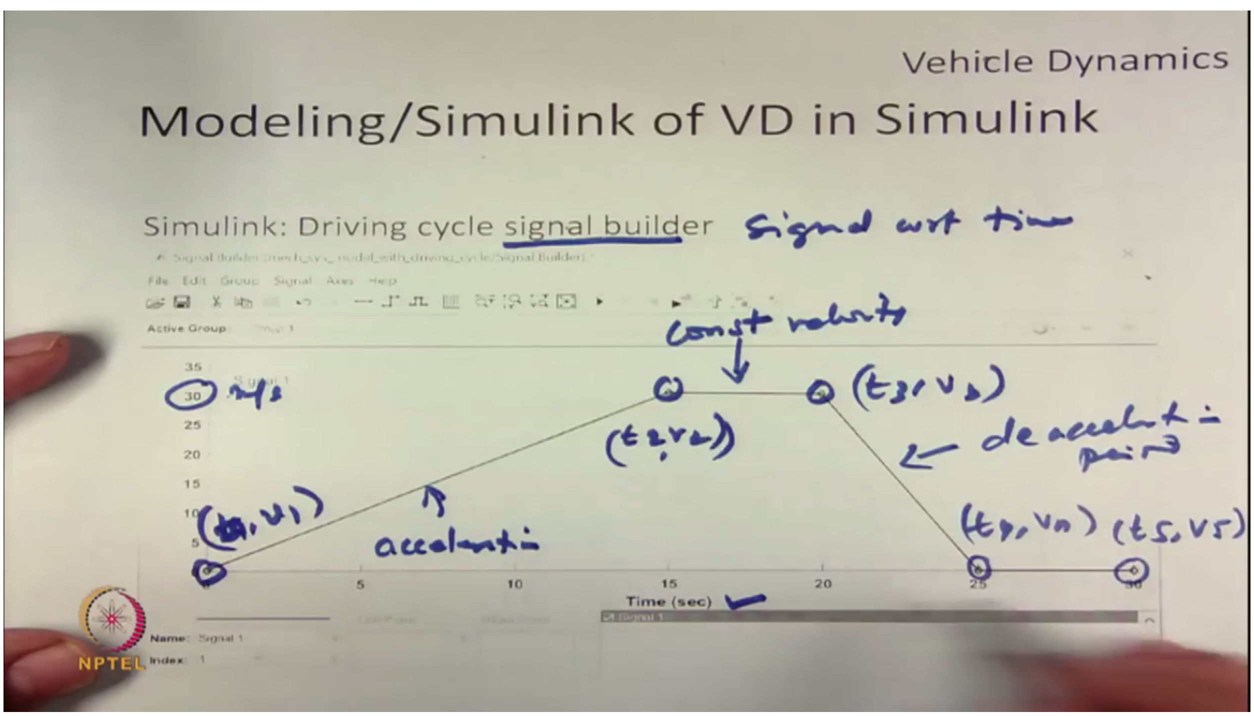


So in this graph in addition to torque and power as a function of time, so we can also plot the velocity of the vehicle. So it increases from 0 to 40. 41 basically this is 41 meter per second. So this is V max. so we get V max of 41 meter per second when we reach constant speed mode. So the rating of the will be somewhere I think it will be 15 meter per second maybe the rated velocity of the vehicle and it will go to 41 meter per second in constant speed region. So this is kmph max. This is V max. So V rated maybe in order of 15 meter per second.

So we can do simple simulation and get the results of V of T, torque respect to time. Power respect to time.

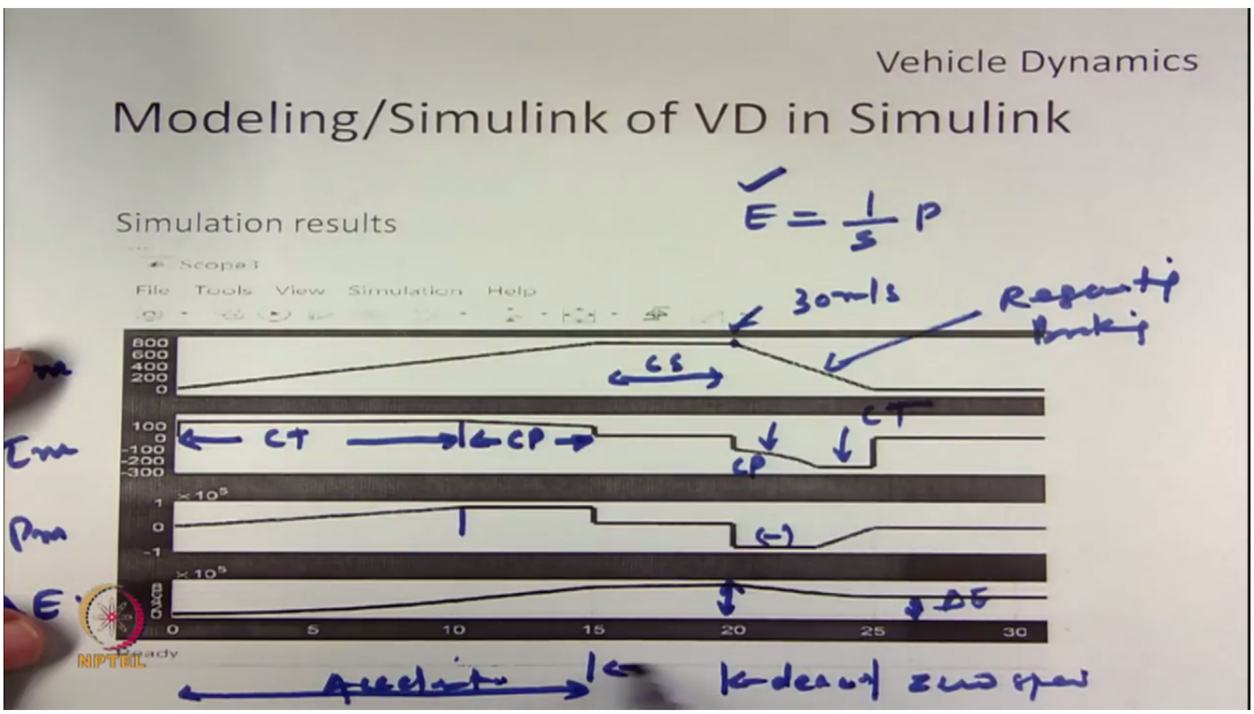


So we have also discussed the driving cycle of any electric vehicle. So when a mechanical system is driven on a driving cycle we can use that simulation for calculating range. So let us see how we can incorporate the driving cycle to the mechanical block. So there is basically a block which is known as builder in Simulink which is very useful block and it can be used to generate any kind of driving cycle profile of velocity versus time.



So this block is signal builder. It can be seen here. So here basically these are different points. So these points can be selected in a XY graph. So we can say that the X-axis is time in seconds. So the signal builders gives any signal with respect to time. So time in seconds can be so these values can be – so basically these are kind of XY coordinates. So this is basically t1, v1. this is t2, v2. T3, v3. T4, v4 and t5, v5. So all these coordinates can be selected in this signal builder. And we can get any driving setting profile. So we have seen that the SAE J227 driving cycle profile is very similar to this.

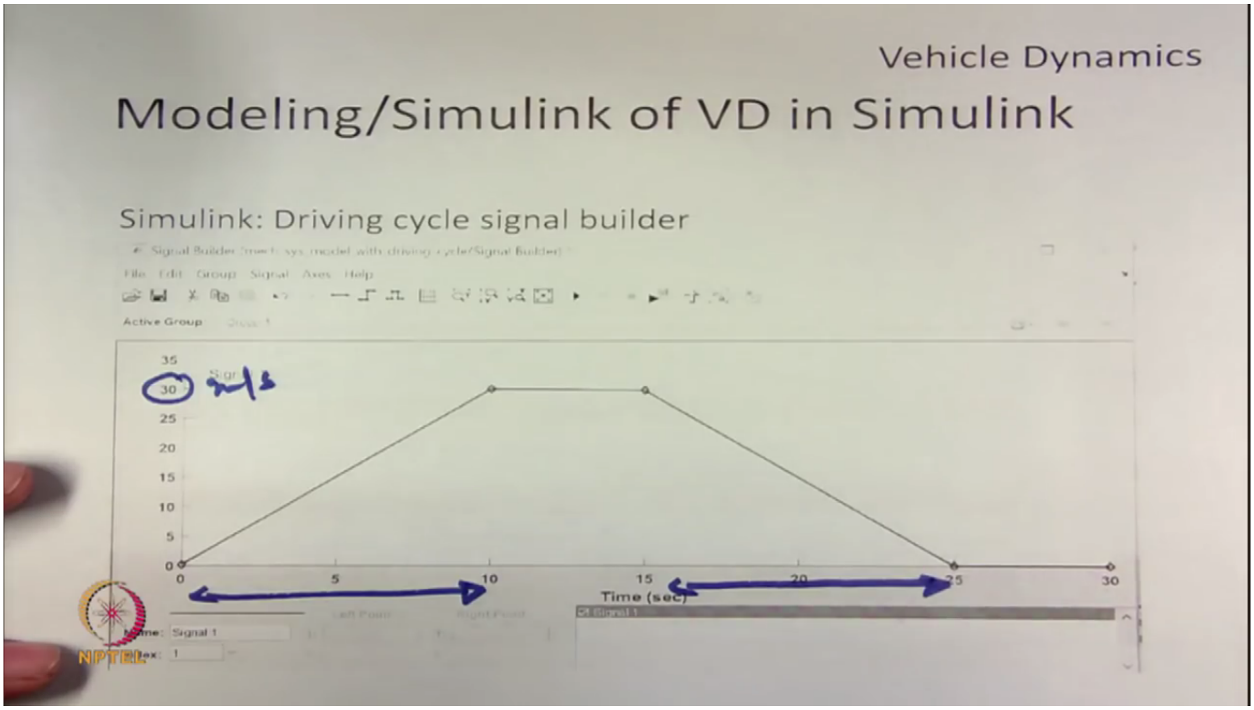
So we have a acceleration period. So this is basically acceleration period. This is constant velocity period. This is deceleration period. This is kind of idling period. So let us try to see the simulation of mechanical system when the input is this kind of driving cycles. So there are some results so let's say if you use a driving cycle like this where we have acceleration from zero to 15 seconds. So the vehicle is accelerated from zero to basically 30 meter per second in 15 seconds and then we have a constant speed of 30 meter per second from 15 to 20 seconds. Then we have deceleration from 30 meter per second to zero from 20 to 25 and then we have a zero speed from 25 to 30.



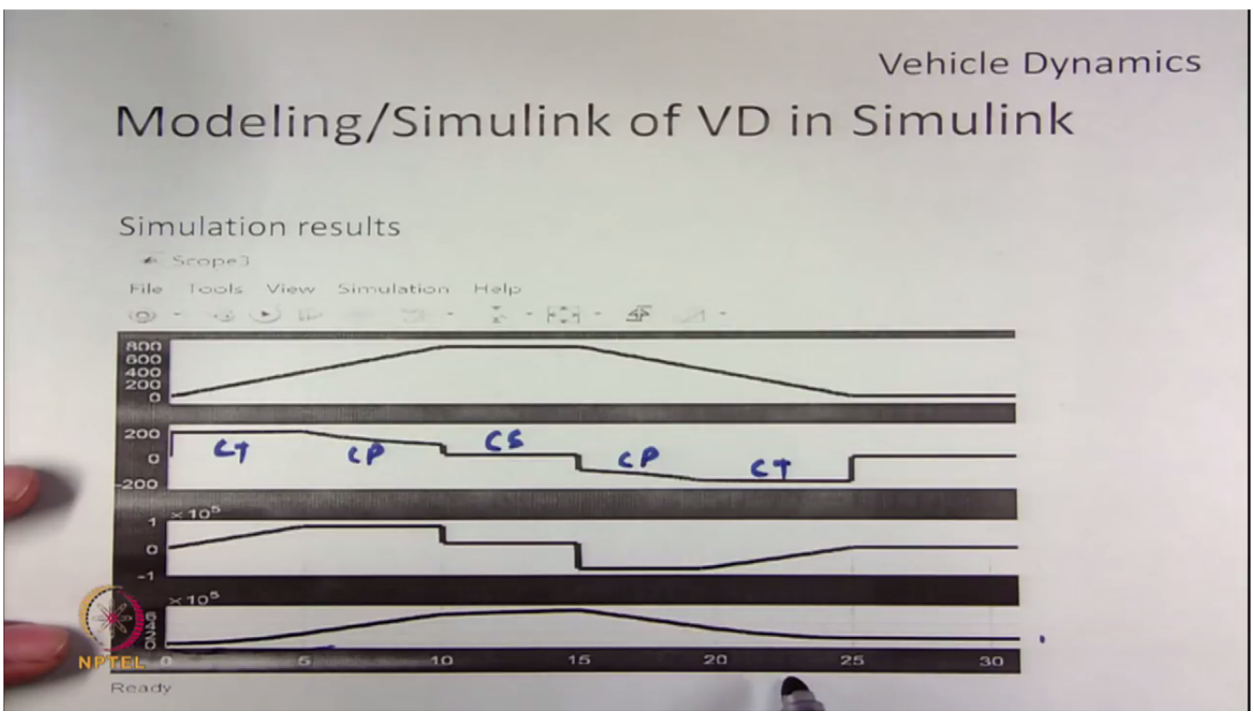
So if we try to see the results so these are basically the results of the motoring side. So basically this is omega m. This is Tm and this is Pm and this is the energy required. So this is delta energy. So how we get energy basically the energy is very simple. So energy can be calculated one by S of P. So if we just integrate you can get the energy value. So once we have the power value getting the energy is very easy.

So you can see that so we are accelerating from zero to 15 seconds. But you can see that so this is acceleration period. But a part of it is constant torque and part of it is constant power. So you can also see that when the speed of the vehicle become constant the torque also becomes constant to a lower value and power also becomes constant since power is torque into omega m. And you can see that the rise of energy required increases here. It increase very slowly because we don't have to supply the accelerating torque in constant speed region. So this is constant speed region or constant velocity mode. So when we are decelerating from again so we are accelerating from basically 30 meter per second to zero we also have to go through the same mode. So initially it will enter constant power mode. So this is basically again constant power mode and this is constant torque mode. So since the deceleration time is lesser, this period is also lesser. Here the acceleration time is more so we have a bigger constant torque and constant power modes.

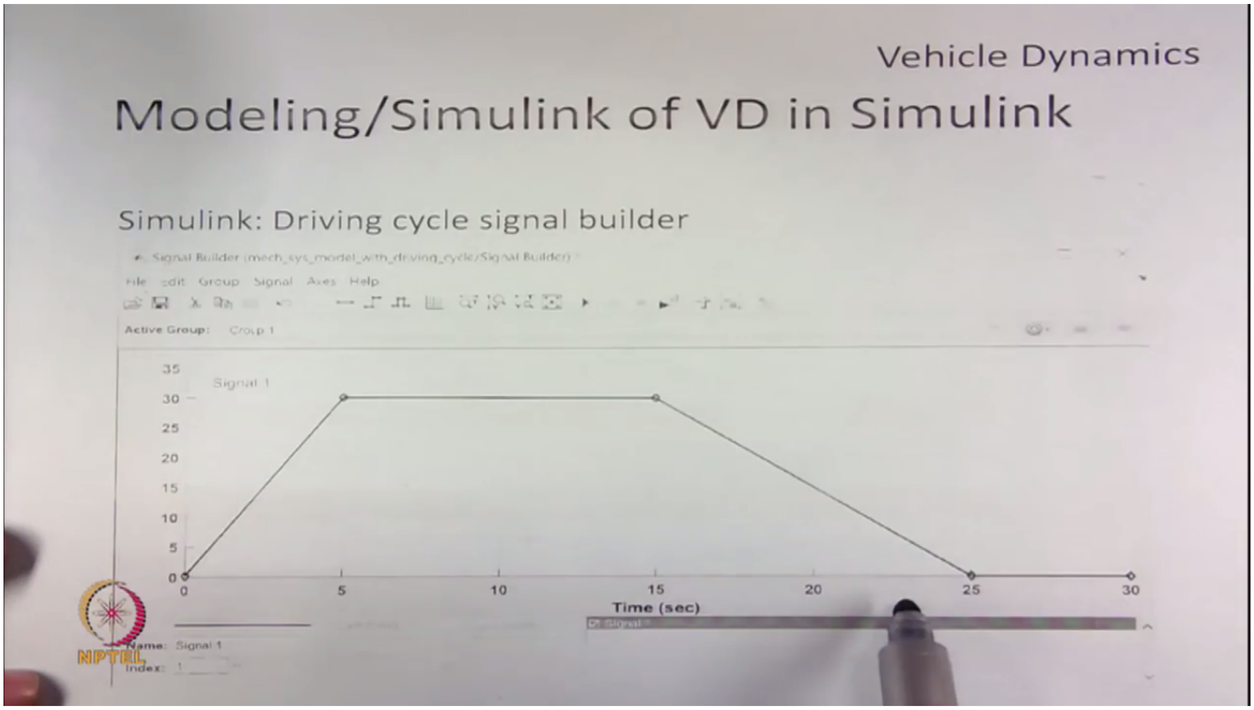
So if you see the power plot, we can say that – so we are – so power is increasing linearly and constant torque region it becomes constant and constant power region. It becomes very less. All it support losses in constant speed region. It becomes negative. So this is negative value of power. So this is negative period. So here we can see that when the power input to the system is negative it means we are regenerating. So if that option is there in the electric vehicle to absorb power from the wheels to decelerate the vehicle we can add to the batter. So you can see that so this is the dull energy. So it increases upto here and then it decreases. Decreases mean now the battery is getting charged. So if we would operate the vehicle upto here the delta energy will be like this. But if we operate even the deceleration mode the E required will be less. So you can say that some energy what we have given for accelerating and constant speed region is recovered during deceleration. So basically this is the regenerative braking where power becomes negative and energy is absorbed by the battery. This is deceleration and zero speed and here it is basically constant speed. Acceleration, constant speed, deceleration and zero speed.



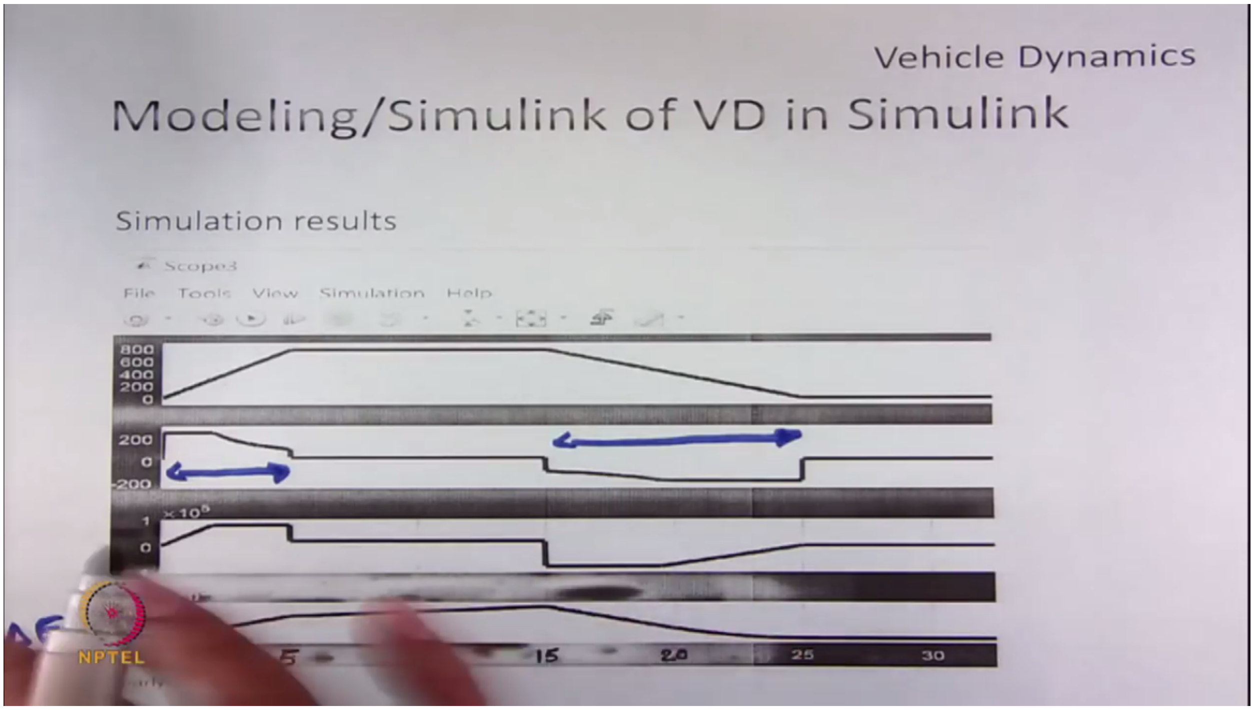
So let us try to see results for a different profile. So here same graph. So the maximum speed is 30 meter per second but now we are accelerating only for 10 seconds but we are accelerating for 10 seconds and we are decelerating also for 10 seconds and the constant speed region is 10 to 15 seconds. So we will see what kind of results we get.



So again similar graphs. Constant torque. Constant power. Constant speed. Constant power with negative power. Constant torque and basically again losses. So we can see that the energy requirement increases but we are able to recover almost all the energy. So the daily requirement is very small. Only just pertaining to losses of the system and the power required to support this constant speed mode. So you can see that almost everything is recap.



Again if we try to see a system where the acceleration is only for five seconds but the deceleration is greater now. So deceleration is for 10 seconds and the acceleration is for five seconds. We have a constant speed mode from 5 to 15. So what will happen here?



So in this mode you can see that the acceleration is only for this period but the deceleration is for wider period. So here we are able to recover some energy from the wheels so that net energy is negative. So we are able to charge a battery actually if we operate this kind of driving profiles. So one thing is very clear from this simulation results is that if we know the battery capacity. And let's say we have to move from one place to another we can choose the driving profile in such a way that we can able to get maximum range. So if we have periods of acceleration in this fashion we may not loose any energy of the battery, rather we gain something out of it.

So this kind of simulation of driving profiles, mechanical systems, and the suppression of constant torque, constant power, constant speed mode within those vehicle mechanical blocks will be very useful for a vehicle designer. So these kind of simulations are generally used by designers to choose the type of battery, the type of motor, the ratings of the motor, and all the subsytems within a electric vehicle.

So that is all in this last topic of vehicle dynamics. So we have covered the vehicle dynamics topic. So these topics we have covered the last topic today. So thank you for listening the lecture.