INDIAN INSTITUTE OF TECHNOLOGY DELHI

Video Course on

Electric Vehicles Part 1

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Lecture # 17

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Electric Vehicles – Part-1

NPTEL online Course

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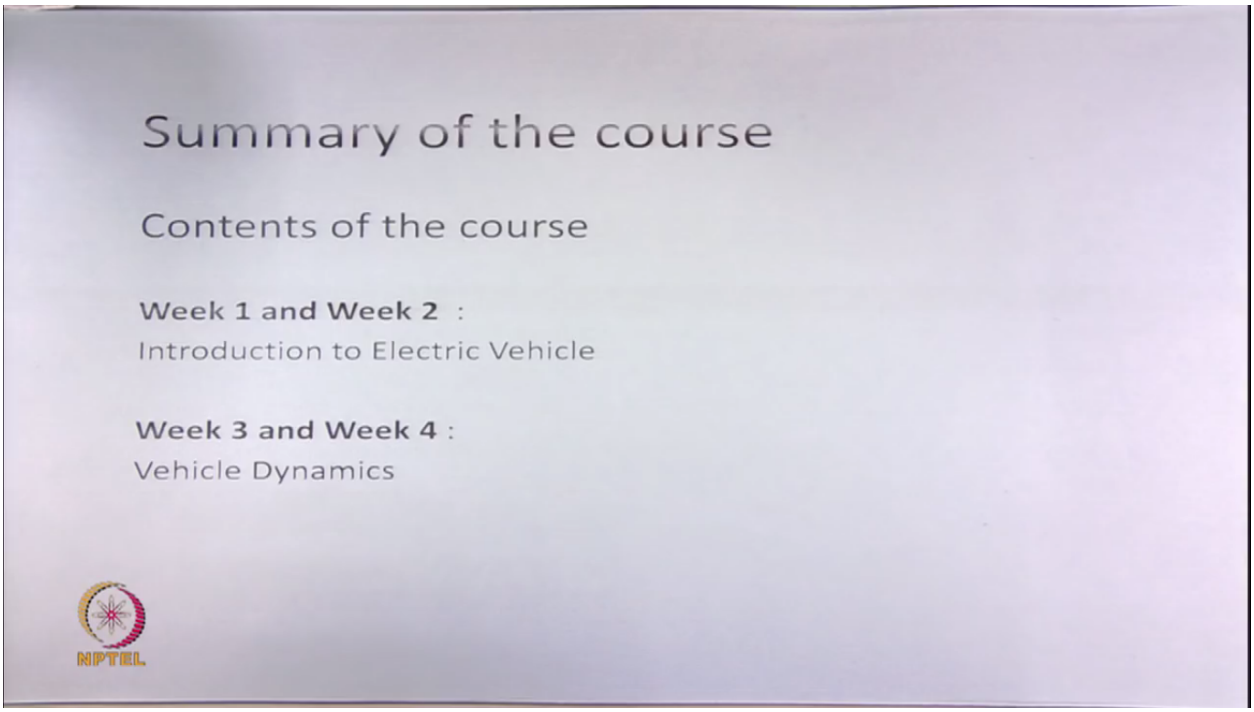
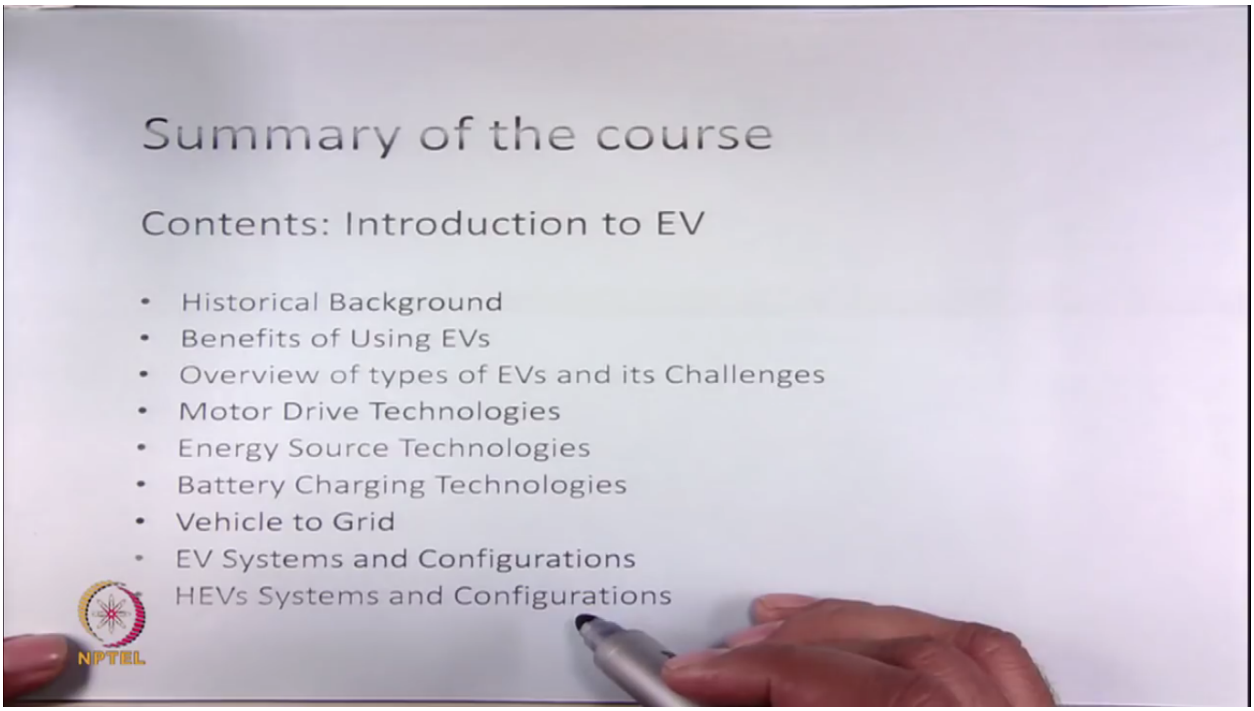
Hello everyone. Welcome to the NPTEL online course on electric vehicles. So in last four weeks we have covered different topics pertaining to electric vehicles. So let us try to summarize what we have discussed in this four weeks.



So basically we were able to complete the discussions on two broad topics under electric vehicles. In week one and week two we have discussed introduction to electric vehicles. And in week three and week four we have discussed the topic of vehicle dynamics in detail. So under the topic of introduction to EV we have covered various subtopics.



So introduction to EV is a important topic for discussion since it gives a overall exposure to someone who is new to this area and since this area is emerging as an important research area and it's very likely that most of the vehicles on the road in future will be electric vehicles. So what we have tried is to give a overview such that anybody who is interested to know more about EV should at least understand the breadth and the scope of this domain.

So electric vehicle has lot of subdomains and we have tried to give a glimpse of each of them. So we have started with a discussion on historical background in initial lecture. So some of us maybe thinking that electric vehicle is a recent phenomena, maybe two or three decades. But in reality that is not so. So in that discussion we have seen that the first electric vehicle was made way back in 1880s and there were lot of manufacturers who were developed commercial vehicles by 1900. So we have some – so we have seen some figures such as 42000 electric vehicles on [00:03:43] rode by 1900s and they were able to achieve performance of 100 plus kilometer per hour of speed and range also 100 plus kilometers. So it was one of the mainstream mode of transport during that time. And as discussion progressed we have seen that because of the emergence of IC engine vehicles by 1925 the electric vehicles started to disappear.

We all know that electric vehicle has a disadvantage that it has to be charged regularly and we need a charging port and charging power supply which is not available everywhere. And on the other hand the IC engine can be fueled by gasoline and other fuels anywhere. So that has promoted IC engine vehicles as mass vehicles during 1930s and 1940s. So EV started disappear.

And as we discussed lot of IC engine based vehicles started to appear and therefore they started creating lot of emission problems and many cities like London and California have seen worst kind of smog and this has promoted governments to take decisions to bring back the EV again in large percentage to the roads such that the problem due to pollution can be addressed.

So the first EV that came as a very successful EV was GM EV1. So the design of GM EV1 was very perfect and it has low tract efficient of 0.19. Secondly the vehicle performance is also extremely good. But as mentioned lack of charging infrastructure and range [00:06:25] it has – didn't carried on as a popular product. However, the hybrid versions became popular because the vehicle owner or the driver doesn't have to worry about the range and the vehicle can be fueled by petrol or diesel but the operation can be more electric. So hybrid electric vehicles such as [00:07:02] and Honda Insights have picked up and they were popular in around the globe by 2000.

Now the last 20 years we have seen many electric vehicles which are pure battery electric vehicles which are able to demonstrate extremely good performance even better than IC engine based vehicles. So vehicles like Tesla, BMW I3, and other pure EVs are very promising and now there is a possibility that EV can become a main mode of transport in the near future.

So in our second discussion which was benefits of using EVs we have seen the kind of harmful emissions that are produced due to IC engine based vehicles specially petrol, diesel, etc. So this type of vehicles generate a toxic carbon oxide, carbon monoxide, NOx gases other gases which are very harmful to human health. Specially we have seen the pollution due to particulate matters such as PM10 and PM2.5. So if they are inhaled by human in high quantity there is a possibility of cancer and even death of many people. So one of the surveys done in California in air research board so they have seen that around 9000 people die every year due to pollution related health hazards. So we have also seen that electric vehicles which require electricity as mode of charge, fueling is available from all kind of energy resources whether it will be oil, gas, coal, or even renewable energy. So in that way it's more versatile while the IC engine based vehicle typically can be charged by energy sources such as oil, gas and coal which are creating lot of health hazards. So one of the important benefits is that it is diverse energy vehicle. We have also seen that the efficiency of fuel tanks to wheels is quite high in EV. So it is 76% and it is very low in the range of 16% in IC engine based vehicles. So in terms of drive and efficiency also electric vehicles are better of compared to IC engine based vehicles.

So in the discussion we have seen also the drawbacks of EV or pure electric vehicle is observing now a days such as you know the size of the battery which we need to keep in a vehicle to obtain same range as IC engine based vehicles. So the specific engine specific power of batteries are quite low compared to diesel and petrol so which also ask for more battery therefore more weight. Charging infrastructure is very important and problem which needs to be addressed to make EV successful vehicle.

After that we have discussed different types of EVs and challenges. So we have seen the divisions of EV as pure EV or hybrid EV. So under pure EV we have vehicles such as battery electric vehicle, fuel cell electric vehicle, ultracapacitor electric vehicle, ultra-flywheel electric vehicles. And under hybrid electric vehicle we have vehicle such as mild electric vehicle, micro electric vehicle, and full hybrid electric vehicle. So these are the three types of conventional hybrid electric vehicle which are known as micro, mild, and full hybrid. And we have some hybrid EV vehicle which are griddable. So in those vehicles there is a provision to charge the battery via a grid interface in addition to filling the petrol or diesel from the filling stations. So this type of HEVs are known as griddable HEVs and they have two deviations so one is known as plug in hybrid where and the second one is called range extended electric vehicle.

So plug in hybrid vehicle is basically topology similar to full hybrids where the size of IC engine is higher compared to the battery. But on a range extended is a kind of adaption of pure electric vehicle with a small engine. So we have also seen the kind of support of integrated started generators in terms of vehicle performance. So we have seen that in micro HEV can only help to start, stop the IC engine and regeneration during braking operation. While the features such as electrical launch, and power assist can be added if the vehicle is a mild hybrid vehicle.

And when we go for full hybrid many modes are possible. So not only start, stop, regenerative braking, power assist, as well as detail launch we can also go for optimization of IC engine fuel economy. So in a full hybrid we have a basically three types of main HEVs which are known as series HEV, parallel HEV and series-parallel HEV and we also have complex HEV which is a extension of series-parallel HEVs.

So in full hybrid further optimization is possible and it's possible to achieve a high fuel economy for IC engine and battery driven motor such that you get the best performance of the vehicle in terms of range and cost. Later we have seen the topic of motor drive technologies. So we all know that we need to use electric motor for driving the wheels in all EVs. So it will smaller percentage in hybrid electric vehicle but it will be a sole mode of driving in a pure electric. So we have seen that compared to IC engine which normally runs at constant speed and it can give roughly constant torque for even variation of such speeds. So for obtaining wide vehicle speeds and torques a variable gear system is required so which will allow IC engine to give high torque at starting at low speeds at let's say first gear and the vehicle can demonstrate very high speeds with low torque in the higher gear let's say fifth gear. So required variable gear box which is last component and convenience to the driver also.

In comparison to IC engine based vehicle electrical motor can readily give low speed high torque operation as well as low torque high speed operation without any variable gears. So it has by design those kind of characteristics in motor torque speed graphs. So therefore, we have to go either no gear or if gear is required it will be fixed gear. So in that ways less loss as well as it's very convenient to the driver. But since the motor has to take all the responsibilities of starting and high sped cruising now design of motor is a challenging area. And we have to design a

machine which are high efficiency in both this low speed operation and high speed cruising. So designing such kind of motor is very tricky and it's important area of research. We have also seen the different kind of motors that are used. So we have seen now the popular motors are BLDC motors which are very easy to construct and they are very popular in low power vehicles such as two wheeler and three wheeler. But when you go for slightly higher end or medium end EVs we generally go for permanent magnet types of machines which are not only high efficient but they provide also high power density.

So we have also seen that many new types of motor are emerging where the magnet will be on a starter and we have [00:19:45] on the rotor surface without any winding or permanent magnets such that the construction can be easy. And there are other machines such as single [00:19:55] motor as well as switch electrical motor which are researched such that they can be incorporated as a electrical motor for this application. So these motors use no magnets and therefore it is simple to construct and less costly.

Later we have seen the different types of battery charging technologies that are in popular use. So there are three kind of charging schemes like normal charging, opportunity charging, when we have rapid fast charging. So various kind of charging we have seen. So some charging schemes can be used at home application via single phase supply is available but when a high rating vehicle has to be charged we have to go for three phase system and when we have to go for very fast charging, the charging of 20-30 minutes we have to go for DC charging of very high DC currents. So such kind of infrastructure is difficult to establish.

We have also seen the different types of charging algorithms. So we have different methods to charge the battery when the supply is there. So it's just constant current charging, constant voltage charging, constant current, constant voltage charging which is a kind of base algorithm for high end algorithm so where the vehicle battery is charged with high current initially followed by slow charging in constant voltage mode. So CC, CV is kind of algorithm understands the behavior of battery while charging very well. And we have advanced charging methods such as multi-step charging etc.

so we have charging called trickle charging which needs to be given to battery for supporting the losses. So if a battery is kept idle for some time it will discharge due to cell discharge phenomena. So small current is always given to a battery such that it can be kept at good condition. So we have also seen the methods which are used to manage the battery which are known as battery management system. So typically we have lot of cells which are connected in series and parallel to obtain the required energy and current and voltage ratings of the battery pack. So when this cells are charged and discharged many times not all the cells will be charged equally and therefore there is a necessity to keep them in good condition and understand those conditions in real time. So the parameters such as SOC, SOH, SOP are important parameters

which has to be evaluated on a real time basis by measurements of currents and voltage. So separate processor will be there which takes care of these things. So this we have seen.

Later we have seen a new area which is emerging because of lot of electric vehicle being charged via utility grid. So when the scale of electric vehicles is low it will not affect the power grid. If there is a lot of electrical vehicles which are simulatenously connected to grid it will put a burden on the power grid and therefore it always advisable to charge the electrical vehicle during light loads conditions of the grid which mostly happens in mid time of the night. So at that time there is a surplus power available on the power grid and it's the battery charging can be even helpful to the grid to support its rating.

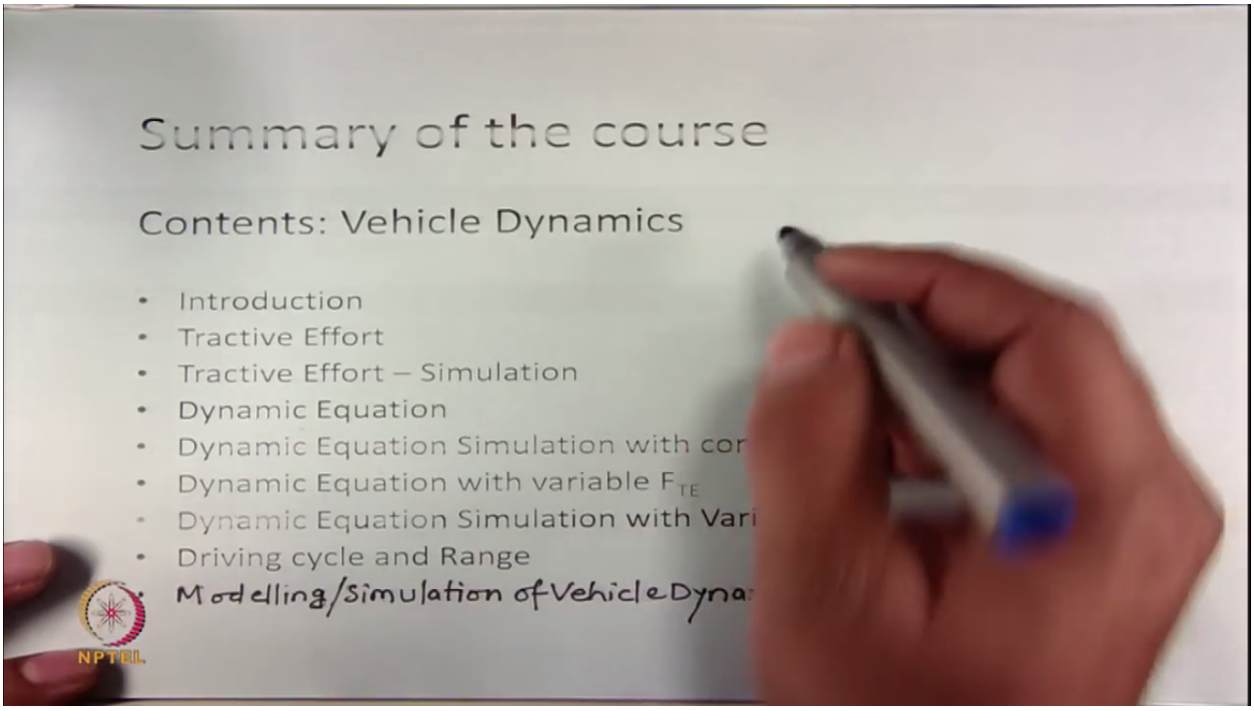
We have also seen that a lot of electrical vehicles can be combined to a common aggregator or a pool it can help the grid in many ways such as it can support as we discussed the night time coordinated charging or the it can support the pick power demand during the pick hours while supplying the energy store in the battery. So most of the vehicles will be parked in some kind of place and the batteries are utilized and they can help to utility grid to support the pick power demand during the mid of the day.

So we have seen many technologies which are emerging such as vehicle to vehicle, vehicle to grid, vehicle to home and other technologies. So this electrical vehicles can also support power grid in terms of spinning reserve asset or it can be used for reactive power composition and many other things. So we have discussed most of these things. So in the further discussions we have tried to understand the EV subsystem different kind of EV configurations within a electric vehicle. So we all know that we have to have a motor with a fixed gear to run the differential which will be connected to driving axle to the wheels. But it is possible to have gear-less electric vehicle where you don't need any gear. Secondly it is also possible to have electric vehicle which doesn't have differential. But if you don't want to have a differential we need to operate two motors so individual motors to each wheels. Let's say if you have a front wheel transmission so in that configuration the two motors operations has to be coordinated such that it can virtually enable differential mode operation. So when vehicle has to be turned right or left one of the motors has to be driven at higher speeds and the other motor has to be driven at lower speed. So then it provides the torque differential for turning the vehicle without any skidding or driving discomfort. So you have also seen the type of motors which are embedded in a rim of the wheel. So there is possible that you have stator windings on the vehicle wheel itself. So if the rotor is on the rim and so you need to provide a gear to bring the high speed operation of the motor to the low speed requirement of the vehicle. But it is also possible to even remove that planetary gear by having a configuration where the rotor itself is the wheel of the vehicle means you have to have a outer rotor motor similar to what we have in electric ceiling fans or hub motors. So we have seen advantages, disadvantage of each of these configurations and what are the challenges the industry is facing to develop those things and how they are being addressed.

We have also seen the energy resources part of EV subsystems. We all know that a battery is required to be connected to electric motor for energy supply. But we all know that a single energy source like battery is incapable of providing both the high specific energy and high specific power in a single pack. But these are the requirements of a electric vehicle we require a high specific power for quick acceleration or pick up during starting but for good range we require high specific energy. So we have seen the different modes or ways where two sources are connected in parallel and supporting the energy supply to the motor such as one battery type of let's say a fuel cell has high amount of specific power or ultra-flywheel has high amount of specific power or ultra-capacitor. So this can be connected in parallel to the batteries and we can support both the low speed high torque and high torque low speed operation with a single energy source. So we have seen all these configurations.

So in our last topic under introduction to EV we have seen a different types of HEVs. So we have series HEV, parallel HEV, series-parallel HEV and complex HEV. So we have seen the configurations of each of these HEVs and how this vehicles operate, starting, normal driving, acceleration, deceleration, battery charging at rest, battery charging while driving, all these features we have seen in detail. We have also seen the kind of planetary gear what is normally used in this HEVs.

So in complex HEV it's we have both front and rear transmission by means of two electrical motors and one IC engine. So we have seen the complex HEVs which are coming in high end vehicles now. So there are many things we have discussed under construction of EV and I hope it has given a good glance of this area to the listeners.



So in week three and week four we started discussion on vehicle dynamics. So vehicle dynamics is important area to be understood for any vehicle for that sake whether it's IC engine vehicle, or a electric vehicle, we need to understand the dynamics of the vehicle. A vehicle normally needs to support lot of opposing forces. So one such force is the force due to gradient. So if you are going on a flywheel or a hill there is backward force equal to mg sine theta which has to be supported by the energy source of the motor.

So we have opposing forces such as the friction due to road condition, the tire pressure or the resistance between tire and road. So this kind of forces also has to be supported. These forces are known as rolling resistance force. We have forces due to the wind conditions. So when the wind is opposing the vehicle it also provides lot of opposing force and this kind of force is a function of square of the velocity and therefore it's quite heavy at high speed cruising operation. So we have understood the different equation pertaining to this forces and we have also seen that how the design of the vehicle is important. So in IC engine based vehicle we really don't care for so much on the weight or the streamlining of the design but for electric vehicle that is very important because any support to these forces from the battery is very critical to the range so we have derived those equation and understood the features of each of them in a topic known as tractive effort.

In our discussion we have also seen the simulation. So in this topic we have started simulation exercises. So for each thing we will try to simulate. So we have seen the different types of resistive forces which vehicle has to support. And some of them are function of gradient. Some of them are function of vehicle design. Some of the features of the air density. Some of them are features of vehicle velocity. So how each of these forces vary with respect to this conditions at different functions of these parameters changes we have seen all these things by means of simulation. So it is useful exercise that can be done to understand this forces in detail.

So there are two ways a vehicle performance can be checked. So one method is like when you are going at constant tractive effort so let's say the motoring torque is constant and we will try to understand how the vehicle performance will be – will come. So we have seen as a – so it's a kind of slightly complex differential equation of velocity and we have tried to derive those final solutions by means of different understanding and we were able to derive the velocity equation as a function of time, distance equation, power equation, average power equation, energy equations all these equations we are able to derive and they were very handy for understanding of the vehicle performance. So we have also seen simulations with respect to this understanding of dynamic equation with constant tractive effort.

In the real scenario the vehicle has to see variable tractive effort. So we all know that we need to operate at high torque low speed operation at starting and lower speeds but as we go to higher speeds we will not be able to support the high torque to do the limitation of power rating on the machine. As well as once they reach maximum speed the vehicle torque requirements comes

very low. So all these understanding were further enhanced by simplified equations with approximations which were quite true at low speed operations but they try to be quite out of calculations when in high speed modes. So we have done detailed analysis and modeling with variable tractive effort to electric vehicle or vehicle dynamics.

We have seen the different types of driving cycles. So why these driving cycles are important? So let's say we have electric vehicle and we want to understand at what range the vehicle can support for a full battery charge. So then the question is obvious that it all depends on how you drive and what is the driving pattern. So and we also know that we have a different style of driving when we are going in a urban scenario. So we have a lot of quick start, stops and frequent stops. But when we are going on a highway mostly we go in a constant speed and that too high speed. So the range of the vehicle depends on the driving patterns. So there are a lot of standard driving patterns in U.S., Europe, Japan. So we have seen the variation of some of them such as the federal urban driving system or scheduled and the very popular one is that SAE J227 from the Japanese regulatory agencies. So we have seen that how the driving cycle will affect the range and some of more discussions.

In the last discussion we have tried to do the modeling of the vehicle dynamics in Simulink. So Simulink is important tool and very useful tool which is popularly and frequently used by researchers and students for dynamic simulations. So we have done the modeling of vehicle dynamics such that it suits the Simulink tool and we have also demonstrated the models developed and their performance for constant FT operation, variable FT operation as well as when the vehicle is given different driving cycles. So all these simulation regions also were shared and at the end I hope the listeners to this lectures will be able to appreciate the knowledge shared in these lectures and will be helpful in their growth as professionals in this domain as well as for academic purpose teaching loads or course credits.

So as a instructor I have tried my best to give whatever knowledge I have gathered and understood with all of you. So we will probably come with electrical vehicles course part two in the coming future where we will discuss the next topic or the other topics in details. So we have a lot of topics which are yet to be covered such as the batteries, the performance, evolution of batteries, charging infrastructure, modeling of electrical machines and the control of electrical machines, the understanding of power converters. So lot of area yet to be discussed and probably they will be covered in future versions of this course and so I thank the listeners for listening to all the lectures.

Thank you.