Hello everyone. Welcome to NPTEL online course on electric vehicles. So let us start the next topic under vehicle dynamics, which is the simulation of dynamic equation, when the vehicle is driven by constant FTE.

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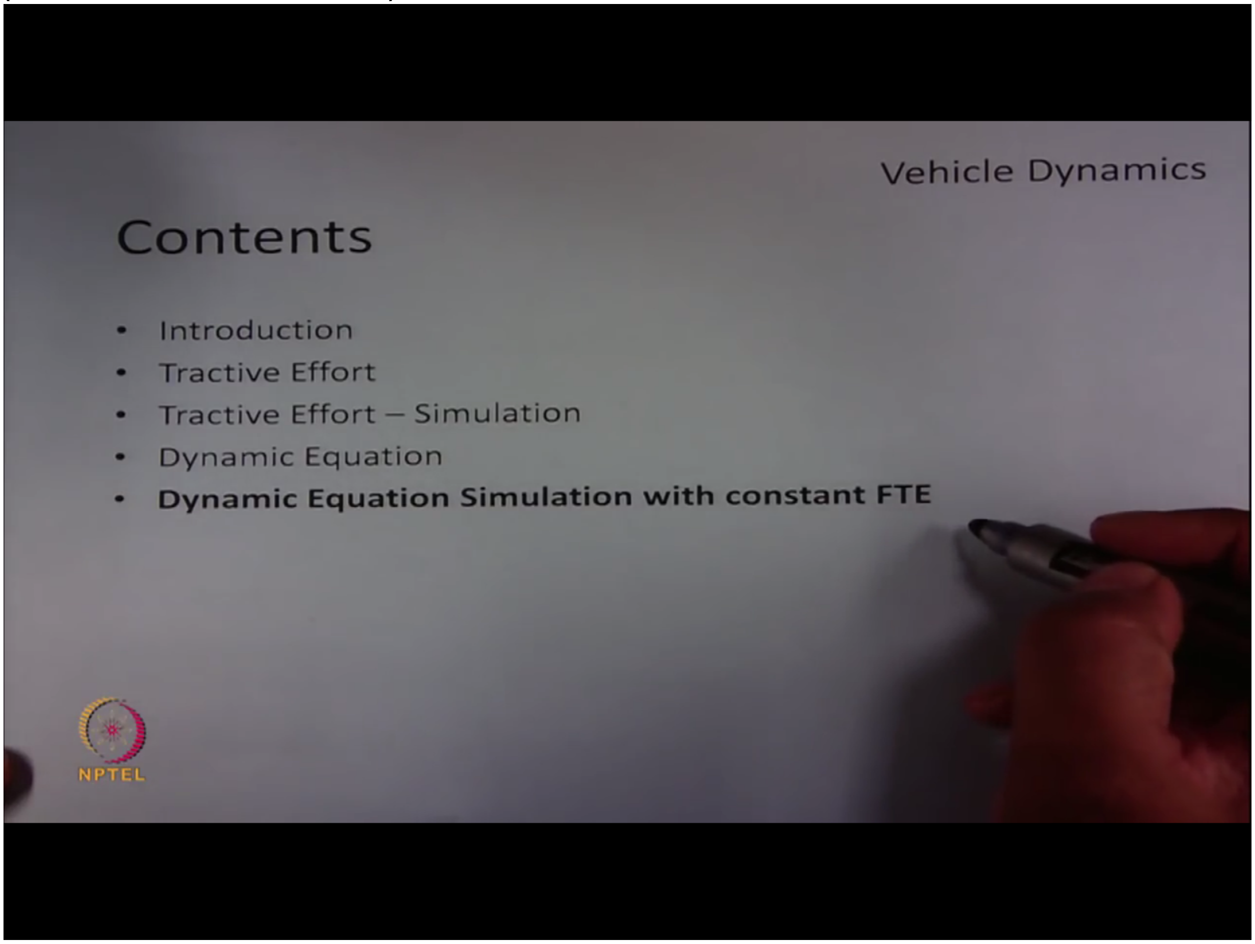

So in our previous interaction, we have derived many dynamic equations for the case where the vehicle is driven by a constant Tractive effort force, so we can say that the motor is driven by a constant torque output. So in this case we have seen the equation of DV/DT in terms of the motor torque and different resistive forces. So we have written the equation in terms of constant K1 and K2, so K1 is constant because these terms are constant and K2 is constant because all these terms are constant in addition to the motoring torque. So K1 and K2 have these values.

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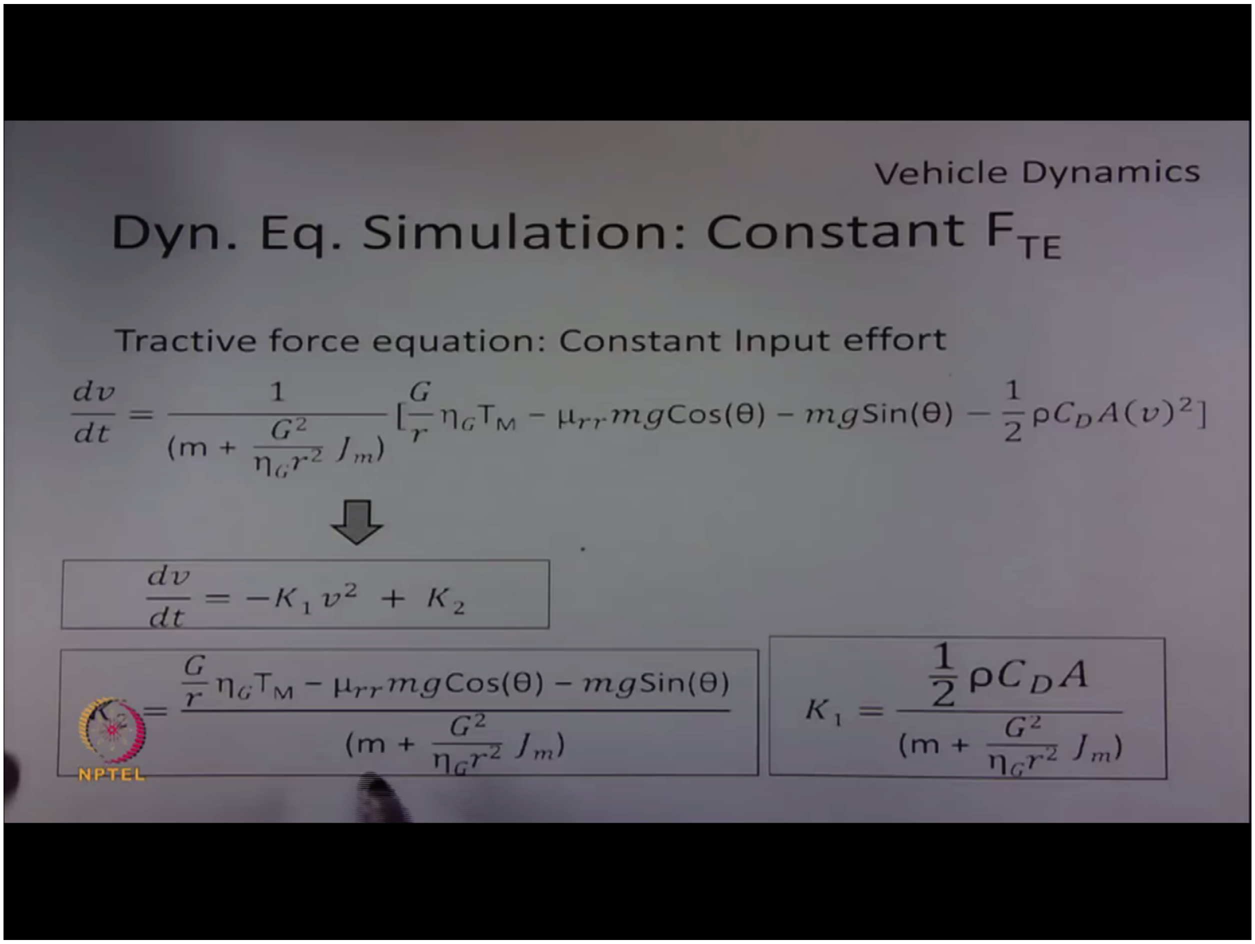

And we have solved this equation and re-written them in terms of terminal velocity and K1. So this was a equation, we have derived, where the terminal velocity is root over K2 by K1.

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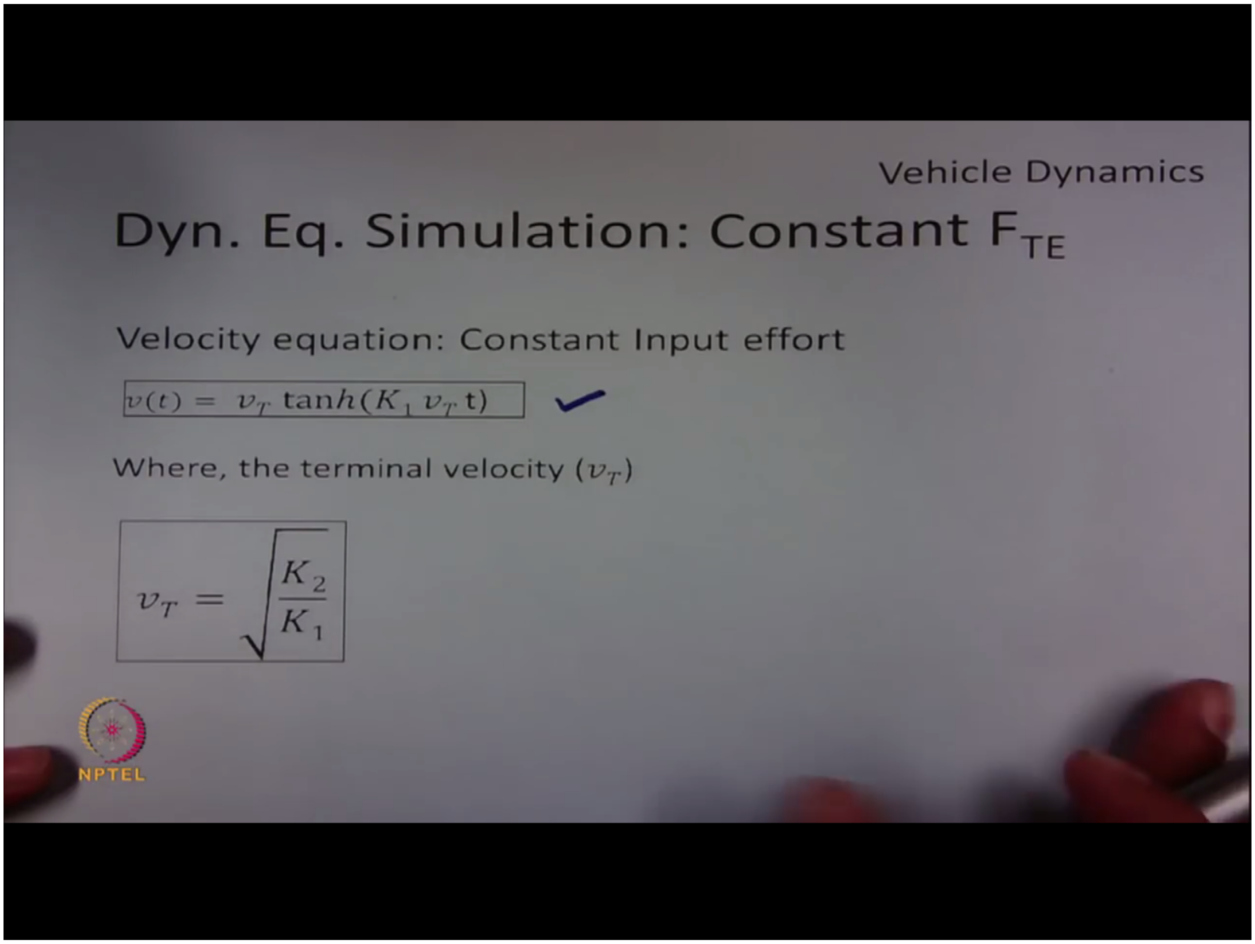

So since the velocity has graph similar to this and if we assume VT to be constant here and so we are very interested to find the time taken to reach the vehicle for a speed, which is equal to 0.98 VT, so we have got expression = TF = 2.3 divided by K1 VT.

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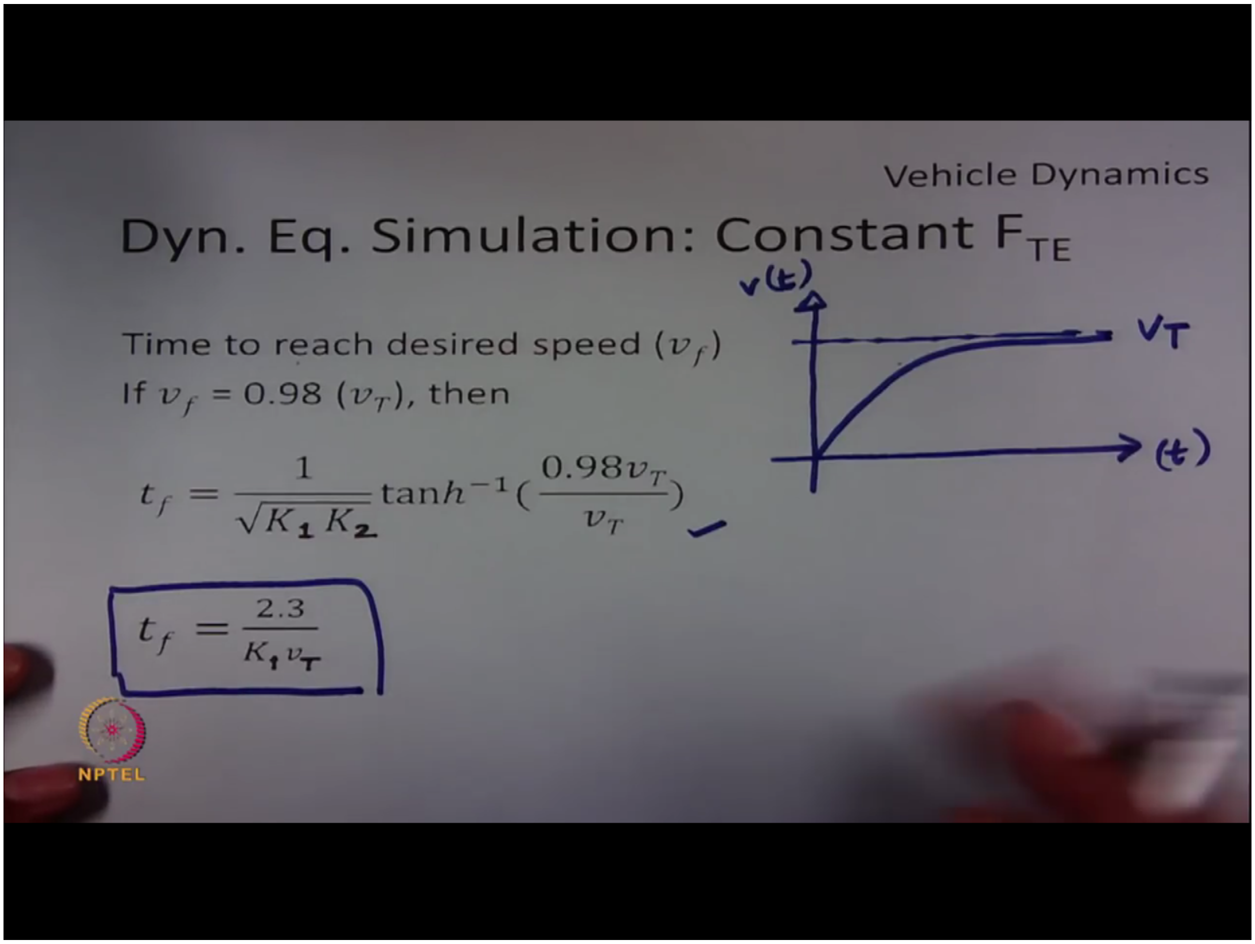

Similarly if we want to calculate the distance travelled in time TF, it can be found out using this equation. So power respect to time has very similar graph as the velocity, because the FTE is constant and PT expression of time is a product of FTE into VT. So P also will have a similar graph as velocity, this is P of T, this is terminal velocity of power. So the terminal velocity will be again FTE into root of K2 b y K1.

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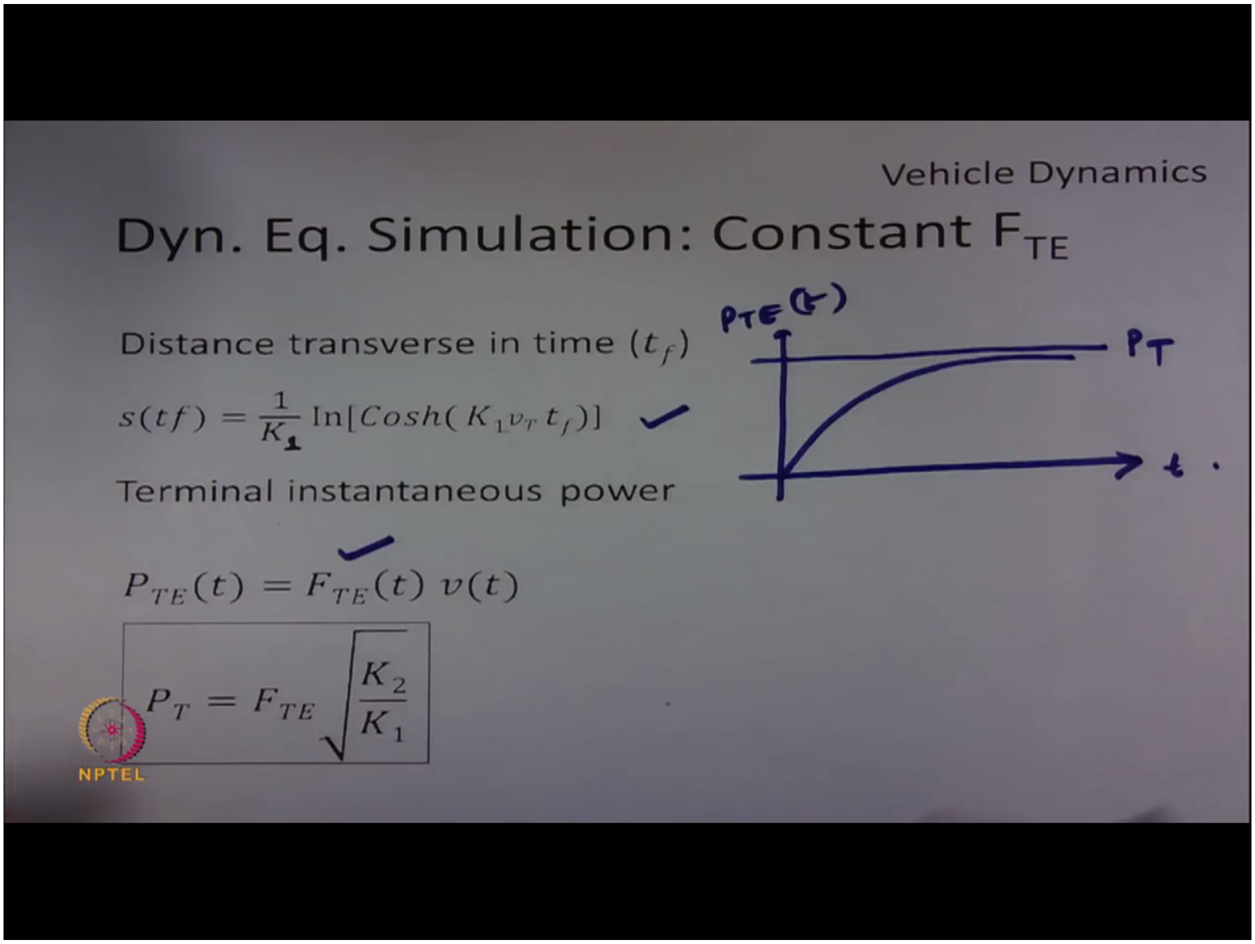

In our previous interaction we have also seen that a calculation of average power due to tractive effort is a function of PT terminal velocity divided by TF one by root of K1 by K2 into log of cos H root of K1 K2 TF. So the calculation of P average is very handy because it will help us to know the energy which is required to drive the vehicle up to terminal velocity or the velocity, which is equal to VF, VF is 0.98 VT, we have assumed. The energy required can be calculated just as a product of the time elapsed and the average tractive effort power.

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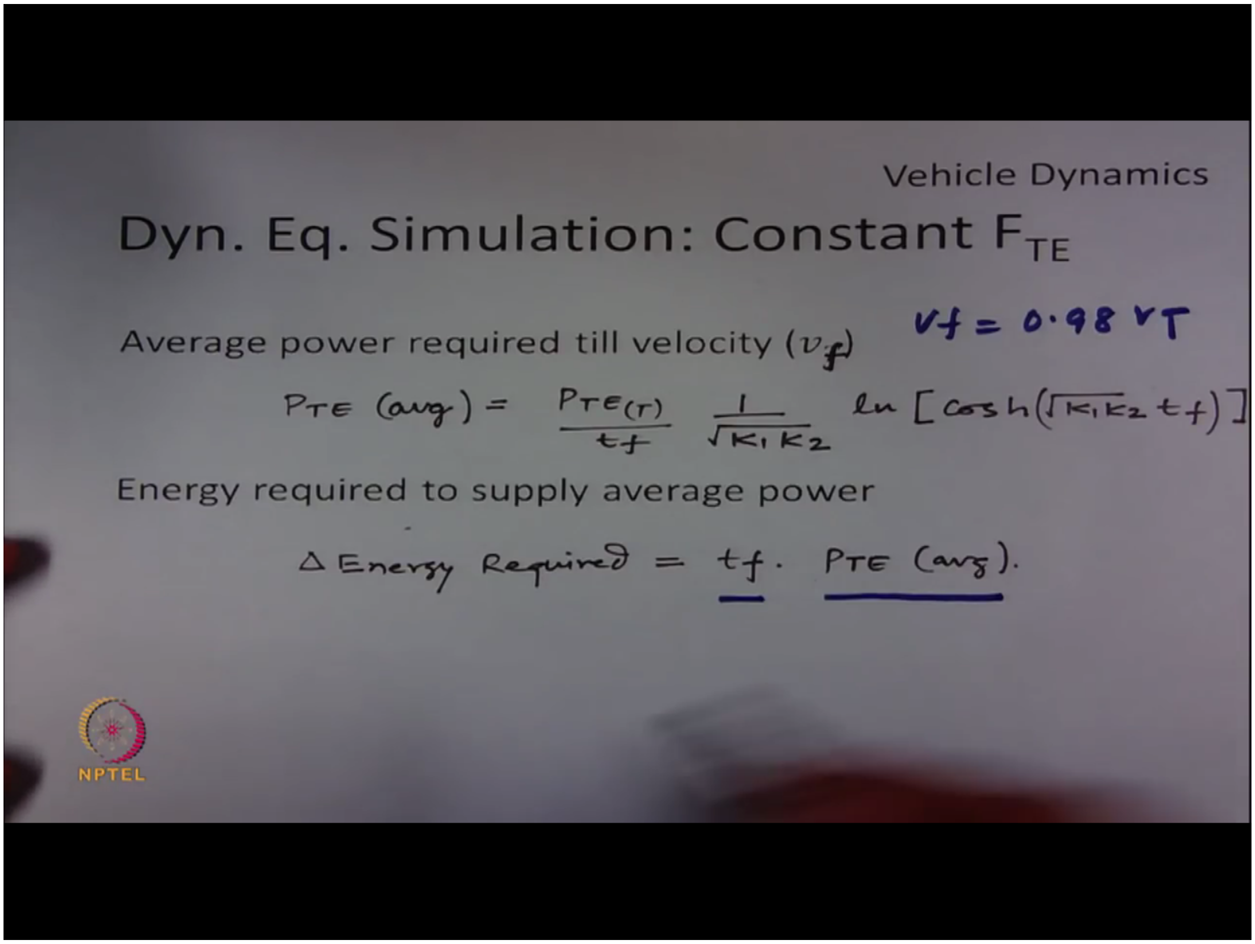

So let us take an example and calculate all these variables. So let's take example of a battery electric vehicle, which is given a constant input motor torque. So let us assume that the gear ratio is 10:1, the radius of the wheel is 0.2 meters, the rolling resistant coefficient, which is Mu RR is 0.01. The drag coefficient due to aerodynamic force is 0.26, the frontal area is 2.2 meter square... Let's assume that the mass of the vehicle is 1200 kg. We also have to calculate the equivalent mass due to inertia of the motor, which is JM x G/R square into 1 be efficiency of the gear. So if this JM is not known, the equivalent mass with respect to this term can be assumed to be 5% of the mass of the vehicle. So let us assume that, and it's quite reasonable approximation. So M1 let us... that is 5% of M1. The efficiency of the gear let us take as 0.9, the air density 1.25 kg meter cube. Let us take the maximum torque of the motor, which is equal to 40 Newton meter. So this is the torque, which is given as input to the system. To start with, let us assume that the slope angle is 0 degree and the wind velocity is also 0.

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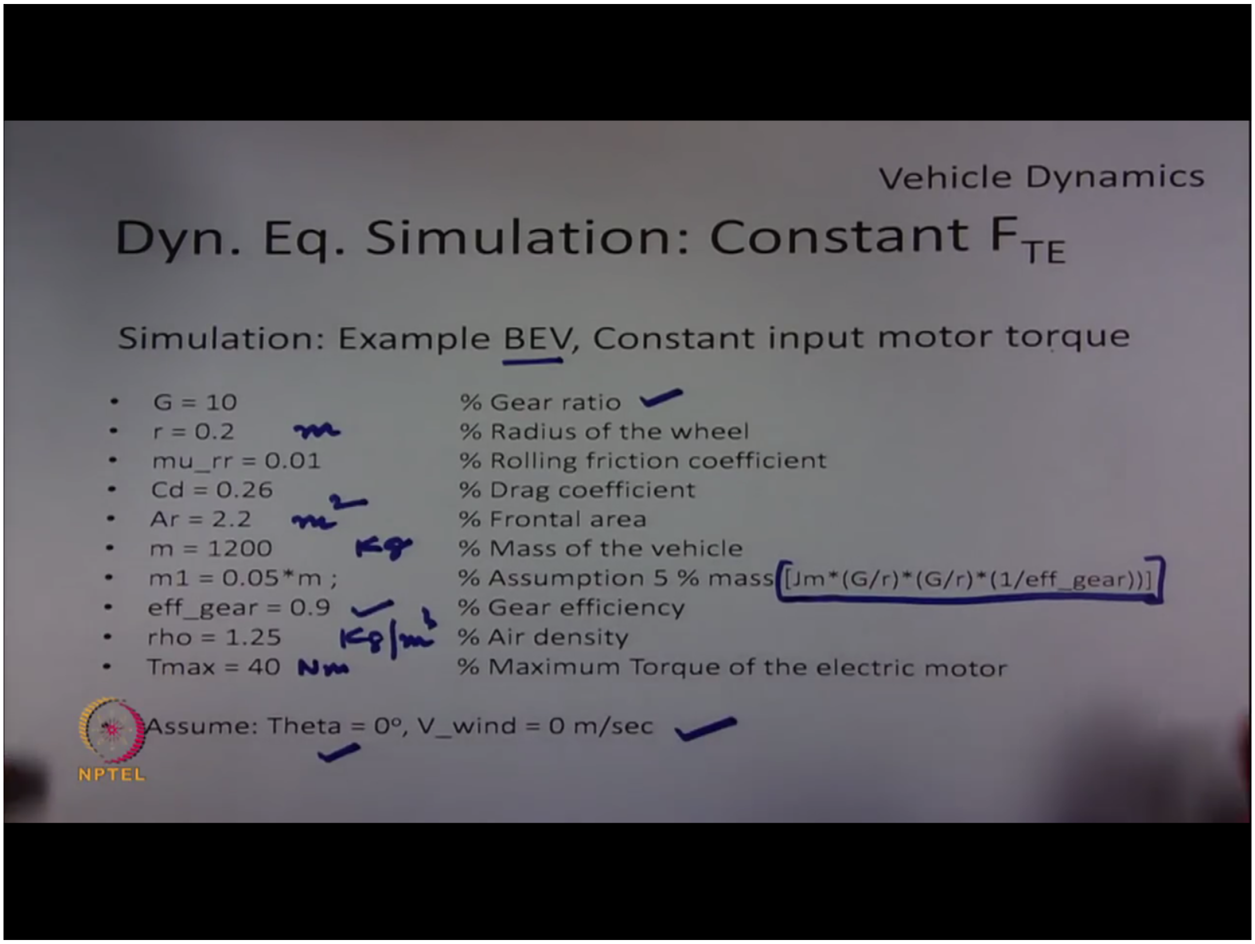

So with the parameters of the given vehicle, we can estimate the value of tractive effort force as G by R x Tmax x efficiency of the gear. So it will come out to be 1800 Newton. So it is basically 10 by 0.2 x 40 x 0.9. Similarly we can also calculate the force required to… for rolling resistance force, which is Mu RR x MG cos of theta. So cos theta is 1, therefore this is coming to be 117.72 meter. The force due to gradient will be 0 because the theta, what we have assumed is 0 degrees. Let us also calculate the constant term of the aerodynamic force, which is 1 by 2 Rho AR x CD. So 0.3575 to be used for calculation of K1 and K2. So contact K1 is FTE - FRR – FGE by M+M1. So M1 is 0.05 M1. So if you substitute all these values here, we will get a constant K1 of 2.83 x 10:-4 m/sec sq. Similarly the constant K2 can be evaluated as the constant way multiplied here divided by MN+M, which is 1.33, the unit is 1 by meters. So since we have all these values available with us, we can now calculate rest of the parameters.

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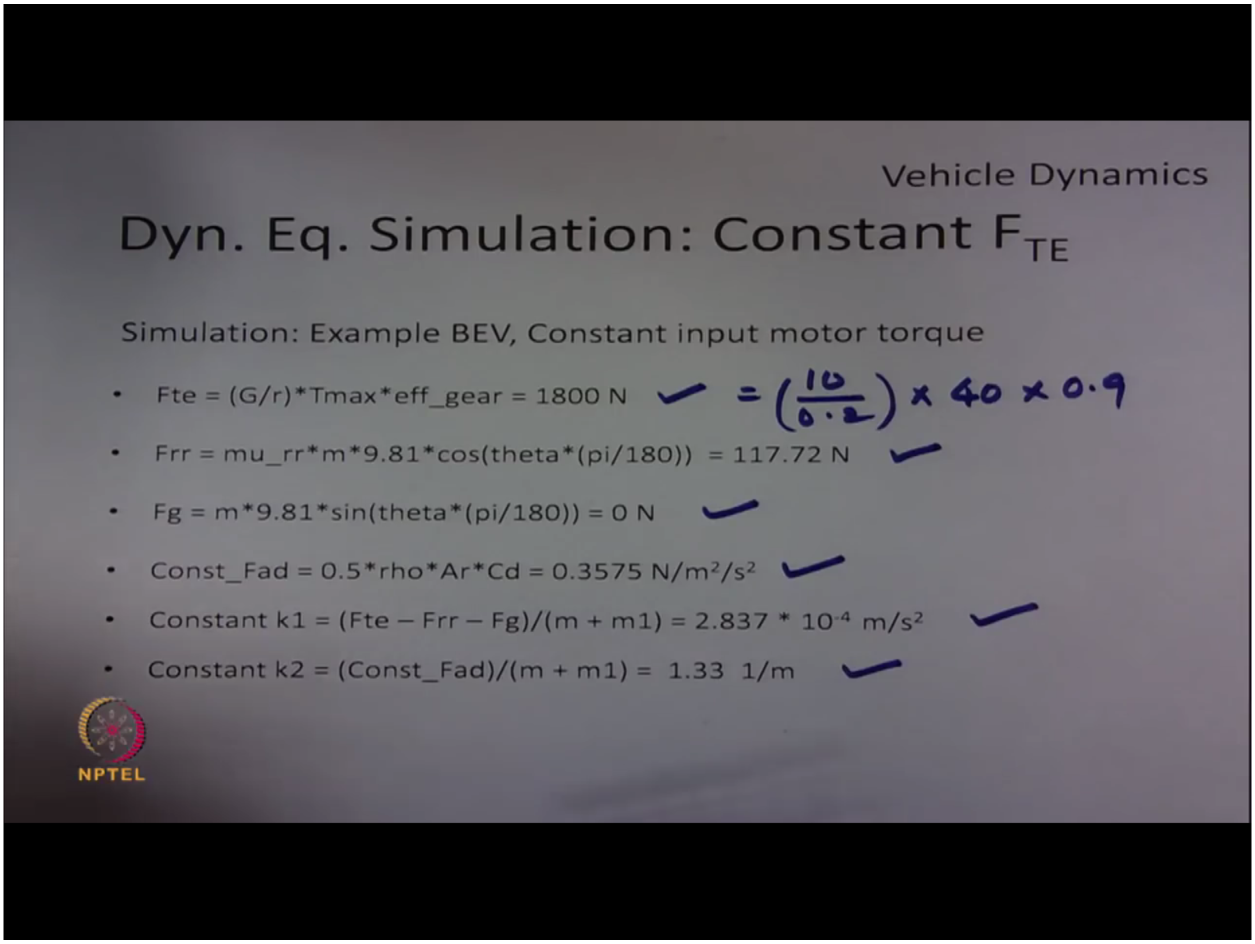

So the terminal velocity is a square root of K2 – K1 and it can be calculated as 65.89 meter per second. So which become 246.95 km/hour. So this vehicle can go to a maximum speed of 246.95 km/hour for a constant input torque from the machine equals to 14 Newton meters. If you want to calculate most of the variables for the value of velocity, which is 0.9 times of this terminal velocity, which is equal to 242 km/hour. So the time required to reach this velocity can be calculated by using this formula. So 2.3 divided by K1 x V terminal. So this is 118.17 seconds. So it takes almost 2 minutes to reach this velocity close to 0.98 V terminal velocity. So the distance the vehicle travelled in time TF, calculate using this formula, we have seen earlier. And if you divide by 1000, we will get the value in km. So the distance travelled is 5.7 km. Similar to terminal velocity, we can also calculate the power, the maximum power this system will take is V terminal x FTE divided by 1000. So we will get the power in KW. So it is 123.47 KW. The power that is required to operate the vehicle at 0.98 of V terminal, which is VTF will be equal to 0.98 of this value, so it is 121 KW.

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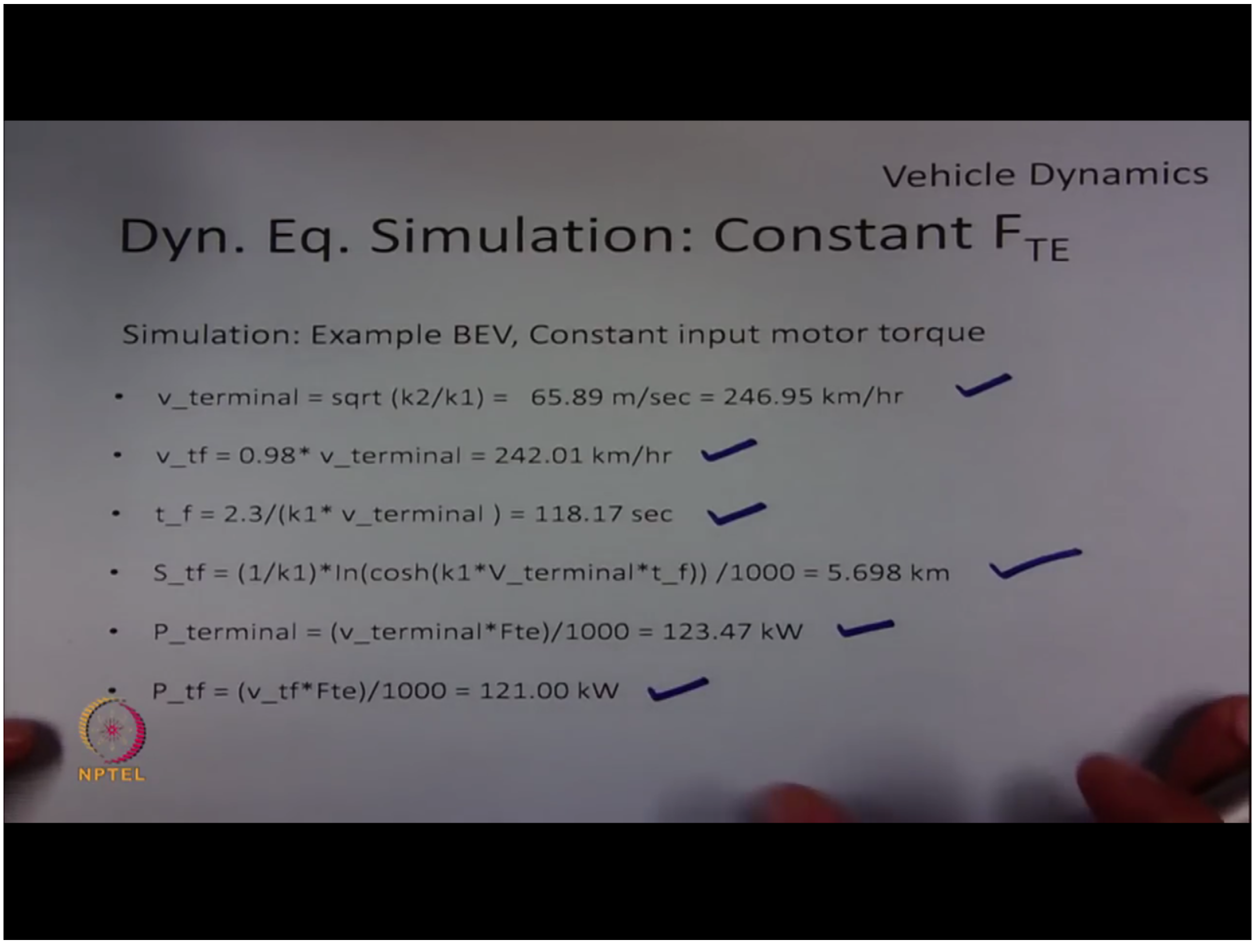

So as we discussed it will be very handy to calculate the average value of power that is required to bring the vehicle to a velocity, which is 0.98 x VT. So if we substitute this formula here and gives suitable values of TF and V terminal K1 etc., this value comes to be 86.80 KW. So this value of P average will be used in calculation of the energy required to bring the vehicle to time TF or velocity equal to 0.98 VT, will be equal to P average x the time elapsed, which is TF and we have to divide it by 3600 to bring it into our value. So it will be 3.165 KW. So the equivalent value of jule can be calculated using this formula as well. So we are able to calculate the values of most of these variables using simple formulas, which we have derived.

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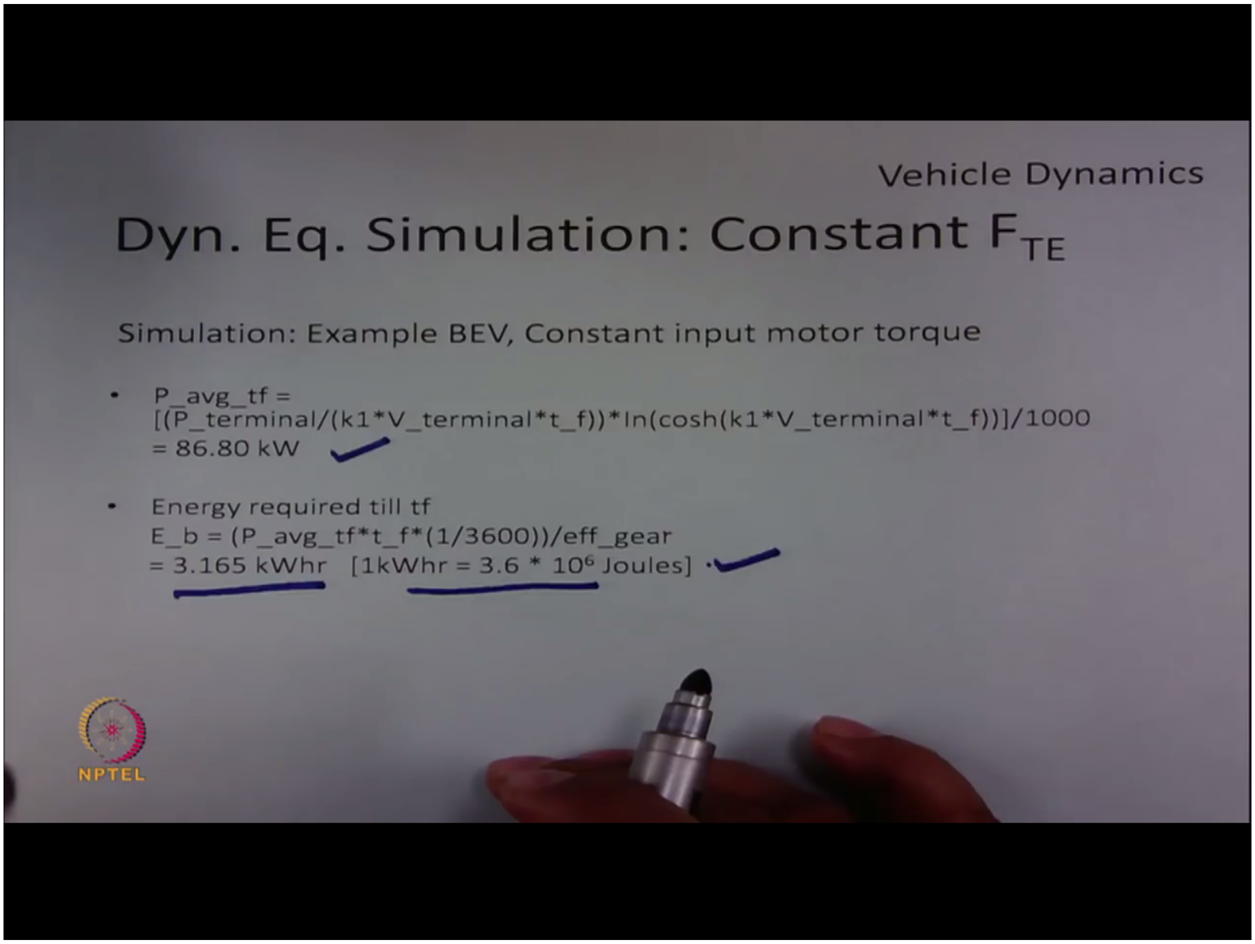

Now let us try to plot this using simulating program and see the actual variation of different variables with respect to time. For the same example, if we want to plot the velocity with respect to time, it will come like this. So the velocity will start from 0 in 0 seconds and it will go all the way and become steady state, so the value BET after some point of time. So we have seen this value of VT = basically 246.95 km/hour. So the time require to reach 98% of the speed which is 242, which will come in a time somewhere here, so this is TF = 118.17 seconds. So here the value of… its 242 km/hour. So this is VF, this is VT, and this is TF. So this plot shows us the variation of the velocity with respect to time.

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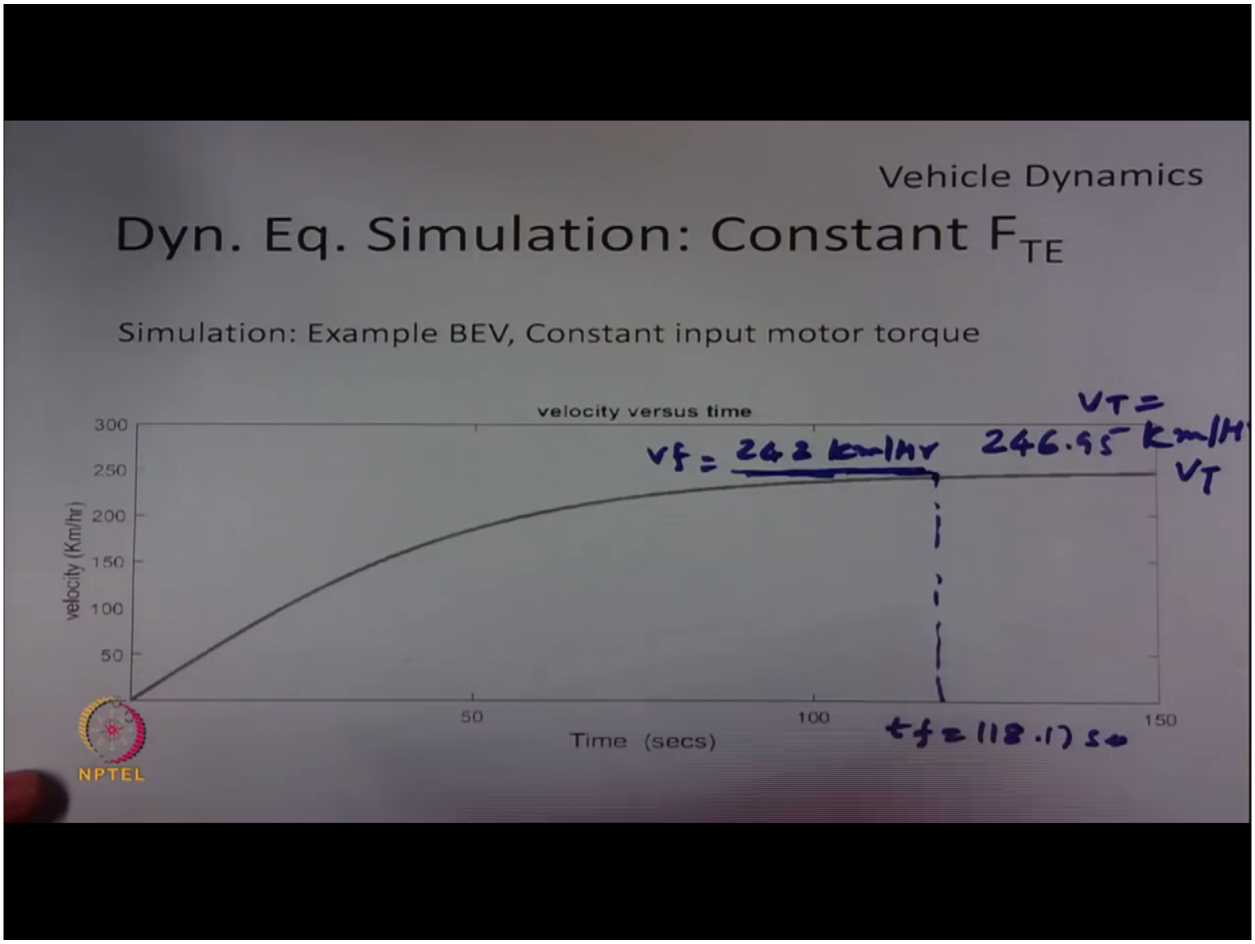

Similarly if we want to plot distance travelled as a function of time, we can also do that using simulating programs. So as the velocity increases, the distance travelled also increases. So in around 118, so TF = 118.17 second, we will reach the speed... speed of 242 km/hour and the distance equal to, so this SF=basically 5.698 km. So this also, values is coming as per the calculation we have done. So distance will keep on increasing because the speed has become constant and distance is speed x time. So it will keep on increasing, because speed has not become 0 and it is becoming constant.

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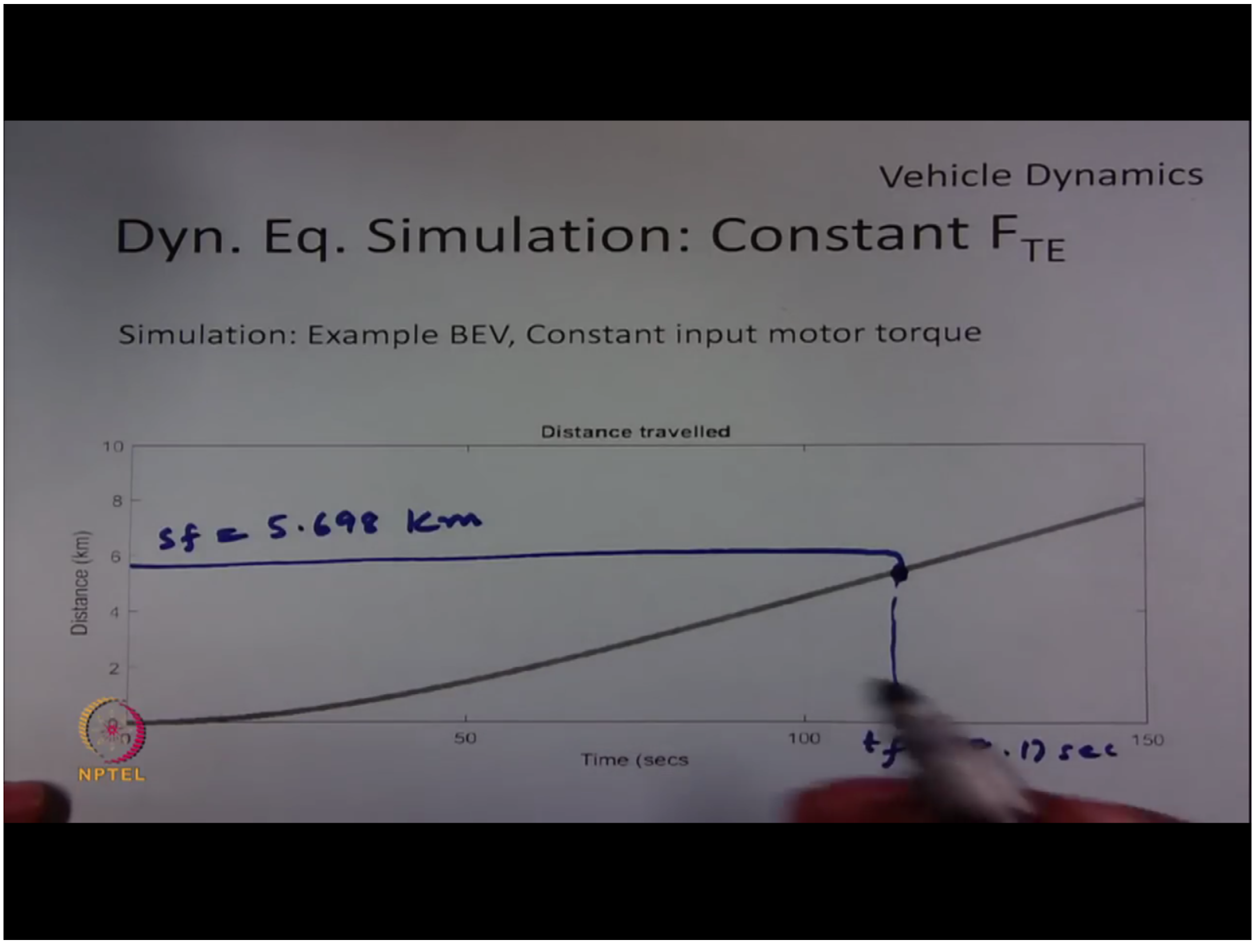

Similarly we have the plot of instantaneous power, which is PTE as a function of time. So we can see that the plot of instantaneous power is very similar to the velocity graph, that increases from 0 and become constant at value = P terminal. So P terminal in our case was basically 123.47 KW. So at TF, the P required at TF was 121 KW. So if we try to find the average value, which we have done, the average value is this and it will be = P average was 86.8 KW.

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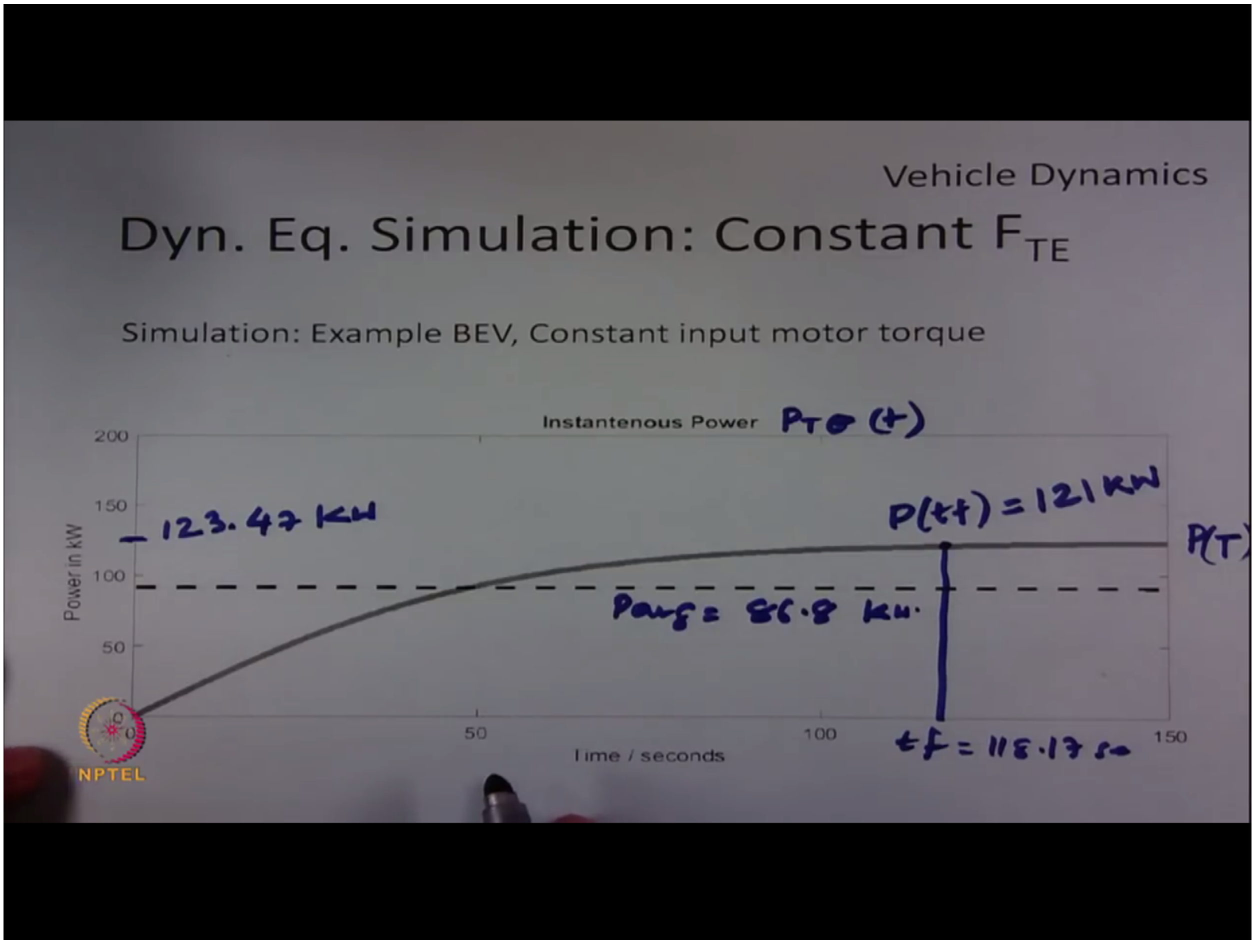

So it will also be an interesting idea to see all these graphs together in a single sheet. So the bold graph is… so this graph is what we have seen in previous three graphs. So let us take a example where the same vehicle is traveling on a constant slope of 5 degrees. So in our previous case we have assumed the value of slope at 0, but if there is a condition that the vehicle is driving on a slope of constant 5 degrees, then what will be the graphs and the vales of voltage distance and power. So the second case of slope of 5 degrees is plotted in dotted line. So if we see the VT1, the terminal velocity for case 1 is 246.95, we have seen. The terminal velocity for second case is 154.3 m/sec. So it means that the terminal velocity is reduced in this case. The time to reach 98% of a terminal velocity will be 118 for the first case and almost 190 second for the case where the slope is 5 degrees. The distance travelled in this time is same, because distance is product of velocity. The average power that is required in the first case was 86.8 KW we have seen. In the second case the average power required becomes low, which is 54.23 KW. So the average power has reduced. On the other hand the time required to reach 98% of the terminal velocity has increased in the second case. So because of this thing, the energy required, which is product of P average x TF remains constant for both the cases.

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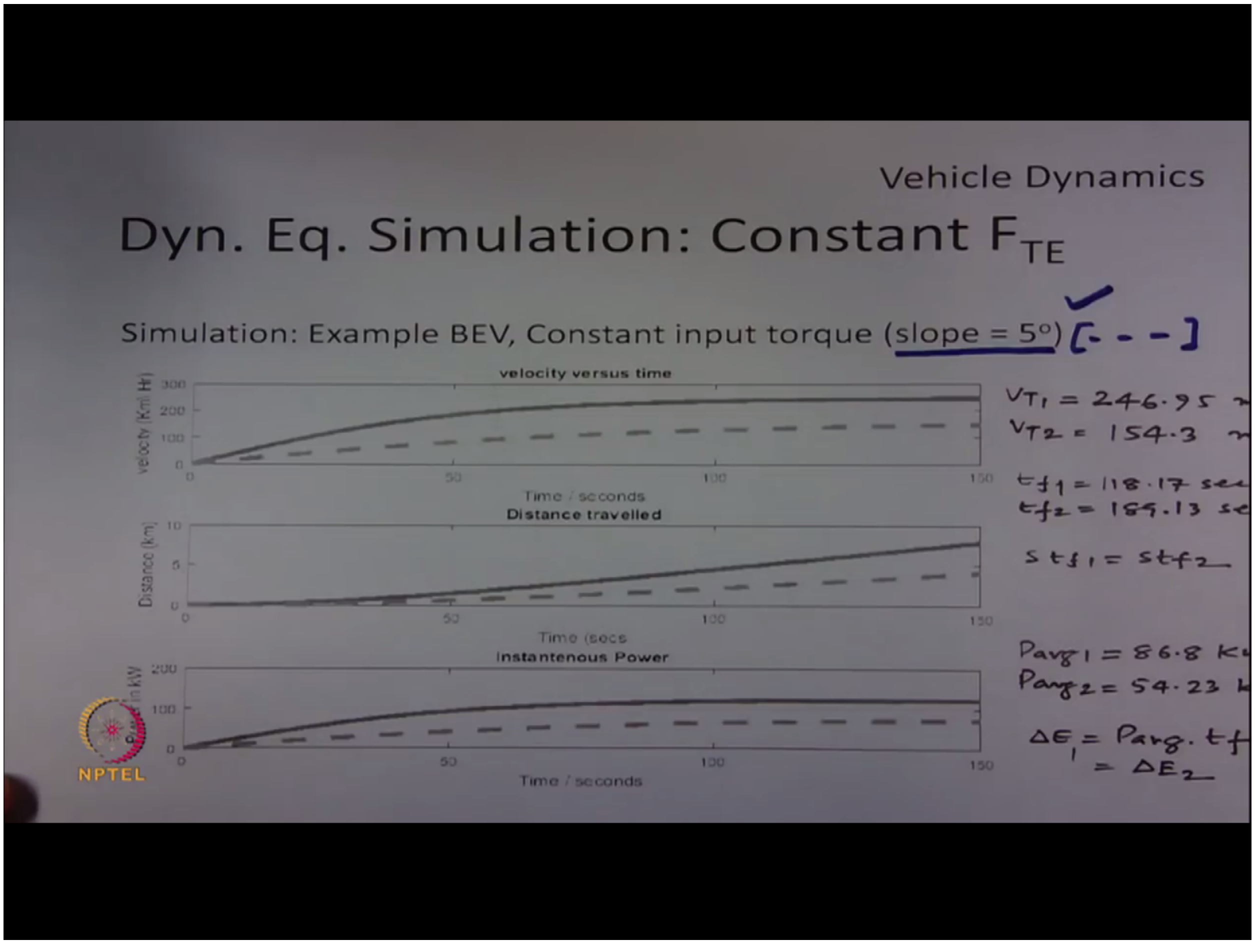

Similarly let us assume a case where the mass is reduced from 1200 kg to 800 kg, so the graph pertaining to 800 kg will be plotted in a dotted curve. So there is no much difference between the two graphs. So the acceleration is better in the case where the mass is lower. So terminal velocity are very similar. So in first case, it was 246.95 and second case it was 249.85. But since the acceleration is faster in the second case, the time required to reach the 98% of terminal velocity is lower in the second case. So it is reduced from 118 to 77.87. The distance travelled to reach 98% of the velocity will be 5.698 km in the first case and it was 3.79 km in the second case. The average progress is also similar, but this interesting thing that the energy required to travel in the second case has reduced from 3.165 to 2.11, because the average power is similar, but the time required to reach 98% of the velocity has drastically reduced in second case. So the proportional reduction of energy can be seen. So using these kind of simulations, we can check the vehicle performance for the constant input motor torque by different kind of change in variables and conditions.

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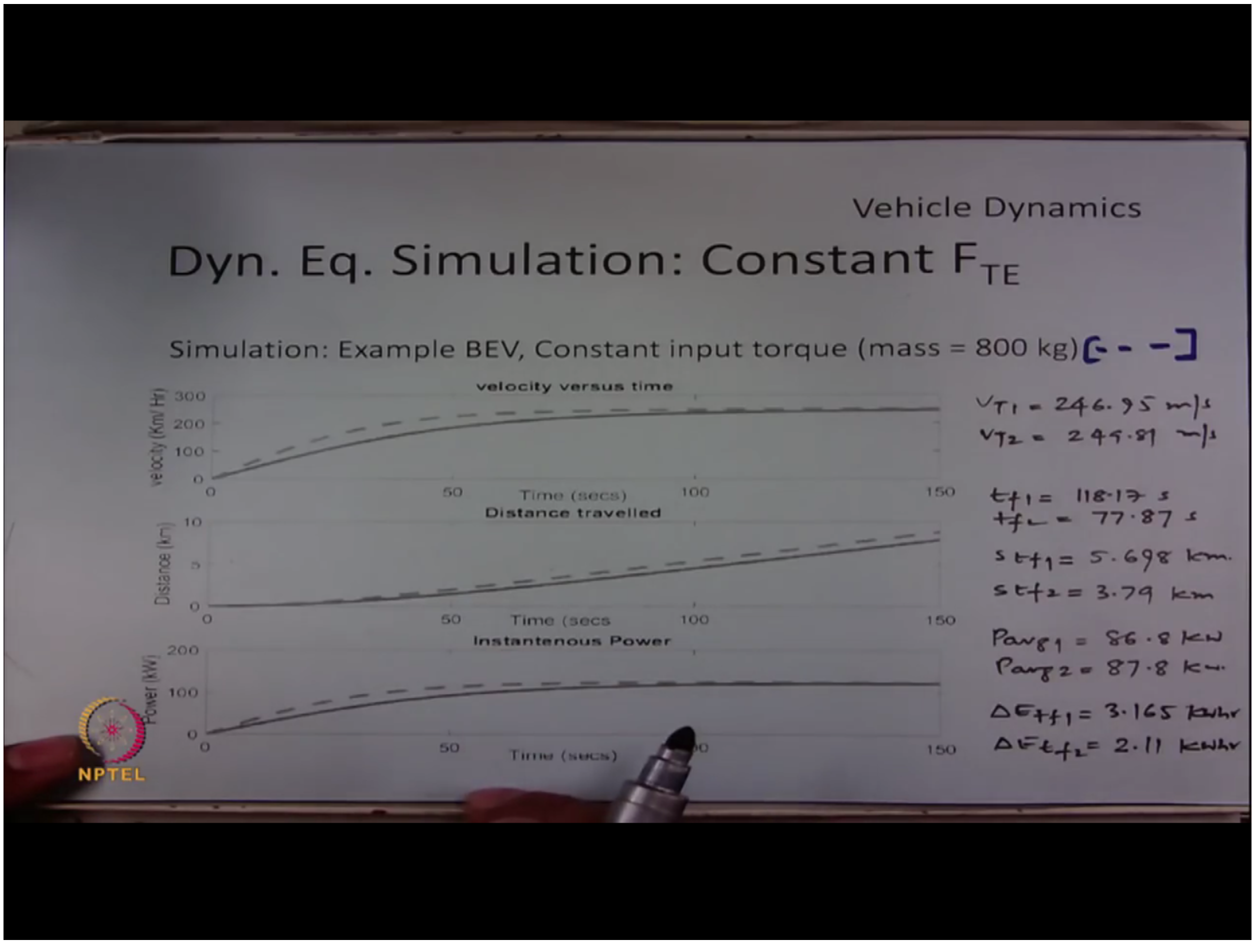

So how do we check this conditions. So we have to write a MATLAB program, very similar to we have seen in the previous interaction for calculation of different registry forces. So we know the equation of velocity is DV/DT = -K1 V square + K2. So this equation is a function of time and we can do time step simulation, which is possible in MATLAB or C programming or any other, even Excel can be used to do this. So we can write DV/DT as V N+1 – VN divided by delta so if we substitute DV as difference of V N+1 – VN and DT as delta N, we can get this equation. So VN+1 is VN x Delta T x product of this. So this velocity also will become V of N, which is the correct velocity. So if we start from VN of 0 and keep substituting new values of VN+1 in the next sample for the values of K1 K2 N Delta T. We will be able to plot this values with respect to time.

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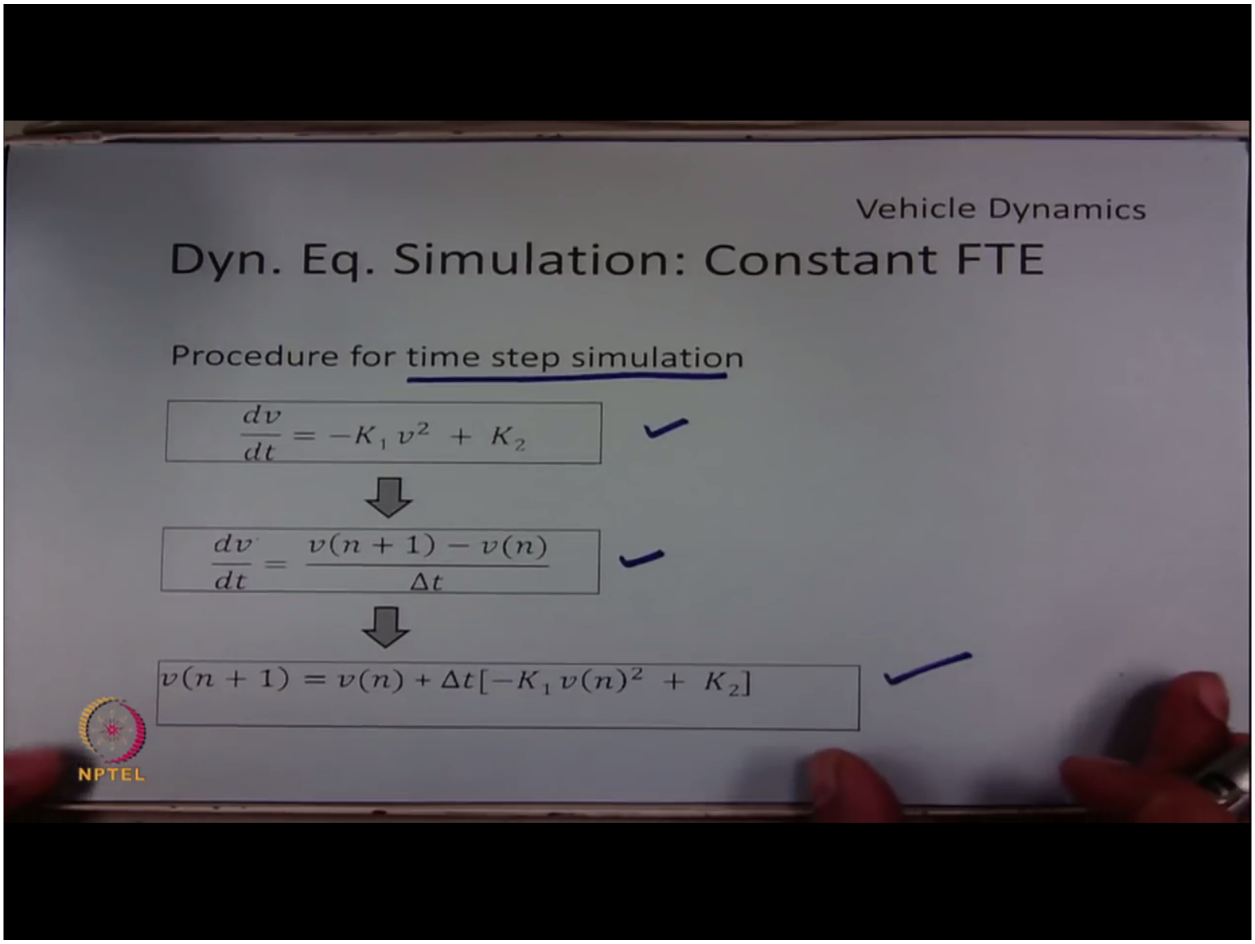

So similar to the previous case of the simulation file for resistive force calculation, we are again putting the simulation file that is used for the plot of velocity, distance, and power here for reference. So first we have to define parameters and values. So G of G=10 R=0.2 Mu RR of 0.01 CD of 0.6… 0.26, AR of 2.2, M of 200 kg and M1 is basically M+0.05 M. So we are together telling this as M1. So this is a total mass. So this is M+ 5% of the total mass of the moment of inertia of the mode. Efficiency of gear, let us take as 0.9, draw 1.25, and maximum torque of the motor is 40 to 10 meter and the slope angle is 0 and the wind velocity is also 0.

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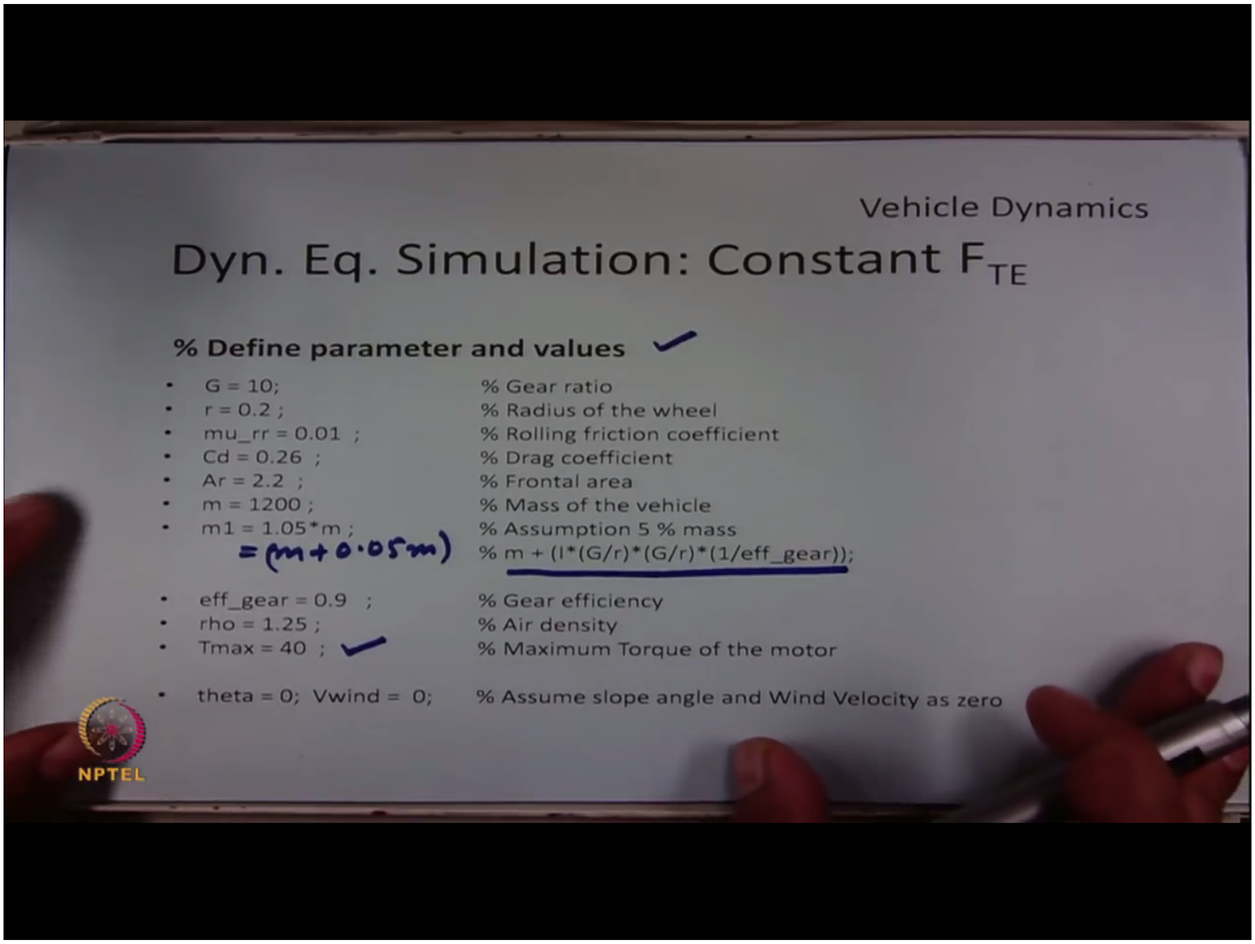

So after defining all the parameters and their values, we can calculate the reactive force, rolling resistance force, gradient force, and the constant of autonomic force using the formulas. So this are simple formulas we have seen.

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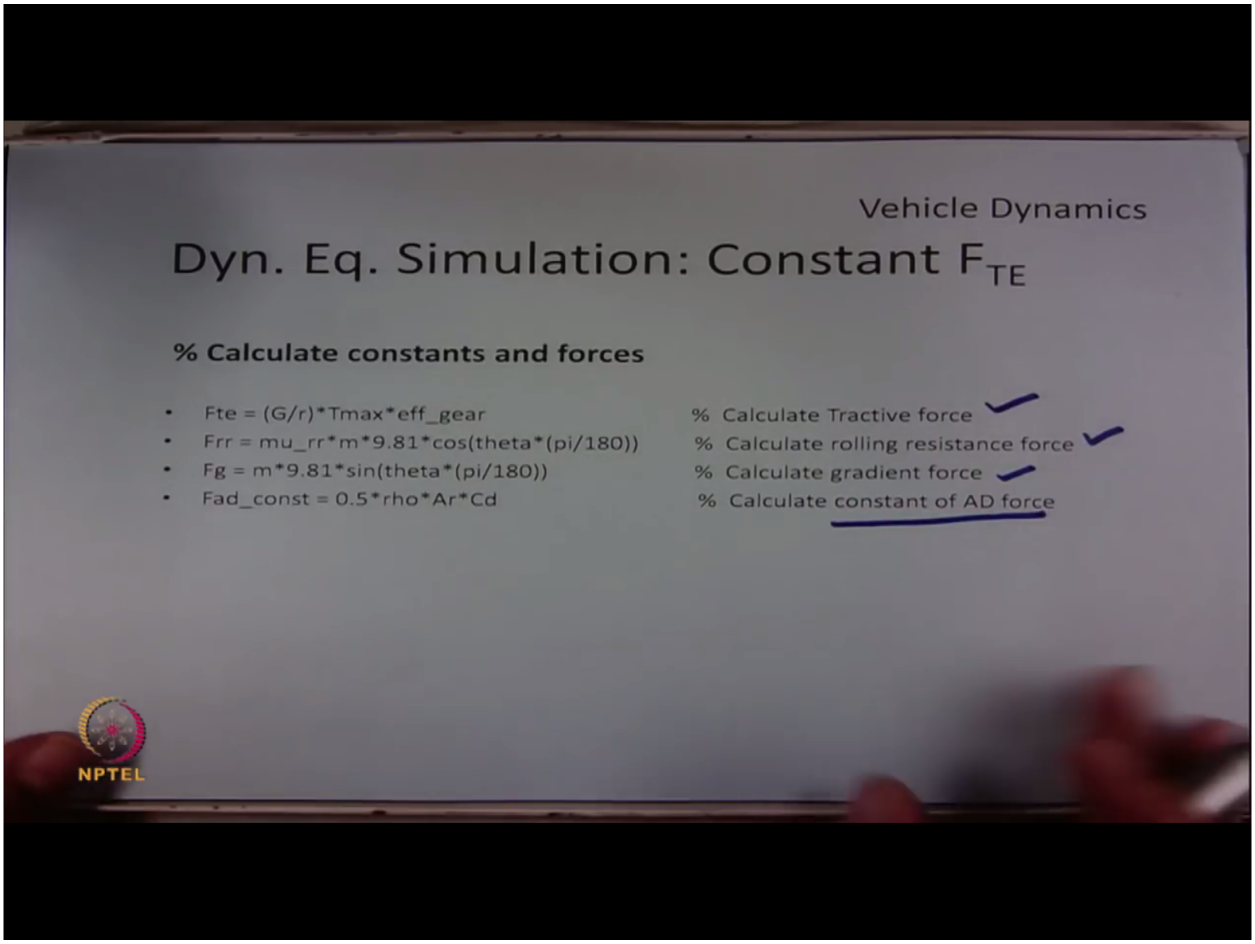

So after the variables are defined, and their values are given, next step we have to write program for initializing the arrays for storing the different values of velocity, distance, and power at different time steps of let's say 0.1 sec for simulation. So first we have to define arrays for storing the values of velocity, distance, and power. So since we are having a TF = 118 seconds, let us take a total time for simulation of 150 seconds, in a time step of 0.1 seconds. So if we do so, we need 1500 values to be stored for each of these variables. So first we have to define that and DT is 0.1 seconds. Later we have to run a for loop, where the new values of velocity, power, and distance will be calculated on the current values of velocity and other variables, so V… N+1 is V of N + D/DT of K2-K1 VN of square. Similarly power is V current value into FTE. We know that velocity is distance by time. So since we know that velocity is distance by time, we can write VN=DN+1-D of N by delta T. Therefore the new value of distance can be calculated as the previous value of distance and the delta T into the previous value of velocity. So in this way we can write the time step based calculation of different variables.

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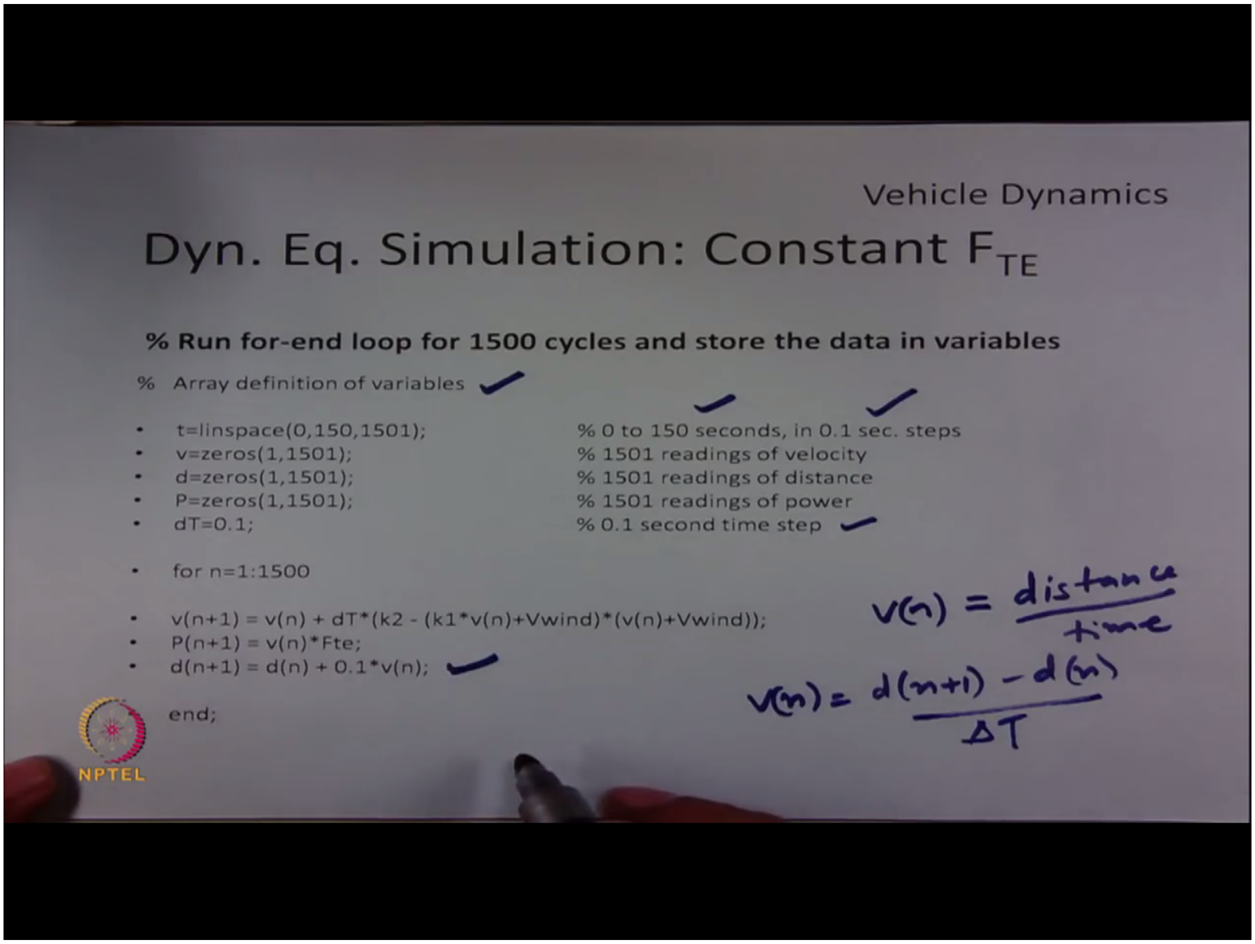

After this, so once the values of velocity, distance, and power is available for 150 seconds in a time sample of 0.1 seconds, we can plot those with respect to time in respective parts.

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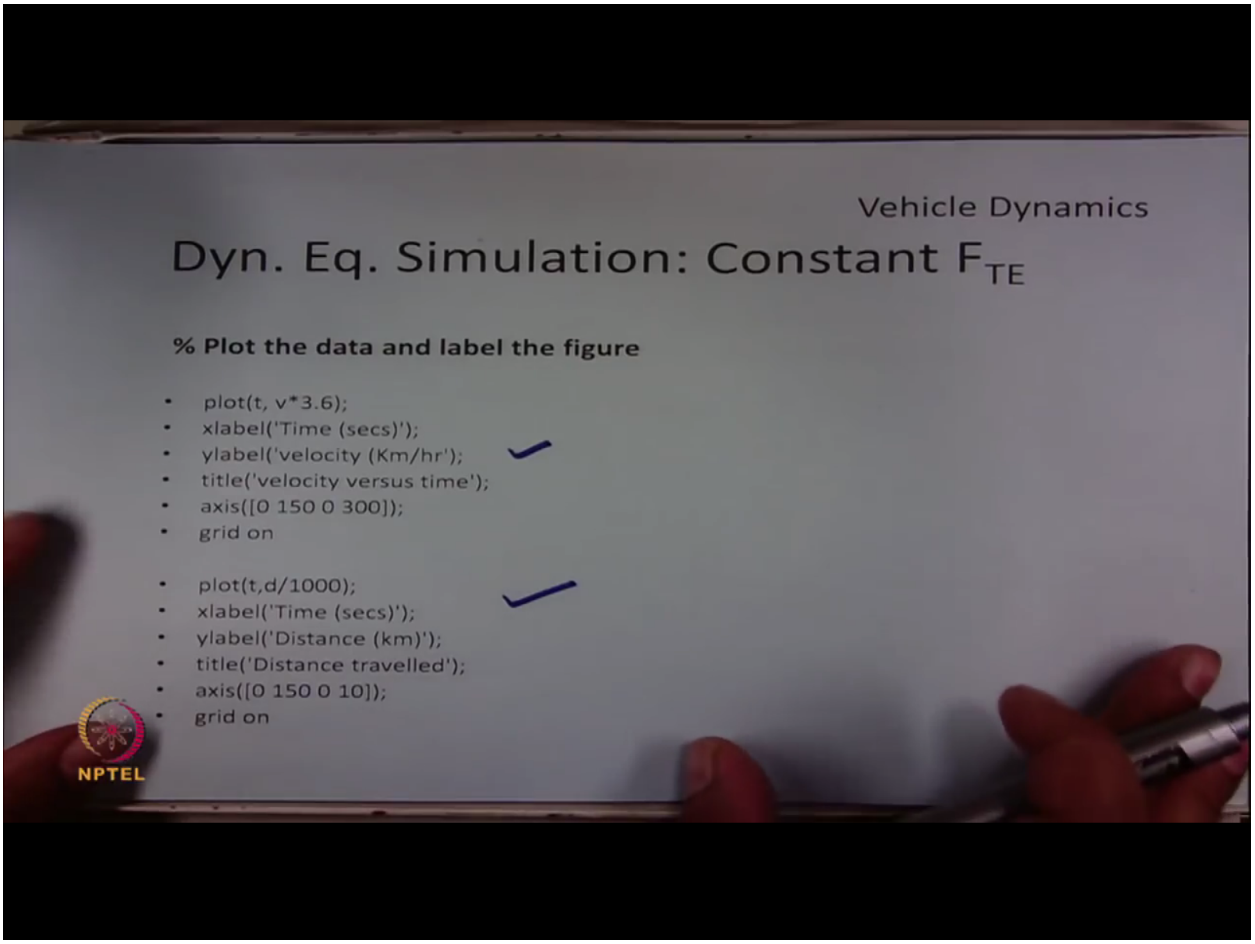

So there is another thing, which we have missed in the previous discussion is that during motoring operation, the power flow happens from motor to the driving axel to the wheel using gears. So equation of T motor is T motor = 1/G 1/efficiency G x TX. So the motor torque is greater than T XL torque, because the power flow is happening from motor towards wheel. But in case of generation of breaking operation. The power flow happens from wheel through gears to the motor, power converter, and battery. So motor will operate as generator and the power is observed from the wheels and given to the battery using power converter. So the direction of torque has changed with respect to the angular velocities and also the power flow. But the equation of TM with respect to T XL is now Eta G/G, why it is so because the input torque is T XL and the output torque is TM. So T XL has to be greater than TM. So this equation change has to be kept in mind.

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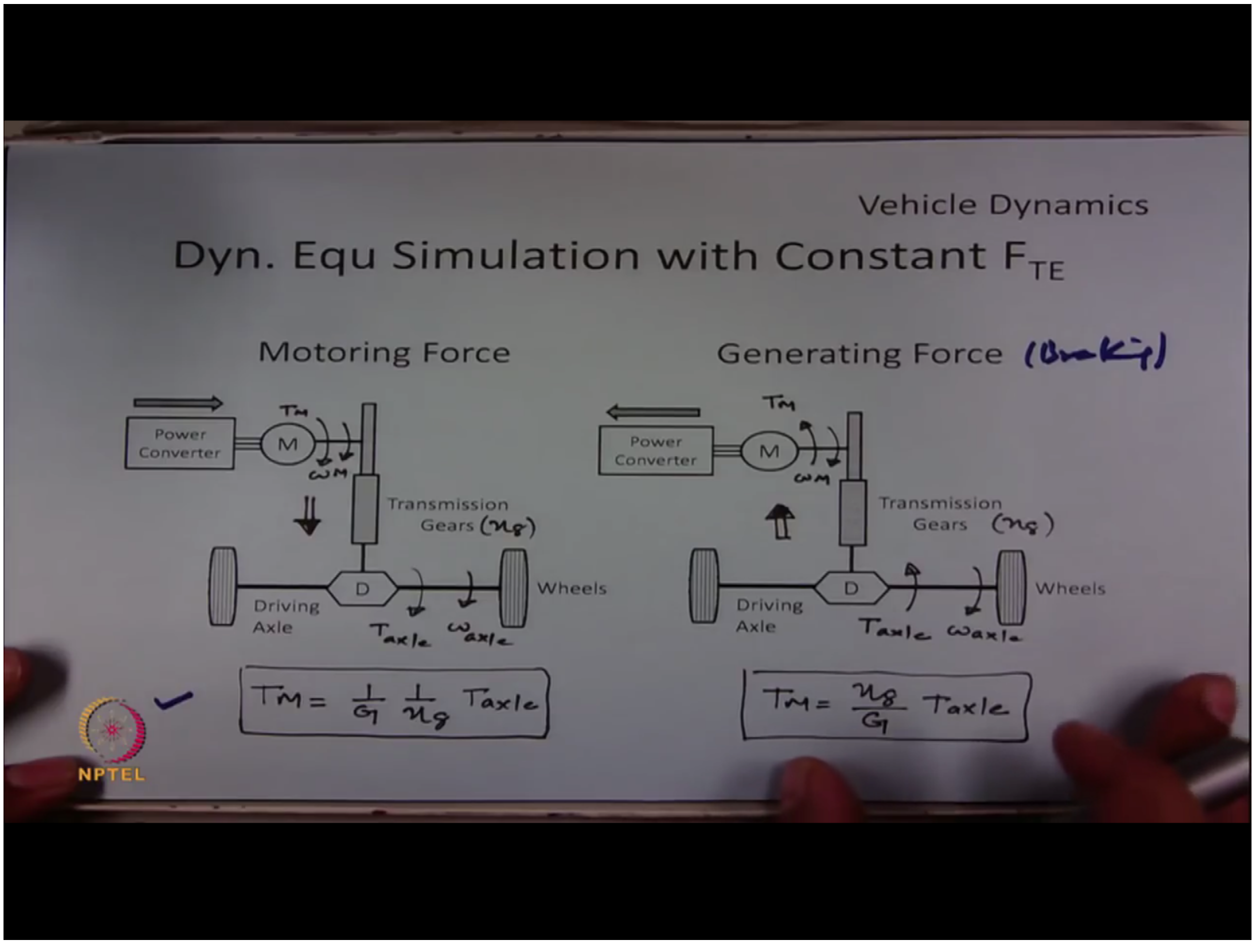

So we know that the tractive effort, which is sum of the forces can be return in two ways. First is FTE = the addition of all forces + accelerating forces. The second way is in terms of ABC constants. So the force equation in terms of ABC has a term, which is BV. So it takes care of the forces with respect to velocity variation. So this is important, because it captures no load spinning losses such as windage losses etc. of all the transmission system. So if we calculate the graphs of velocity, distance, and power energy etc., based on this equation it will be more accurate.

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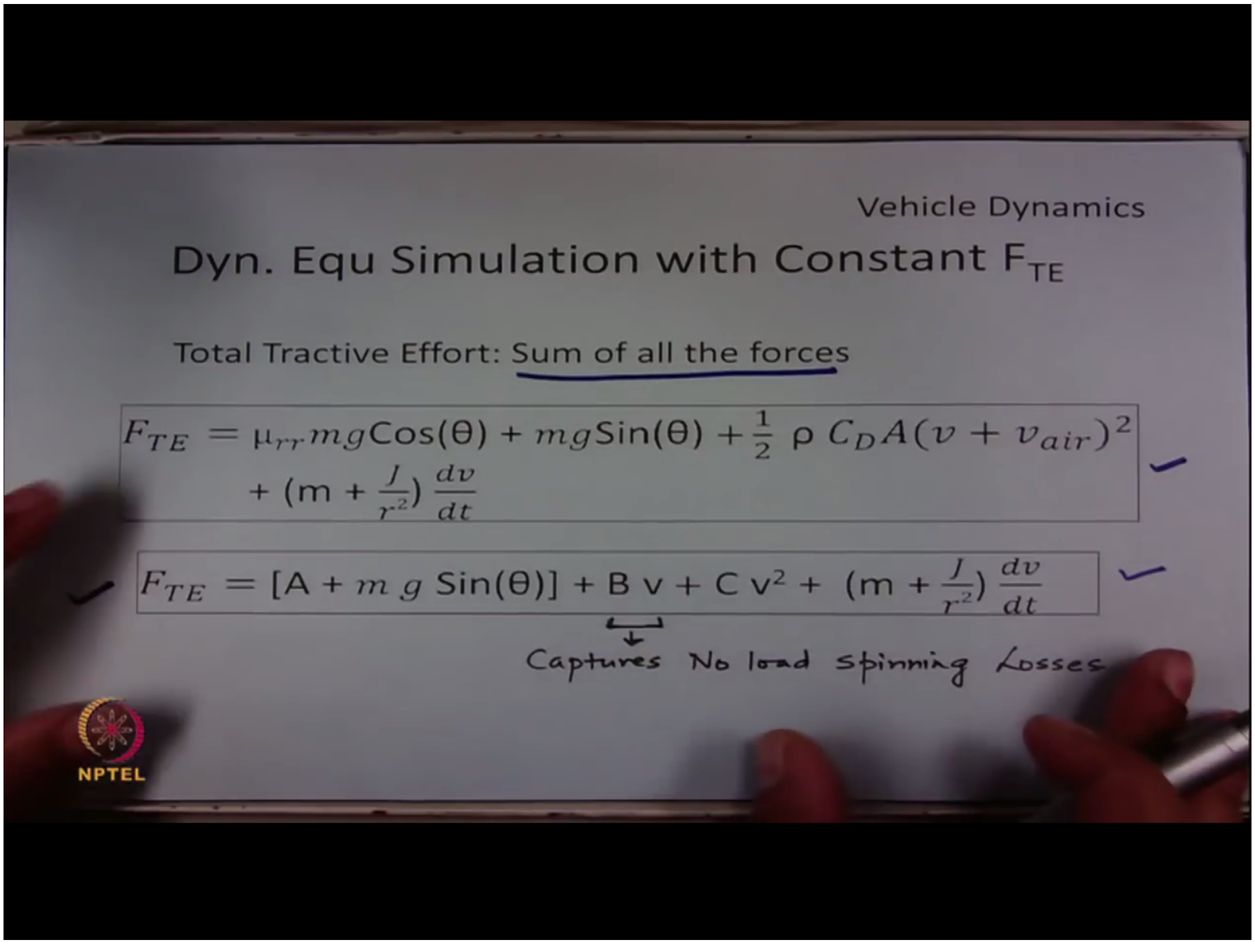

So this is all under simulation of dynamic equation with constant FTE. So in our next interaction we will discuss the dynamic equation, if the input tractive effort is a variable one. So we will see the derivation of equation with variable FTE conditions. So thank you for listening the lecture. Thank you.

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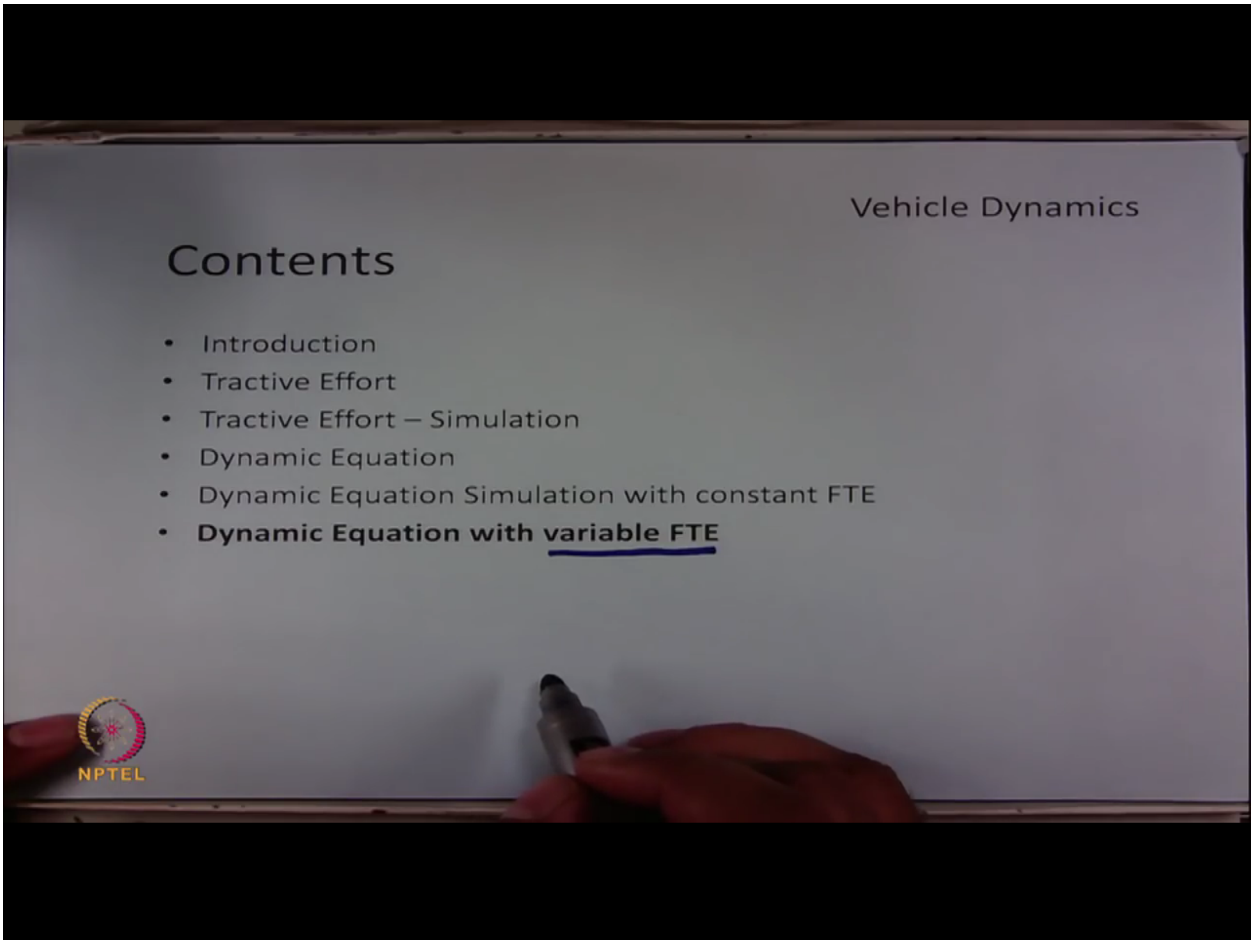

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