INDIAN INSTITUTE OF TECHNOLOGY DELHI

NPTEL

NPTEL ONLINE CERTIFICATION COURSE

Video Course on

Electric Vehicles Part 1

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Lecture # 8

Intro EV Subsystems and Configurations

Hello everyone, welcome to the online mode course on electric vehicles. Let us discuss the next topic under introduction to EV which is EV systems and their configurations,
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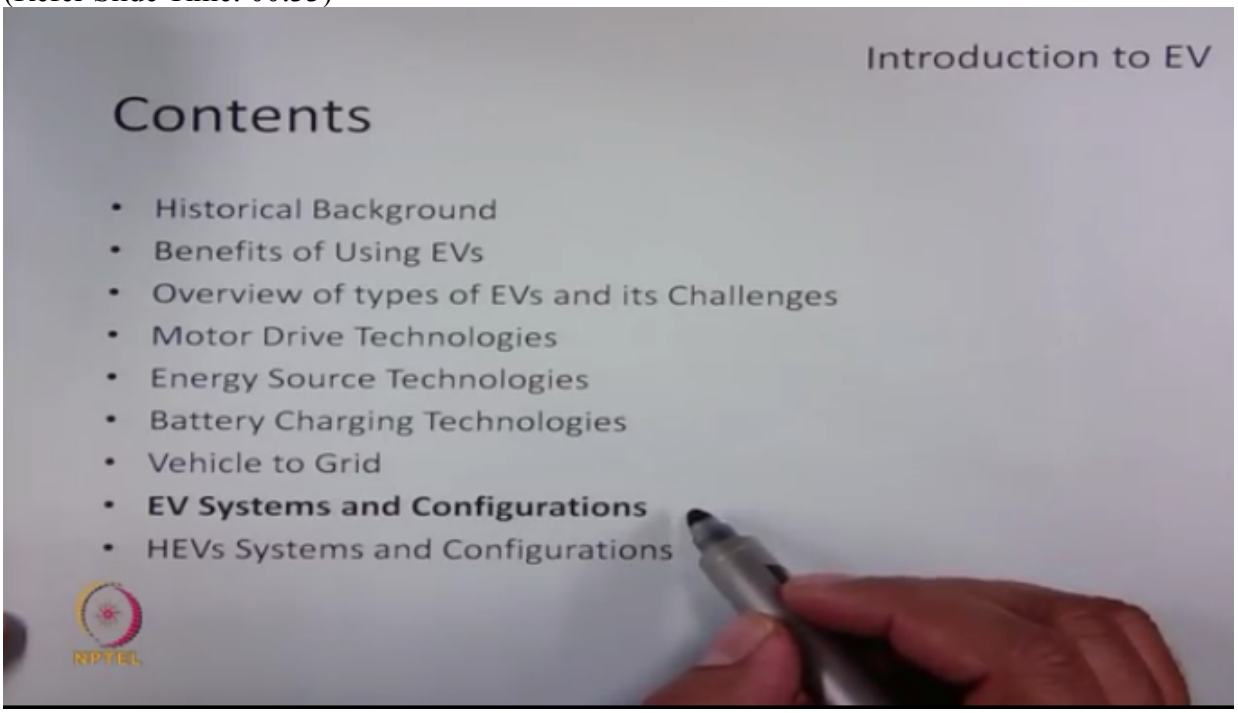

so EV system requires knowledge of multidisciplinary engineering domains.

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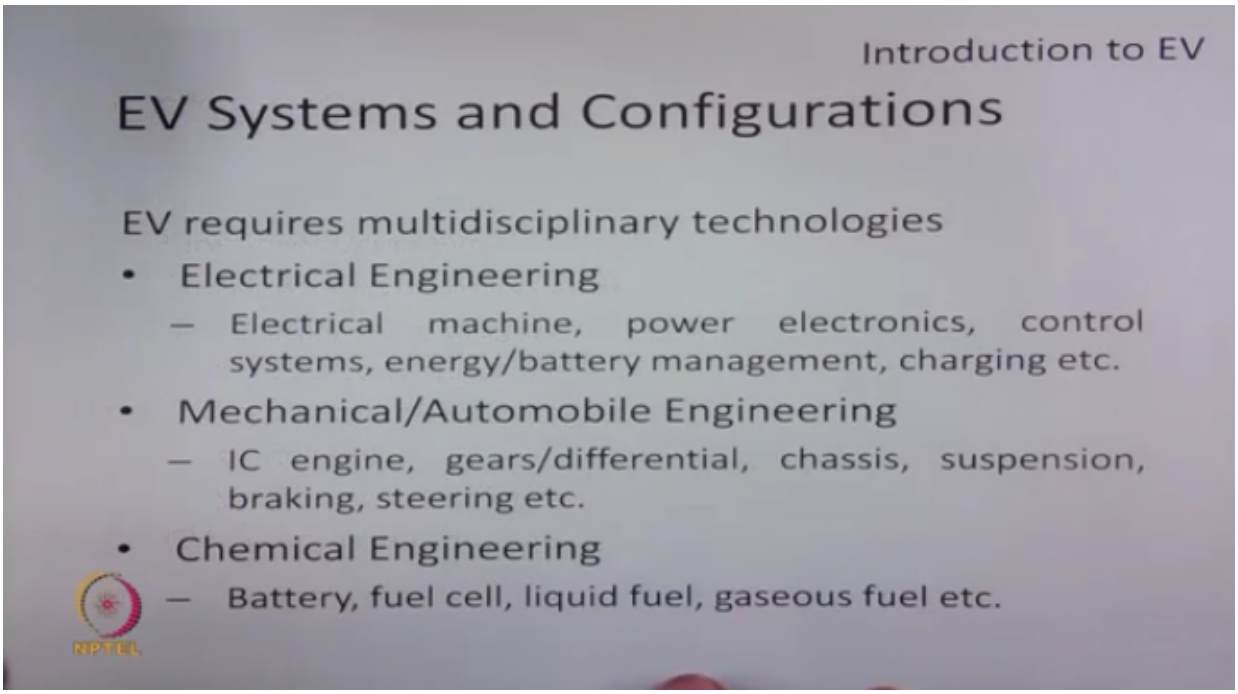

In electrical engineering it requires a expertise of electrical machines, power electronics, control systems, energy and battery management systems and charging.

In the mechanical and automobile engineering domain it requires the knowledge of gearing differential, chassis, suspension, braking, steering etcetera. The knowledge of IC engine is required in a HEV or hybrid electric vehicle.

In chemical engineering domain the knowledge of battery and its different kind of chemical features are required to be known, the knowledge of fuel cell, so battery and fuel cell are energy sources and it also requires the knowledge of fuels, so how the liquid and gaseous fuels operate, it's very handy to have the knowledge for a good EV development.

So what are the different kinds of EV's which are designed today?
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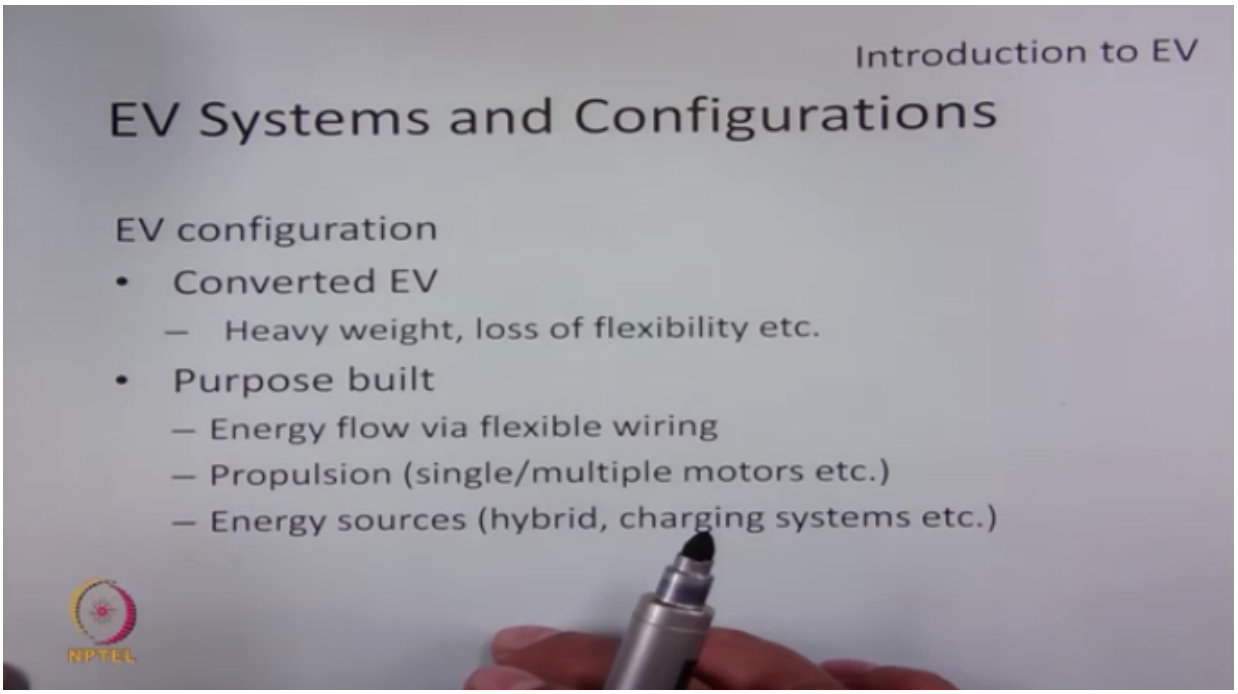

So first type of EV configuration is converted EV, converted EV means a EV which was designed by converting a existing vehicle, probably a diesel engine vehicle or a petrol engine vehicle, so what is done is that in place of the IC engine a similar rated electrical motor is fitted and the rest of components are kept same without any change, so this type of EV design is very simple and it can use the already absolute IC engine vehicles which has completed their service life of 15 to 20 years and they are lying idle, so this type of EV's only popular when the cost to the customer per kilometer of driving is less in the converted EV compared to the diesel engine EV, so this system is not a high performance EV, because it just still carries the heavy weight of the vehicle which exist in a typical IC engine based vehicles, it doesn't have you know much flexibility so the new EV which is developed has to accommodate motor and energy sources in place of the IC engine or it can use the storage capacity of the IC engine such as luggage space etcetera.

Nowadays all modern EV's are purpose built, a purpose-built EV means the body and the frame of the vehicle is newly designed such that it takes into the set ration the structural requirements of the EV and it also uses all the flexibility the EV system offers. So let us see what kind of flexibilities and requirements needed in a design of a purpose built EV, so we all know that in IC engine based vehicles the power flow or the energy flow is done mechanically, means they will use bolted, frames and rigid systems to transfer energy from one system to another, but in a EV obligation the power flow is normally done using electrical wires, so which is very flexible and it allows the distribution of different components of an EV throughout the vehicle and the energy transfer can be done using flexible wires, so you can say that the distribution flexibilities very high in a purpose-built EV.

Secondly the type of propulsion system used in EV is also deciding factor, so in subsystem there maybe gears and subsystem maybe gearless, some of them may use a differential other may not, some may use single motor, others may use multiple or dual motors, so depending on

the type of EV that design of the EV has to be done, it cannot be the same for all types of configuration.

Thirdly the type of energy sources used in an EV decide the design of EV a lot, so if a single battery based vehicle is design it has to be suitably done, if you say multi battery system it has to be done in other way, so we know that a battery bank can be distributed in many ways, so you can use batteries in the chassis of the vehicle, in the top side of the vehicle or in the luggage space of the vehicle, so all this possibilities are there and there can be connected together using wiring arrangement, but when you use a fuel cell in a fuels electric vehicle that design has to be different, because now the fuel to be store is hydrogen and it took us lot of auxiliary systems associated with it such as conversion kit, high pressure developer equipment etcetera.

Secondly the charging system is also important, so the charging system for different type of energy uses maybe different, secondly it can be on board charger, it can be a IPT kind of system where secondary coils are to be installed in the vehicle, so this all requirements has to be taken into consideration while designing a purpose based EV.

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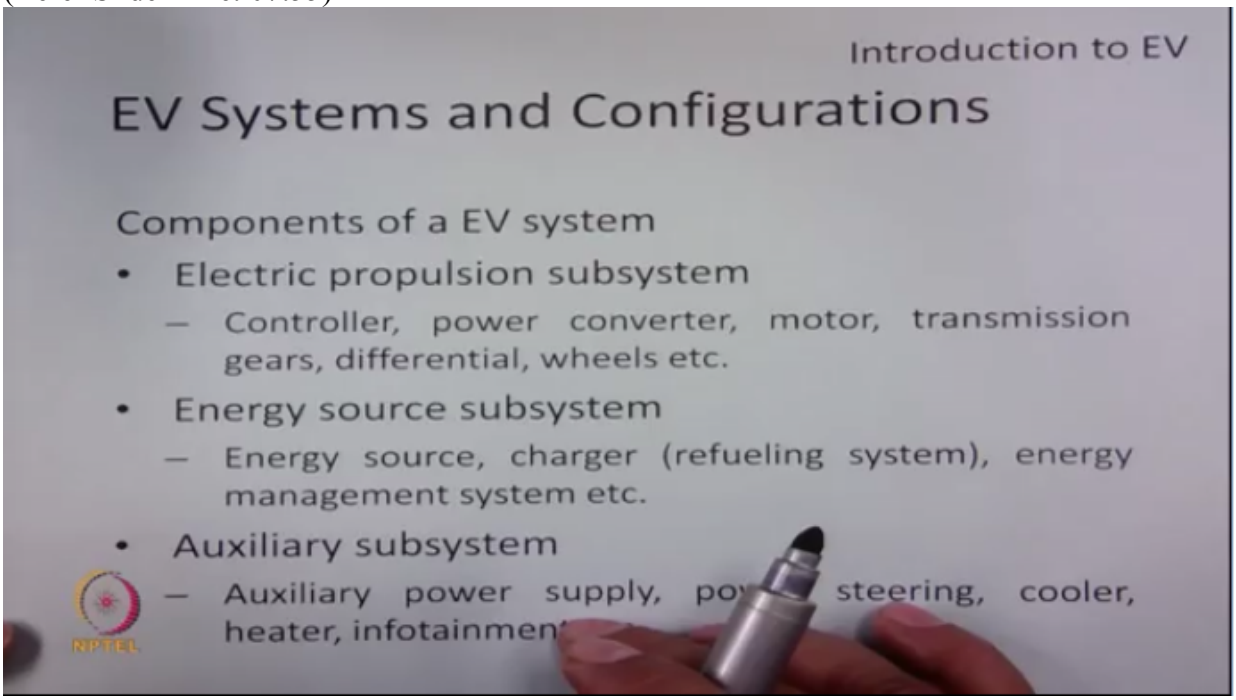

So what are the different components of a typical EV system, it has three main subsystems, first is electrical propulsion system, so under this system we have controller, power converter, power electronics, motor, transmission, gears, differential wheels etcetera, so this all comes under electric propulsion subsystem, so the designer generally tries to optimize these components such that the performance of the vehicle is enhanced together this energy efficiency, means people try to get higher performance operation together with minimum energy, because if you say battery electric vehicle the source of energy is limited once it is charged.

So generally the motor is designed such that it is high power density, it has high torque density, it has high efficiency in wide speed and torque ranges, the power electronics is generally

designed at high switching frequency such that the size of the associated magnetics can be scaled down, it is also seen that some of the components like gears, differential can be avoided such that this are the loss making components and then can be avoided, but they can be only done by means of complicated control and that is a job of a complex control system or the controller.

The second system which is energy source subsystem, the designer has to take care of placing the energy source, the selection of energy source, the design of chargers or the refilling systems in case of fuel cell and other systems, and the managing of this energy flow and by system known as energy management system or EMS which talks to all the components such that the energy within the system can be saved, so in an any EV or any vehicle that sake uses auxiliary power supply, so this power supply is required to support power steering, cooling arrangement, heating arrangement, infotainment etcetera, so now most of the systems are moving towards fully electric type, means the steering has gone to power steering, the cooling the heating requirements can be also made more electric by using a drive based air conditioner etcetera such that the power requirement for this auxiliary subsystems can be minimized.

So let us see the typical _11:15_ of a battery electric vehicle and the associated subsystems we have just seen,
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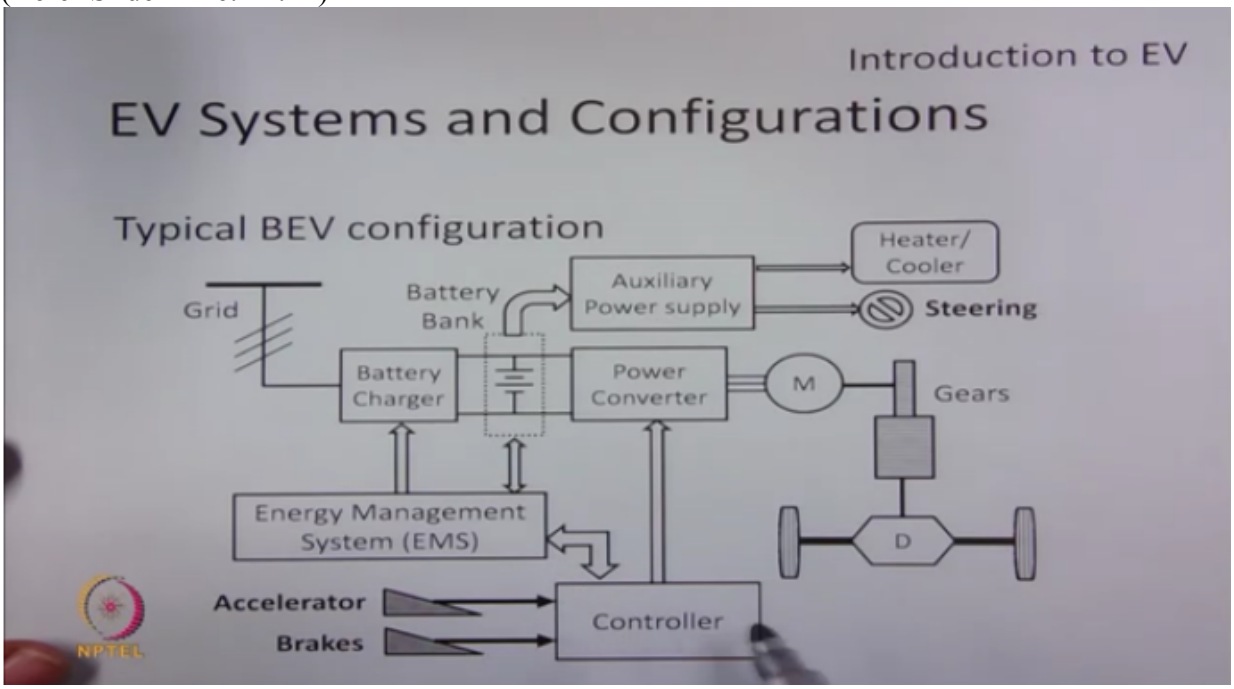

so the input to the BEV is generally come from a driver in terms of accelerator command or braking command, so this command goes to a electronic controller which then acts and give information to the electric drive which means the combination of power converter in motor such that this action can be initiated, so when the accelerator command is given the power is transferred from the battery to the wheels by operating the motor and when the braking action is commanded the same drive will act in such a way that power can be observed from the wheels and battery can be charged such that we don't waste the energy in the manual braking.

So in braking mode the motor will work as a generator, this is another system which is known as energy management system or EMS which will take care of battery state of health, and state of charge etcetera, and it measures this parameters in real time, and it gives this information to the controller in real time such that if the battery capacity is gone down because of many discharges it will tell the controller that even if these high acceleration demand please limit it to a such an extent that the required range which the driver wants to go can be obtained, so this is important link between EMS and controller.

The EMS also takes care of the heating and cooling requirements and steering requirements, so it always try to talk to the systems and understand the kind of power input they are taking, so again the same case when the battery charge capacity is reduced because of many discharge cycles, it will not allow your high capacity heating or cooling, so it will limit it to an extent such that not much energy is wasted in this requirements, so this whole systems work in an integrated fashion such that the controlling actions, controller, the drive, battery, the auxiliary supply and the associated components all are watched and controlled in a EMS.

So let us see different types of mechanical arrangements in a typical BEV system, so we have seen converted EV's,
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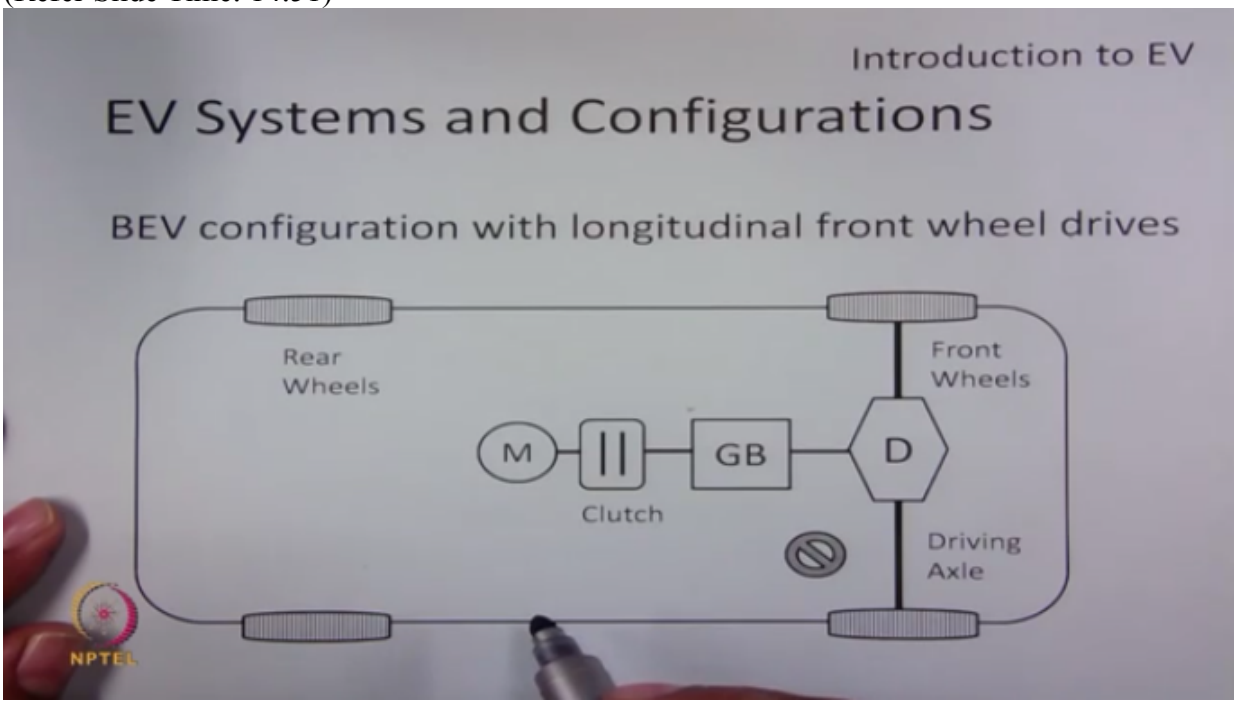

so converted EV's typically use the technology of IC engine based vehicles which is longitudinal front engine, front wheel drives, so it replaced the IC engine with a similar rated motor, and the rest of the mechanical assembly is same like it has clutch, it has a gear box which is irregular gear system and a differential, so the requirement of the motor is, it should work at full speed with capacity of delivering the full torque, it doesn't need to operate in a variable speed and variable torque operation, because that purpose is done by the variable gear systems by means of clutch system, so this system is very easy to build and it is normally done so in a basically a three wheeler or a very smaller rated car where not much expertise is

required from the electrical domain, so the motor that can be used is conventional motor and it doesn't have to be designed for EV application, it can be any conventional motor,
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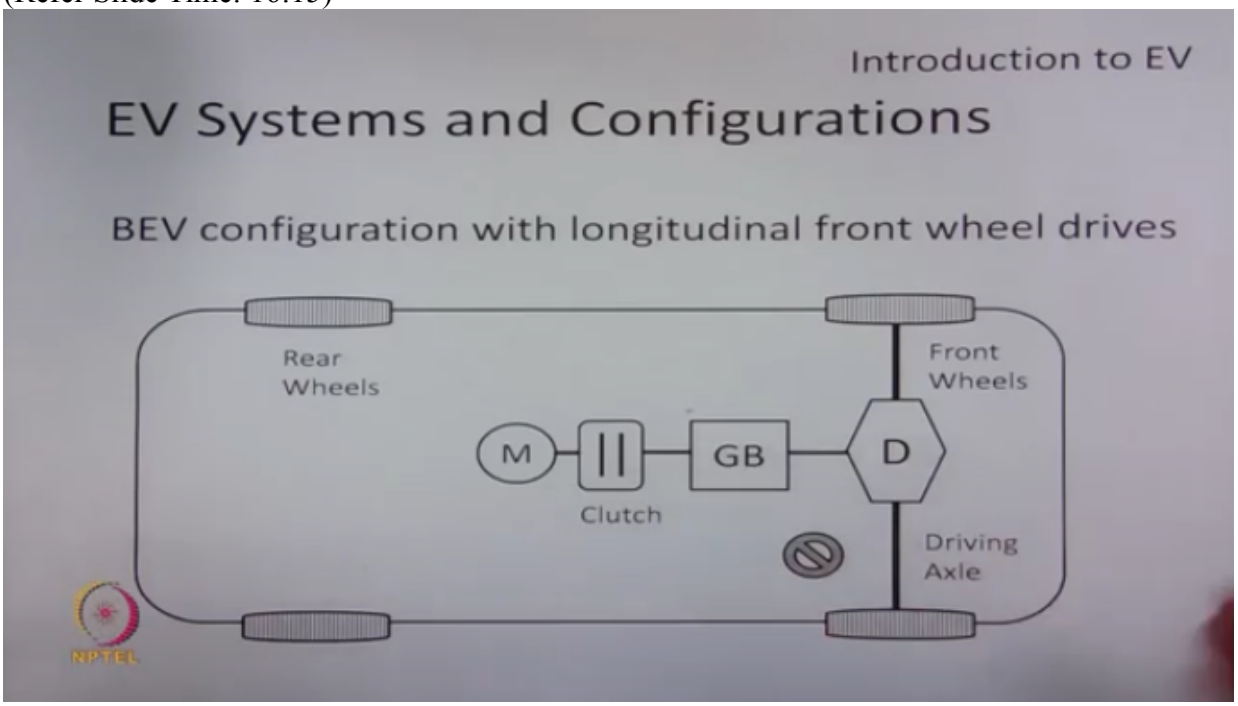

so there is several system where you know the bulky components such as clutches and the variable gearing systems can be avoided,
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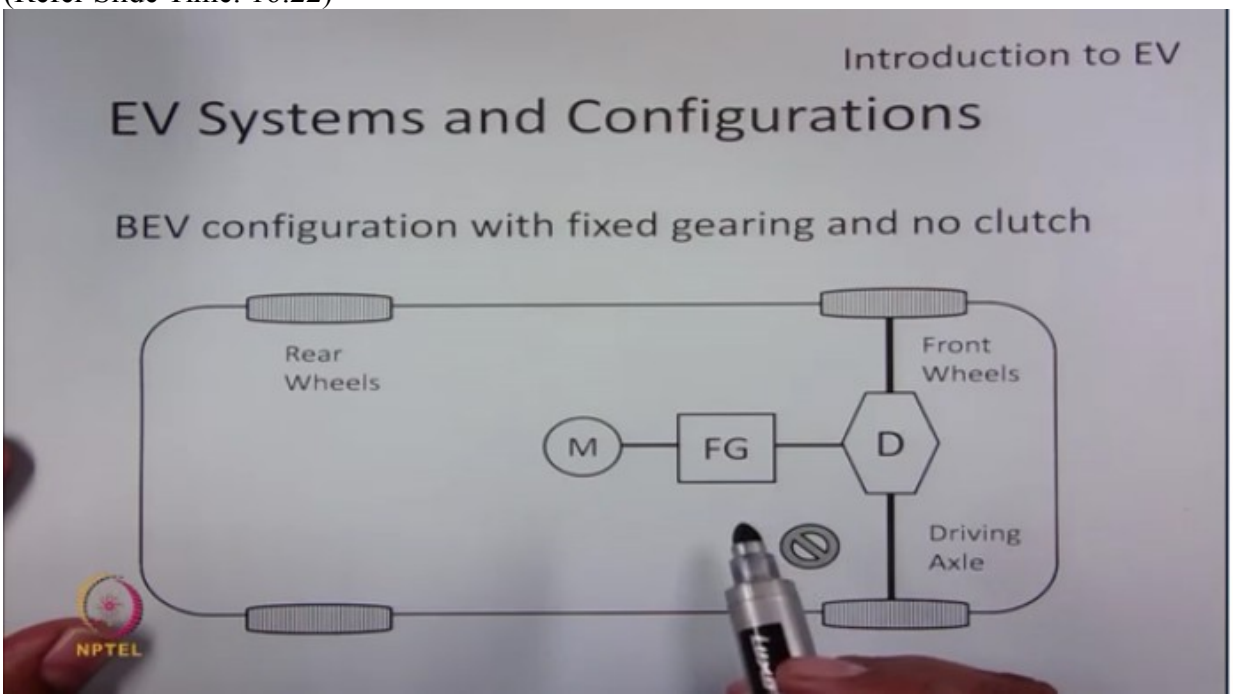

so this system uses electrical motor with a fixed gearing, so here your fixed gear ratio typically 1 is to 10 ratio is normally used.

So in this system the motor has to be properly controlled such that it will only decide the speed of the vehicle and the torque requirement of the vehicle also has to be separate by this motor, so it doesn't get a support of variable gearing for controlling the speed or torque, so here the design of electrical machine is important because the efficiency of electrical motor has to be seen that it is high in all the operating regions, so this motor has to not only support very high starting torque operation, it also should support a low torque, very high speed operation or closing application, so there is also a push towards avoiding the transmission system,
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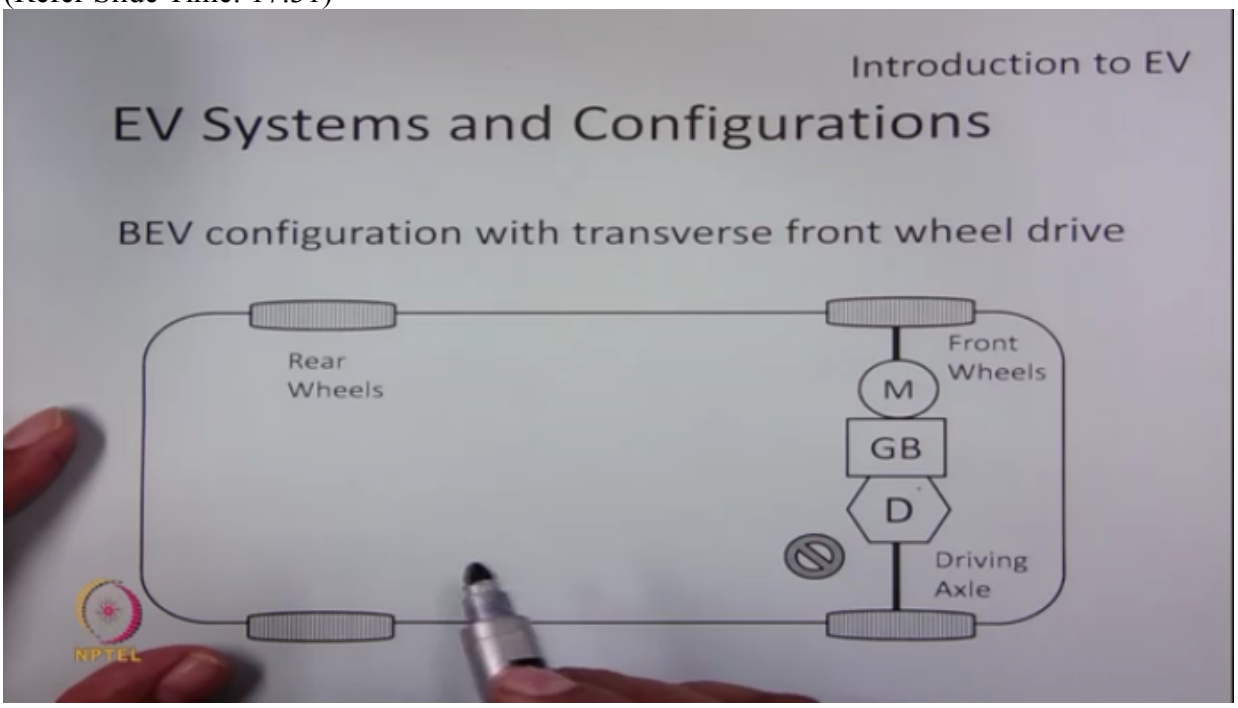

so there is a trend to use the technology of transfers front engine, front wheel technology of a typical IC engine vehicle for the BEV configuration.

So in this application, so this is fixed gears,
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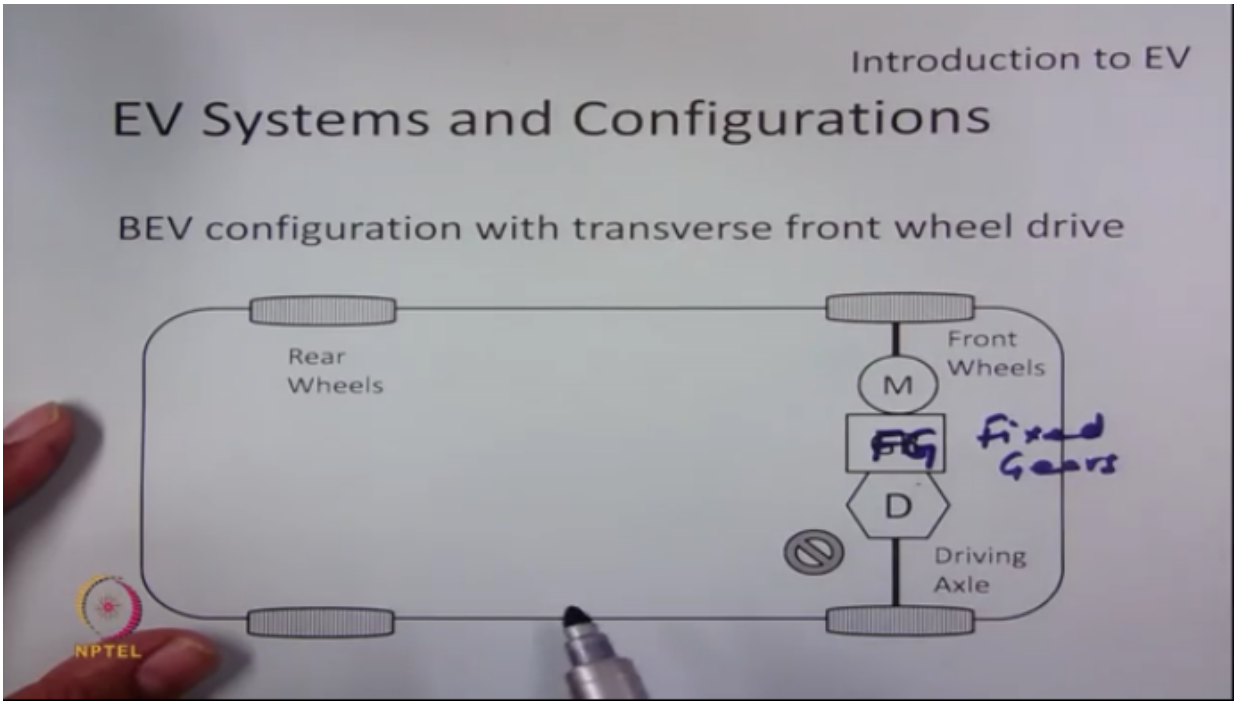

all the components such as motor, fixed gears and differential are integrated together, so these are all integrated into one assembly such that the transmission axle is reduced and it's a very compact system such that it not only takes the very less value, it is very less weight compared to the previous configuration,

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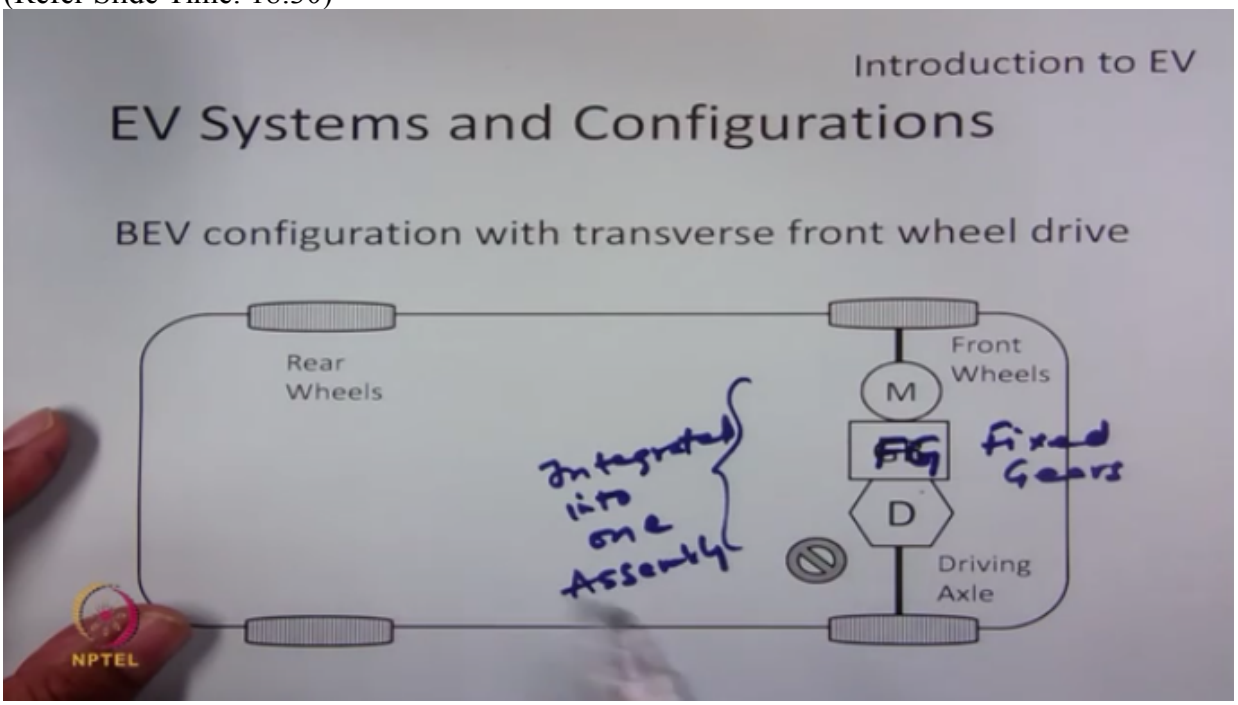

so this is adopted in all modern EV's, even this kind of technology is used in tesla vehicles, so we all know that differential is a very important mechanical device which is used to create

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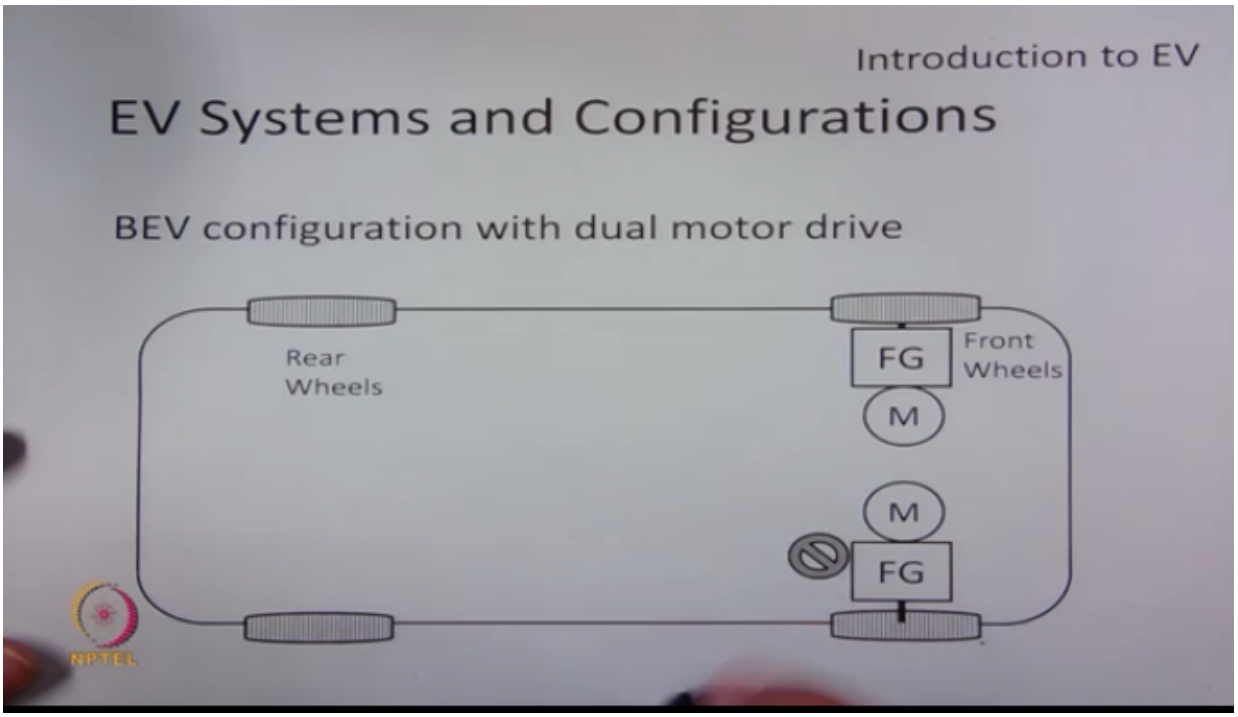

differential in the speed of the front wheel such that it allows the adding operation without any discomfort to the operator or without losing any control, so this differential can also be eliminated if we use a dual motor system, means now we will have two motors which is coupled to the individual wheels by means of fixed gears, so this system is simple and it is less bulky compared to the previous configuration, but now the differential action has to be carried out by the mutual control of this motors, so this motor cannot be operated individual mode, so they have to be coordinated such that the control enables the differential action,

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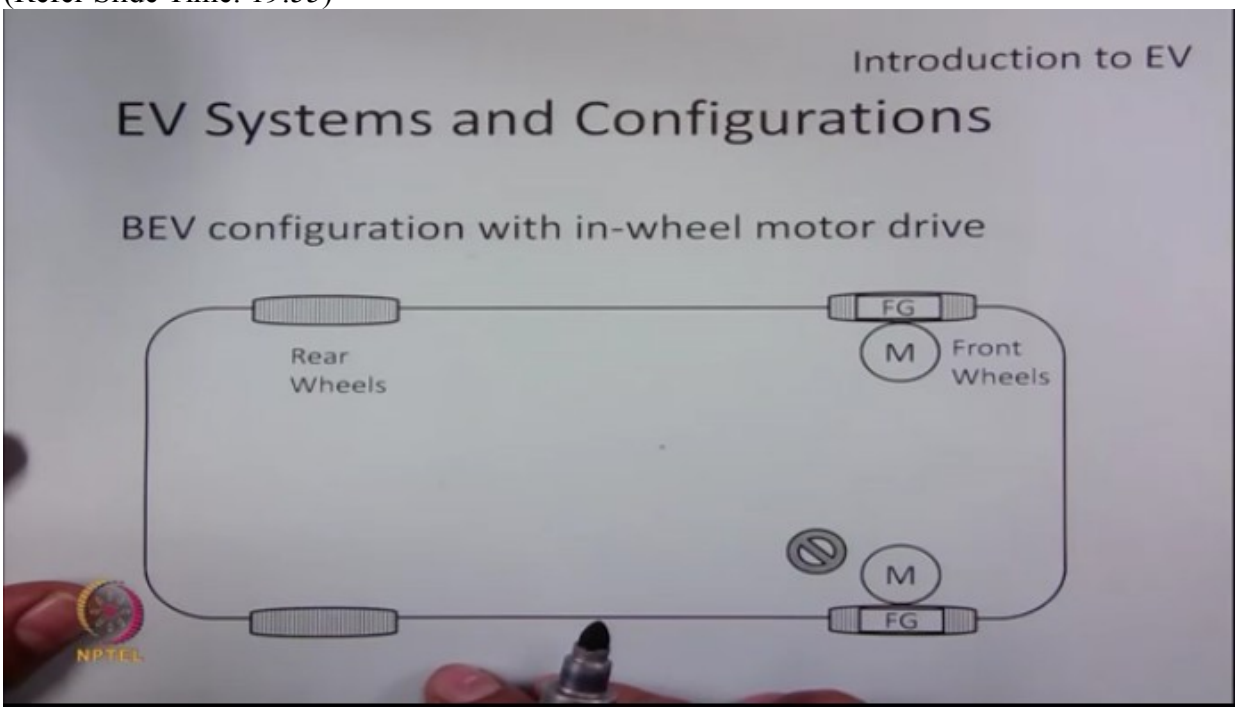

so it is also possible to reduce or rather basically eliminate the driving action totally, means there is no driving shaft connecting the motor to the wheels, so this type of configuration use a motor which can be inside the wheel, so this configuration requires the gearing system because motors are generally high speed devices while the wheels requirement is low speed, so fixed gear is required but this is a complex system known as planetary gear system, so this is also an important development in the EV configuration where this type of EV's are developed.

There is another type of inbuilt drives where we can also eliminate the gearing system, so as we can understand if there is no gearing system involved, the speed of the motor is the speed of the wheel, so we are talking about a low speed motor configuration, so this is only possible by a system known as outer rotor motor means the stator will be in the rim and the outer portion which actually drives the vehicle is a rotor of the motor, so you can see this type of motors in a ceiling fan application where the rotor is outside, while the actual stator of the motor is inside, so this is also one of the EV configuration which is becoming very popular, so we have seen the different types of electrical or propulsion systems.

Now let us try to see what are the different types of BEV configuration if we consider the energy sources, so let us assume that if we have a single battery and it is used for controlling the motor, so it will be a simple system where battery is connected to the motor using the power converter or power electronics, nice thing about this configuration is now battery is very different from a petrol type of vehicle, because now the battery can be kept in multiple places, we can kept in a luggage, it can kept in chassis or in the top of the system, so it can be distributed, so this is nice about a battery based BEV configuration,
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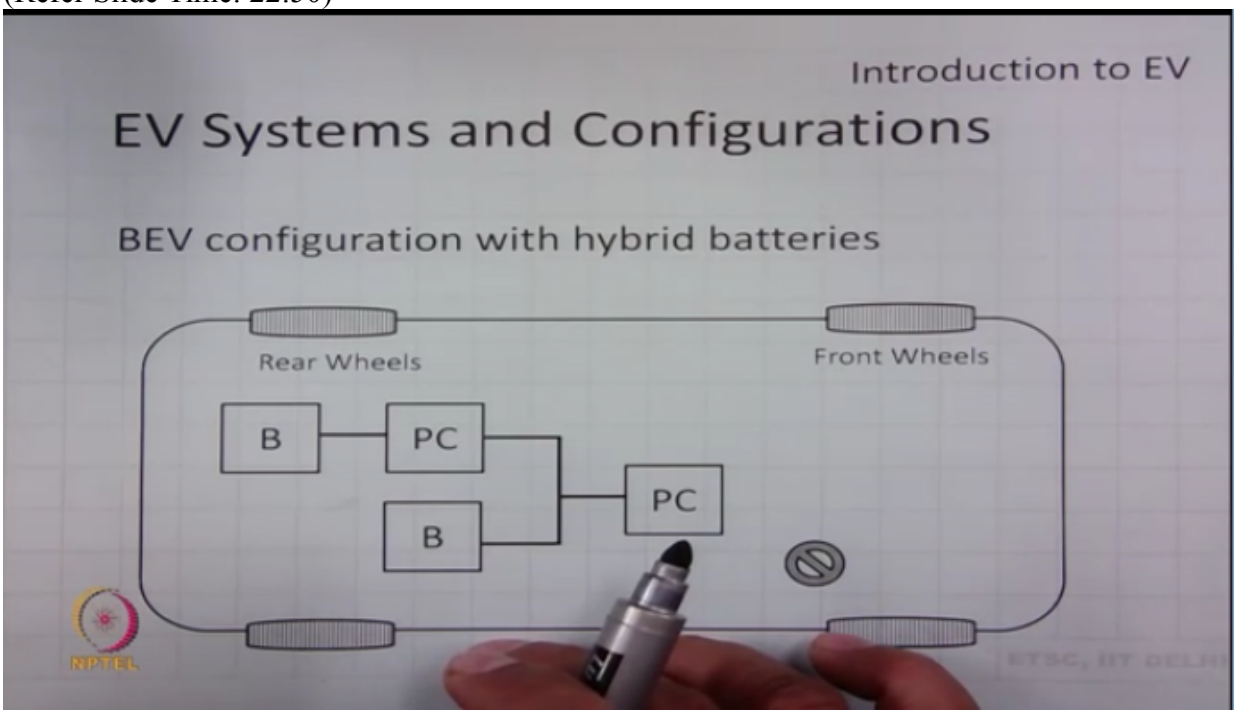

but we all know that the requirements of the electric vehicle is such that it requires both high specific energy and high specific power.

So in the previous configuration the battery has to take care of both this features, so the design of the battery has to be such that it support both this operations, but normally it is very difficult to get both this requirements from a single battery type,
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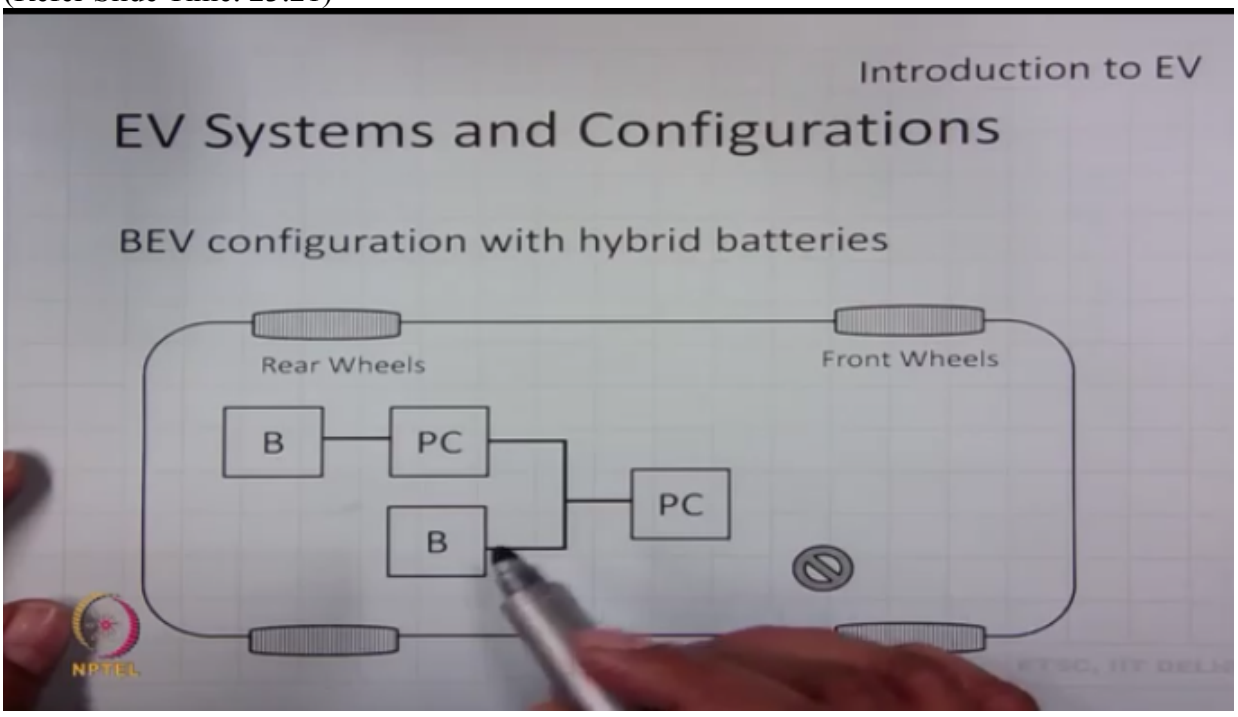

therefore normally we go for hybrid battery systems, so in hybrid battery systems two batteries are used to operate the motor and this battery will be connected using a power converter such that the power flow between this batteries can be controlled.

Now because we have two battery systems is possible to decouple the requirement of high specific energy and high specific power, so one battery can support high specific power, and one battery can support high specific energy which is feasible.

Secondly it also gives an option for in the mechanical batteries such as zinc air, aluminum air, and upcoming lithium air, so this kind of batteries you know cannot be recharged, they can only support discharging of the battery, so in this type of batteries you need a separate battery bank to observe the regenerative braking energy which is coming during braking operation, so this is very popular configuration of energy sources, this is similar requirement for a fuel cell based vehicle,
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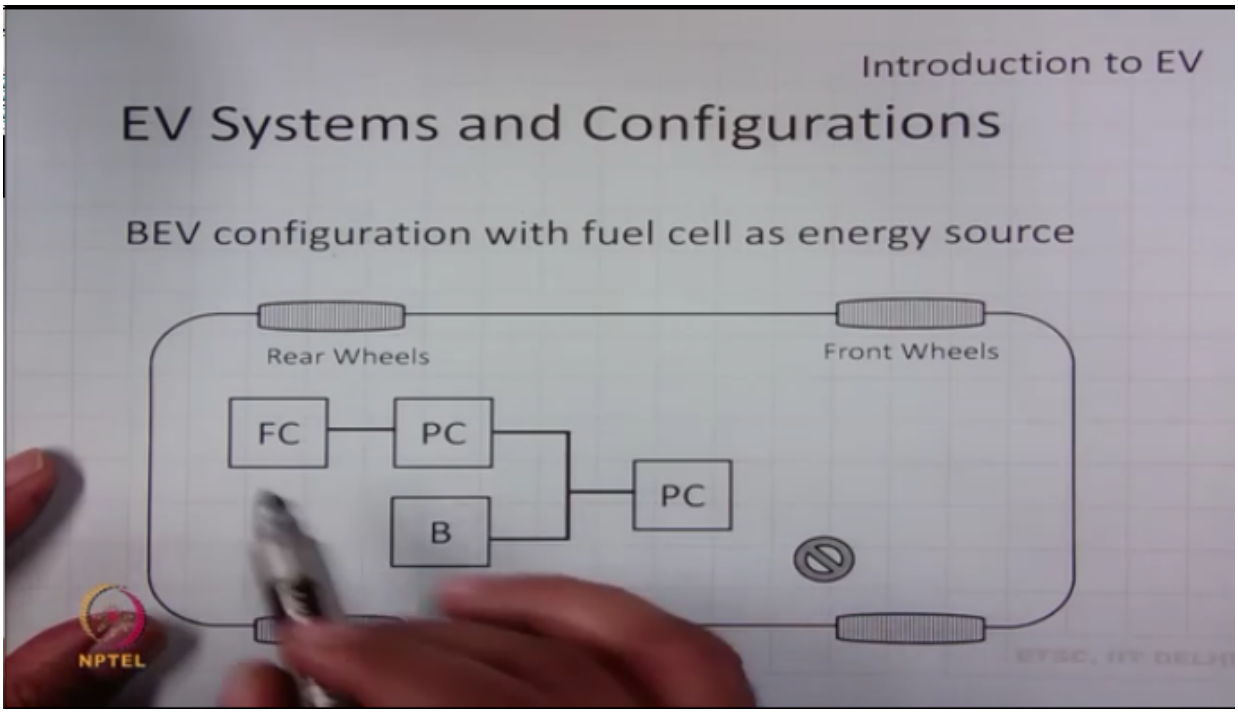

because we all know that fuel cell are not storage devices, this are energy generator devices, so it always need support of battery for storing the regenerative braking energy, so various similar configuration is also used for ultra-capacitor and ultra-flywheel based BEV's, we all know this,

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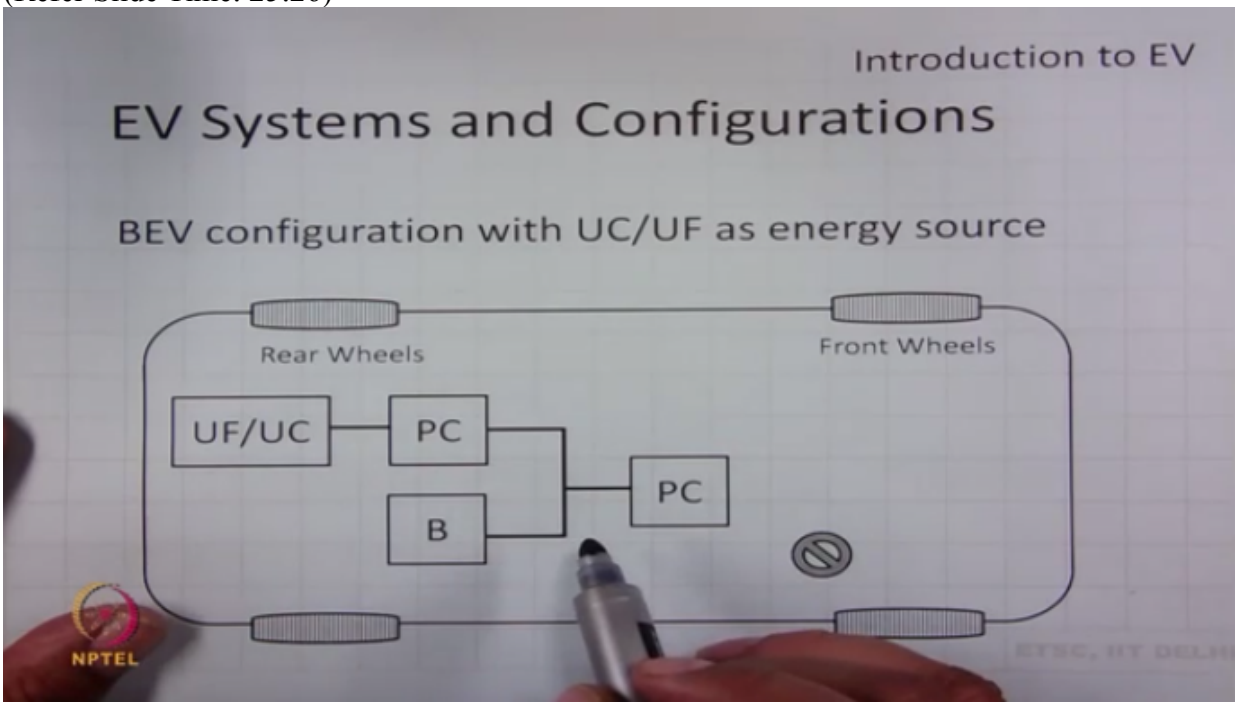

this devices have high specific power and it can very well support the high specific energy of batteries, so this are generally a low voltage devices and it generally requires a boost converter which has to be bidirectional because this can be recharged quickly when the power is coming back from regenerative braking.

So as told earlier the flywheel what is used here is not the conventional flywheels what we used in mechanical devices, so in mechanical applications we generally use a low speed and a high inertia flywheel for storing energy, but that kind of flywheel cannot be used here because of the weight involved, so rather than using a high inertia of flywheel here we go for a very light flywheel, but the system is operated at ultra-speeds, that's why it's called ultra-flywheel such that the energy storage capacity can be enhanced.

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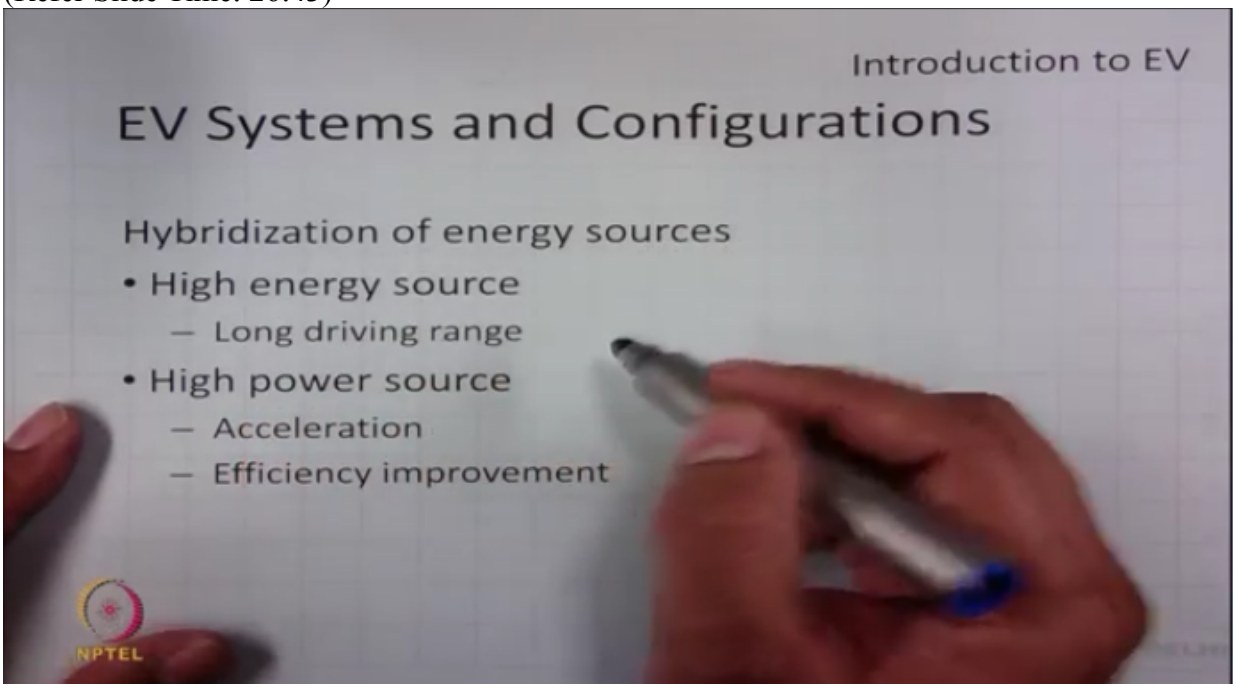

So when we go for hybridization or energy sources as said earlier the requirement of high specific energy or high energy source requirement is due to long driving range, so any EV will look for such a source that at the range requirement is update.

Secondly we need a source which is has a high power source such that the acceleration requirement is taken care which is required during starting overtaking or hill climbing, but this power source also enables efficiency improvement especially during regenerative energy obtained during braking, because it has a capacity to quickly observe the energy coming during braking.

So let us see how the power flow normally done in this hybrid sources,
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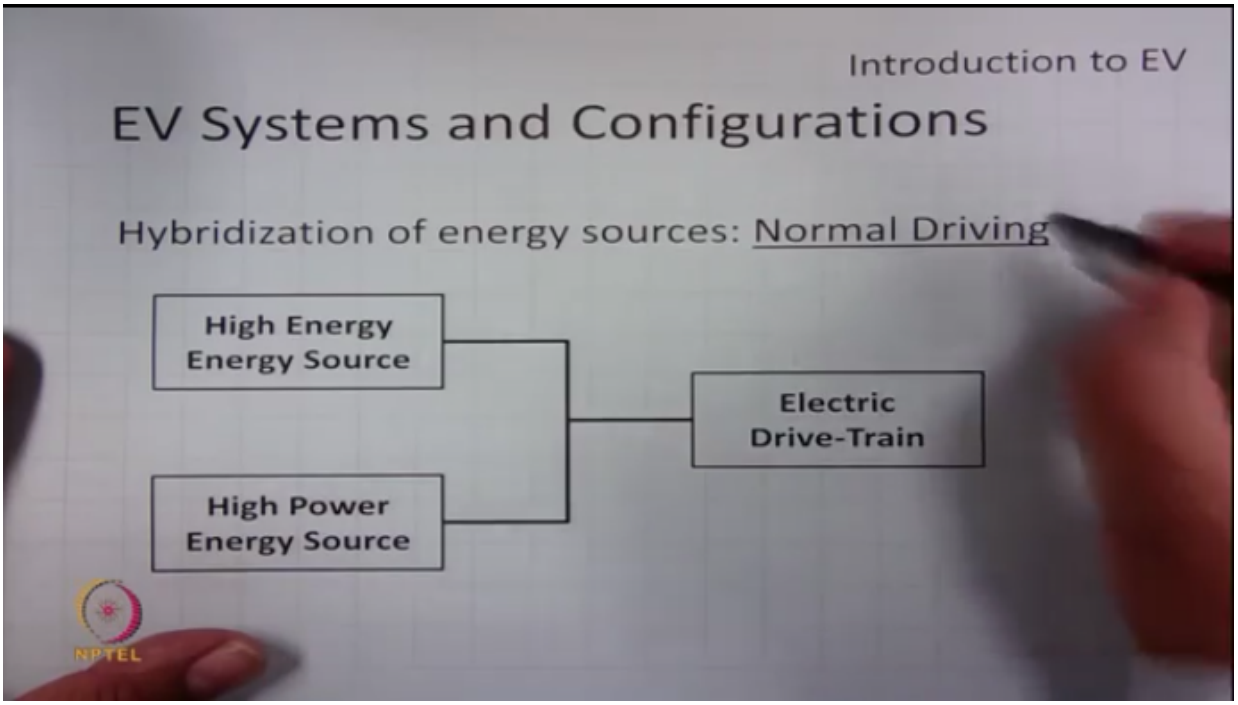

so in case of normal driving the high energy source is mainly used to drive the vehicle such that we obtain a high range operation, independently the energy flow can also happen from high energy source to high power source when we have a light load or very low power requirements in a drivetrain, so this is normally to transfer energy from high energy source to high power source, so high power source generally cannot store energy on its own.

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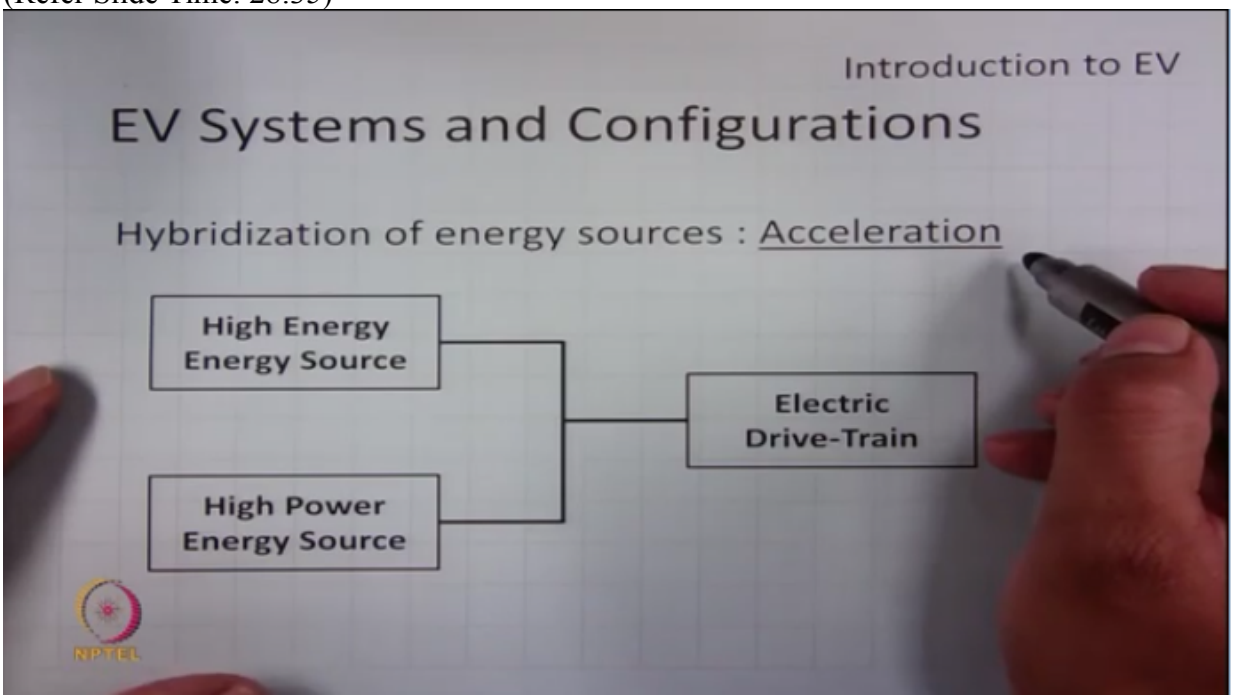

During acceleration we want the system to be fully utilized therefore during acceleration both the system will deliver power or energy to the drivetrain such that the system operates at very high power rate,
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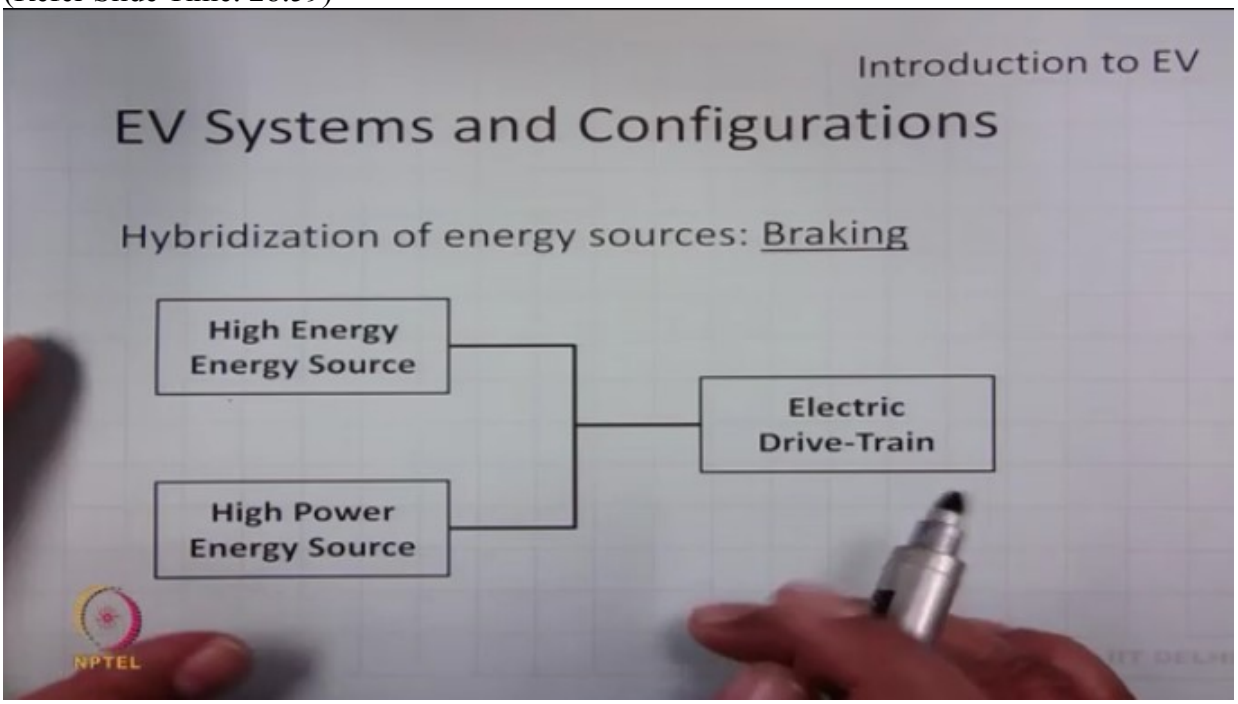

so during braking the energy has to be observed very quickly, so during that time the main source which recovers the braking energy is high power source, since it's a capacity to observe power very quickly, but this can also be used to recover the energy but this is preferred because it can support very quick recovery of braking energy, so this is first priority and this is second priority.

So now let us see you know this configuration is slightly more detail,
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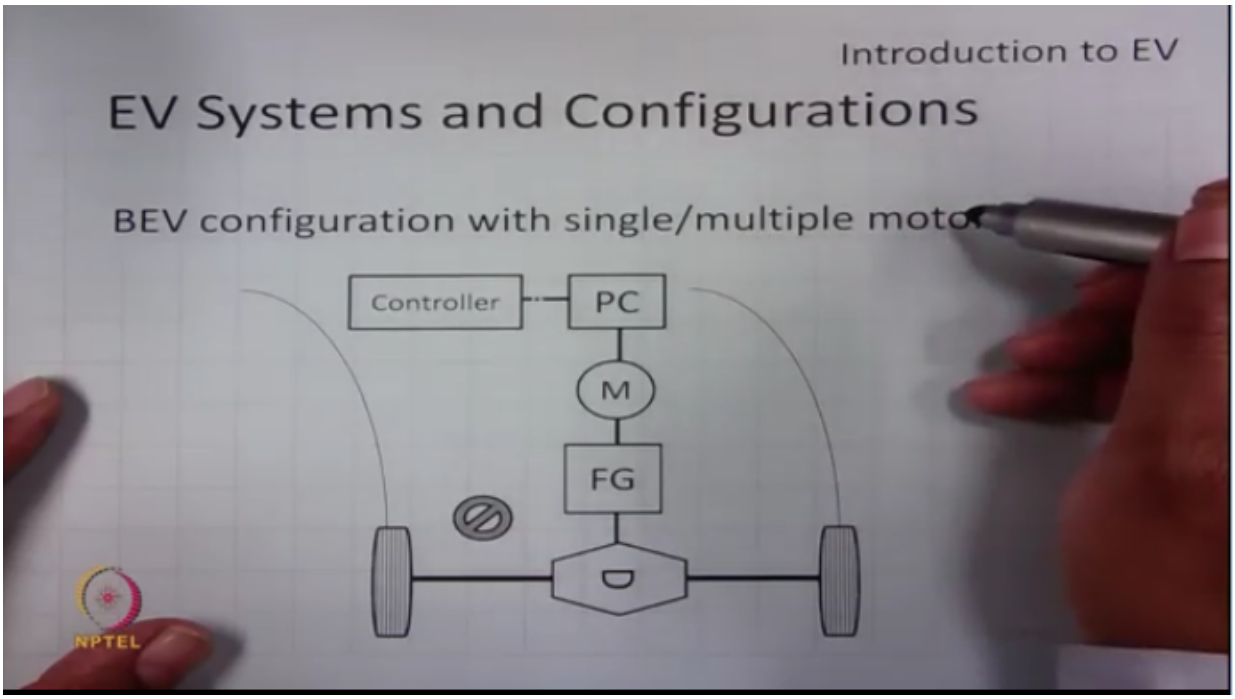

so let us see what is the difference between a single motor or a multiple motor based BEV configurations, so we all know that when we use a single motor we have to use a differential, so what is this differential? Differential is basically a third gear system like, so one gear which is called pinion gear and connected to two axle gears, so depending upon the requirement of turning the vehicle can be turned.

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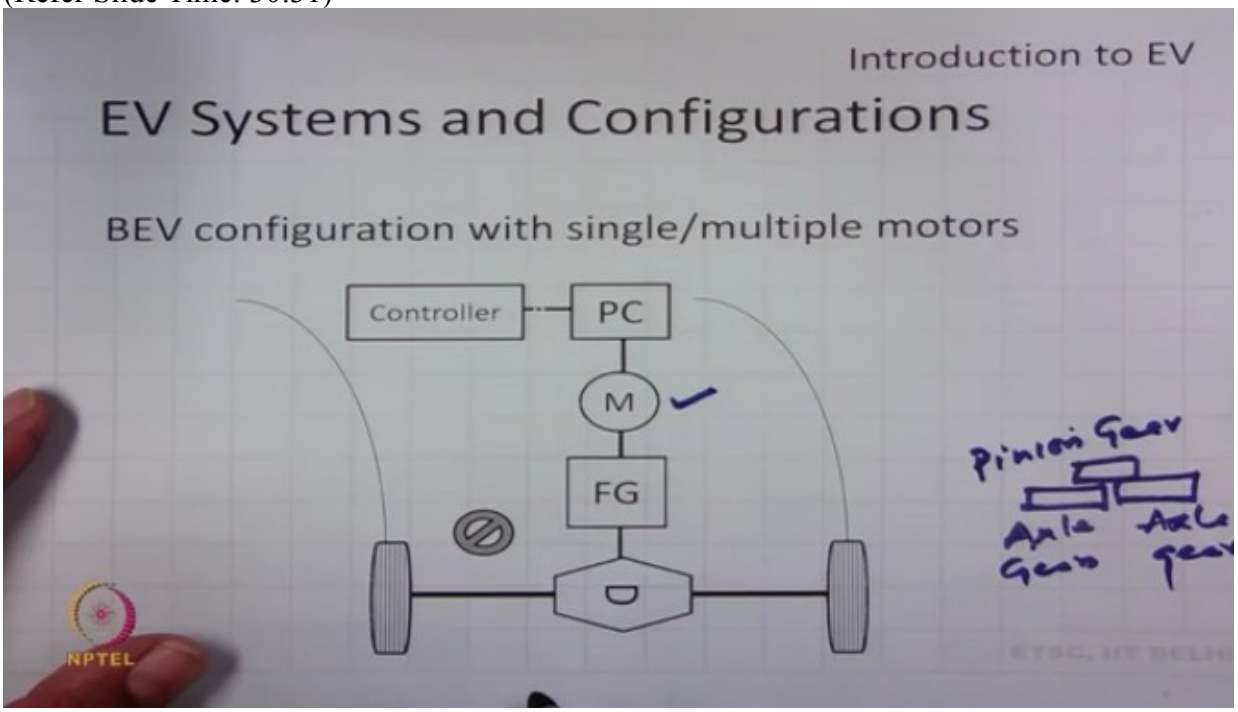

Let us say the vehicle has to turn this side, so for this operation to be successful the speed of this wheel has to be greater than the second wheel means omega 1 has to be greater than omega

2 if you want to turn this side, so this is a fantastic device in terms of this operation, so if we don't do this differential action there is a possibility of sliding or even balance of the vehicle can be lost and also it creates lot of wear and tear to the tires,
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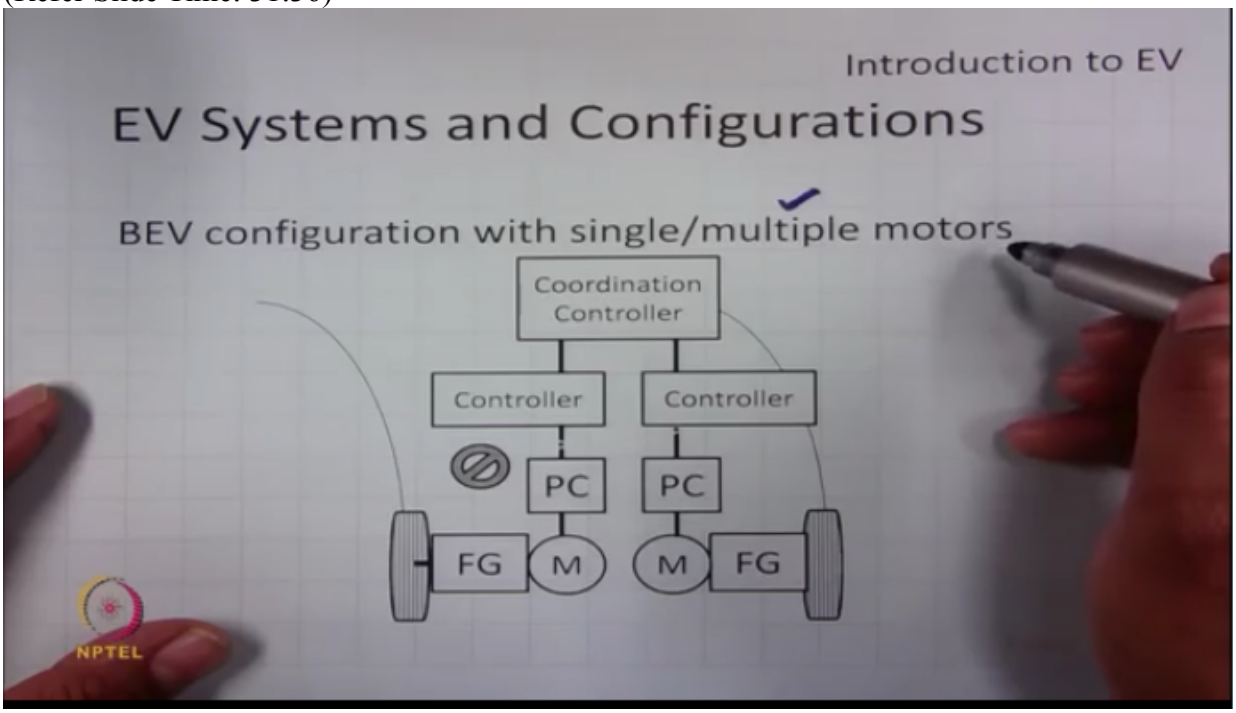

so in case we use multiple motors it is possible to dispense of that the requirement of differential, so multiple motor or a dual motor system uses individual power converter and individual controller to control this motors such that the differential requirement has to be now obtained from the coordinated control of this motors, let's say this motor is operating in omega 1 and this motor has operating at omega 2 and such that it's possible to not turn the vehicle in this side, but during, so this is normally required during turning operation

So when the vehicle has to move straight, so omega 1 will be omega 2 for a straight drive,
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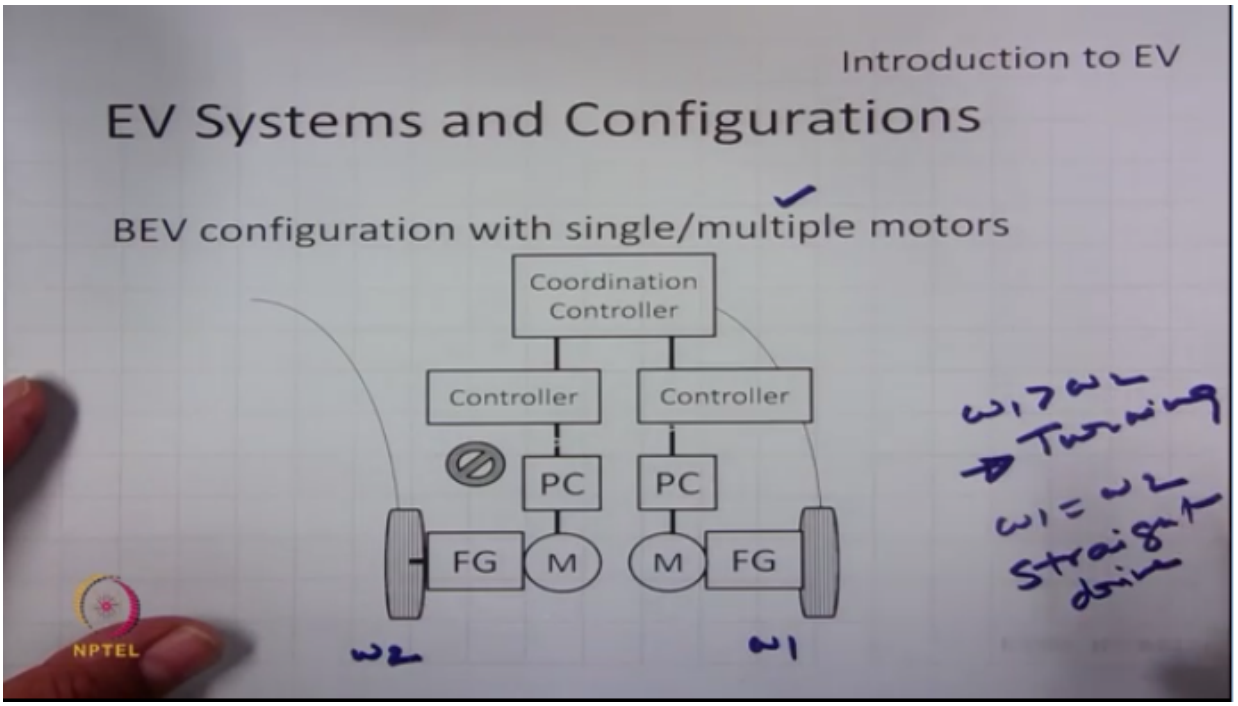

so we can see that this two motors cannot be operated alone, so they have to operate it always in the coordinated wheel, therefore the control of this motors has to have a common controller which is known as a coordination controller which will keep looking for the steering command from the driver and based on the turning operation it tells the two motors to operate in such a way that this requirement can be enabled, so in this system another thing is very important is like all this controllers will be keep talking to each other as watched talks such that all the three controller should work in tandem and none of them should well function.

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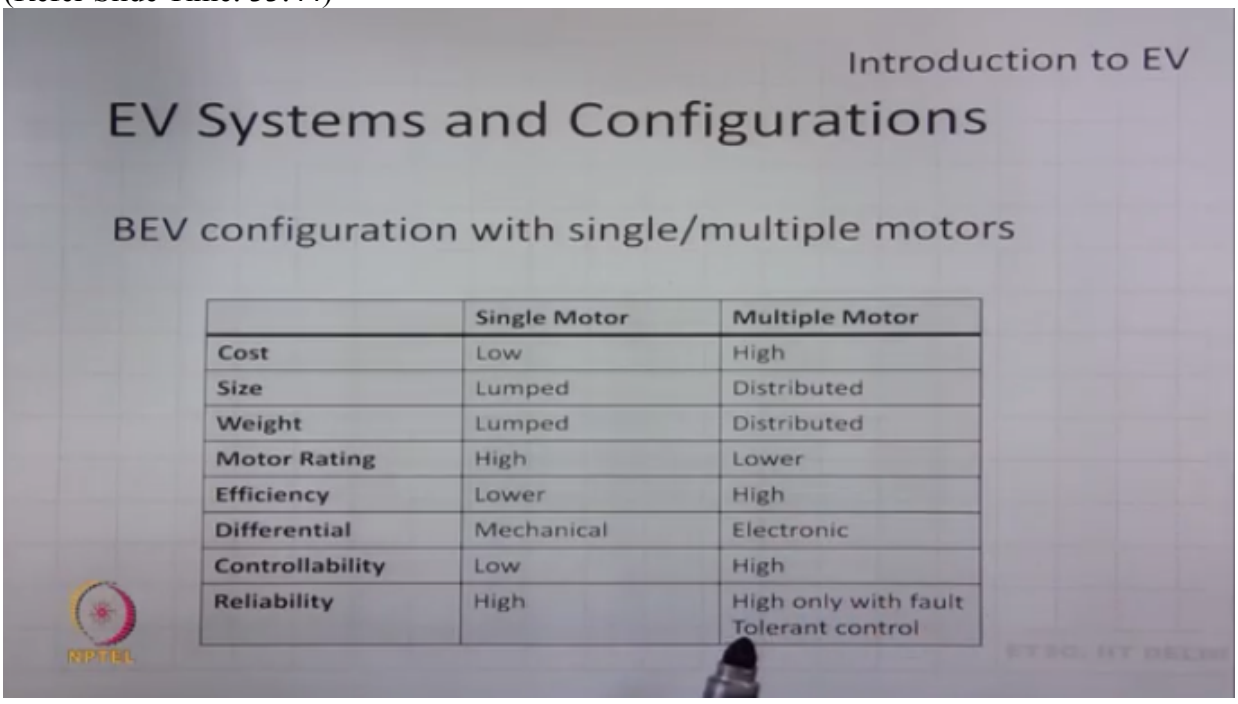

	Single Motor	Multiple Motor
Cost	Low	High
Size	Lumped	Distributed
Weight	Lumped	Distributed
Motor Rating	High	Lower
Efficiency	Lower	High
Differential	Mechanical	Electronic
Controllability	Low	High
Reliability	High	High only with fault Tolerant control

So if we try to elaborate the differences of this two types of motors configurations, we'll see that if we talk about cost the multi motor definitely will be higher cost because it requires two motors, so in single motor the size is lumped which is single, but in multiple motor it is possible to distribute the mechanical requirements, singularly for the weight the motor rating will be comparatively high for a single motor, now since it has to deliver all the torque requirements, but in multiple motor you can have two smaller motors of half of the ratings, deficiency will be higher in this because it will be mostly operated in high rating regions of the motor.

So the differential is a requirement in a single motor, but it is absent in a multiple motor and this obtained electronically by coordinating control of two motors, the controllability is generally low and it is very high in multiple motors, so this feature is very important because this has taken the performance of EV to a much higher level even compare to a IC engine based vehicle, but because of this high controllability and avoidance of differential physically, this liability issue in this configuration and the liability can be only high, if it's a highly fault tolerant control enabled.

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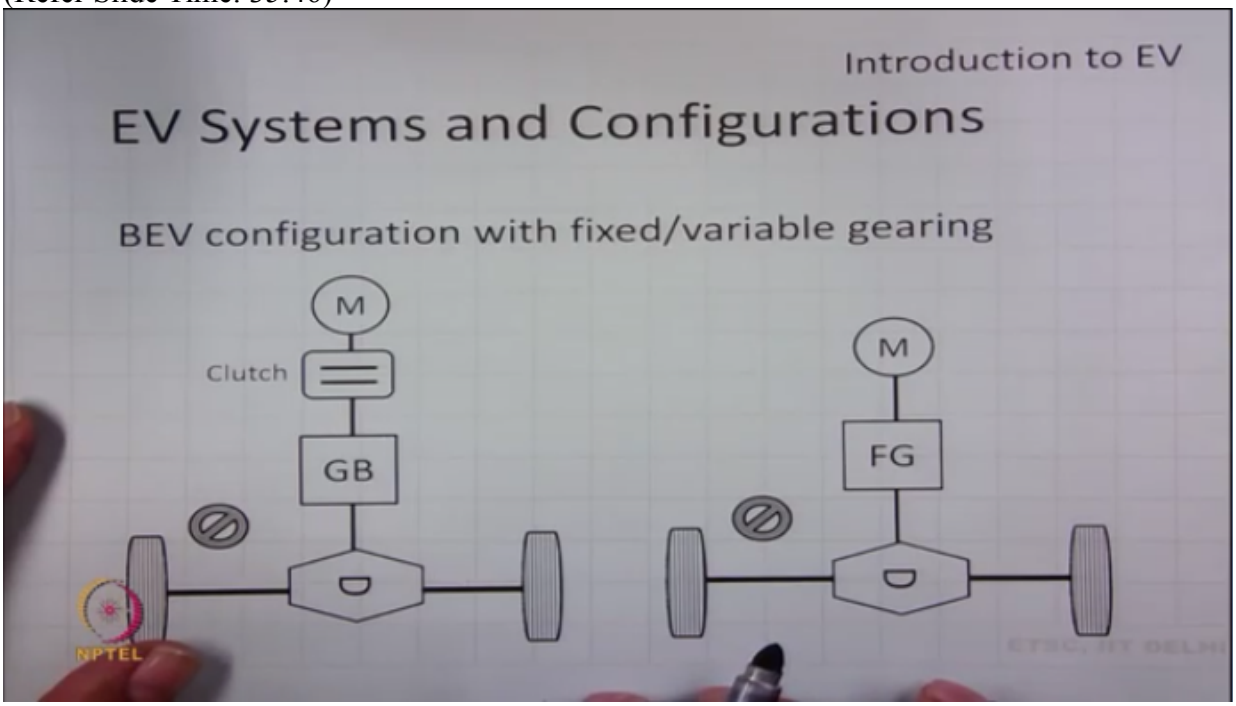

Let us see the difference in BEV configurations with fixed and variable gearing systems, so these are the systems we have already discussed, so we all know this is a kind of bulky system with more weight, size, and this is a simple system in terms of weight, but here the motor has to be high performance controlled and the design of such a motor is also very crucial because now it has to be design in such a way that it delivers high efficiency in all speed and torque requirements, so here this is the control and the design of such a motor is the complex requirement.

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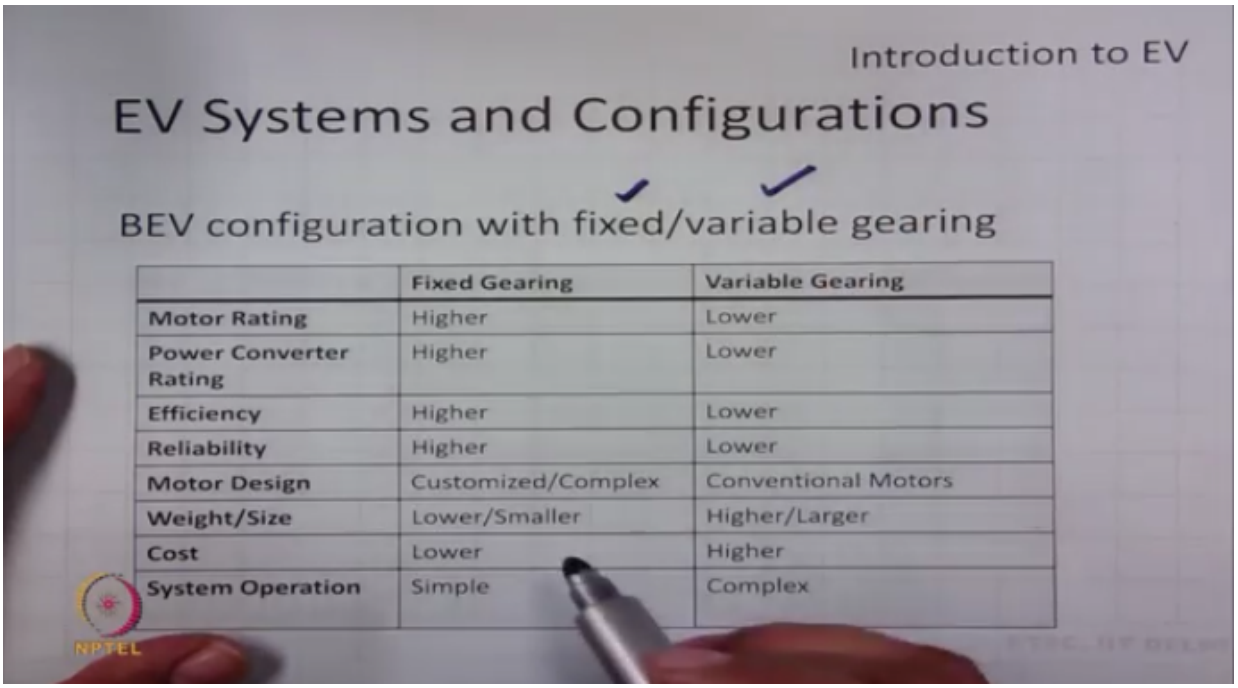

See if you have a quick comparison between these two systems, in a fixed gearing system the motor rating is higher, in variable gear system it is lower because all the action is generally done by gearing systems, the power converter rating is higher, slower in its configuration, efficiency is higher which is very important for an EV application, it is lower in a variable gearing system, reliability is much better because now we don't have to operate clutches or gears and there is a less possibility of faults, it is lower in a variable gearing system because of this is gears and clutches.

If the motor design is now complex and it has to be customized for particular application, it cannot be any conventional motor for that say, so conventional motors can be used in variable gearing system, see if you see the weight and size it is much better in fixed gearing system, and it is higher in the variable gearing systems, the cost is also lower compared to the variable gearing systems, the system is simple it is complex because of lot of mechanical systems.

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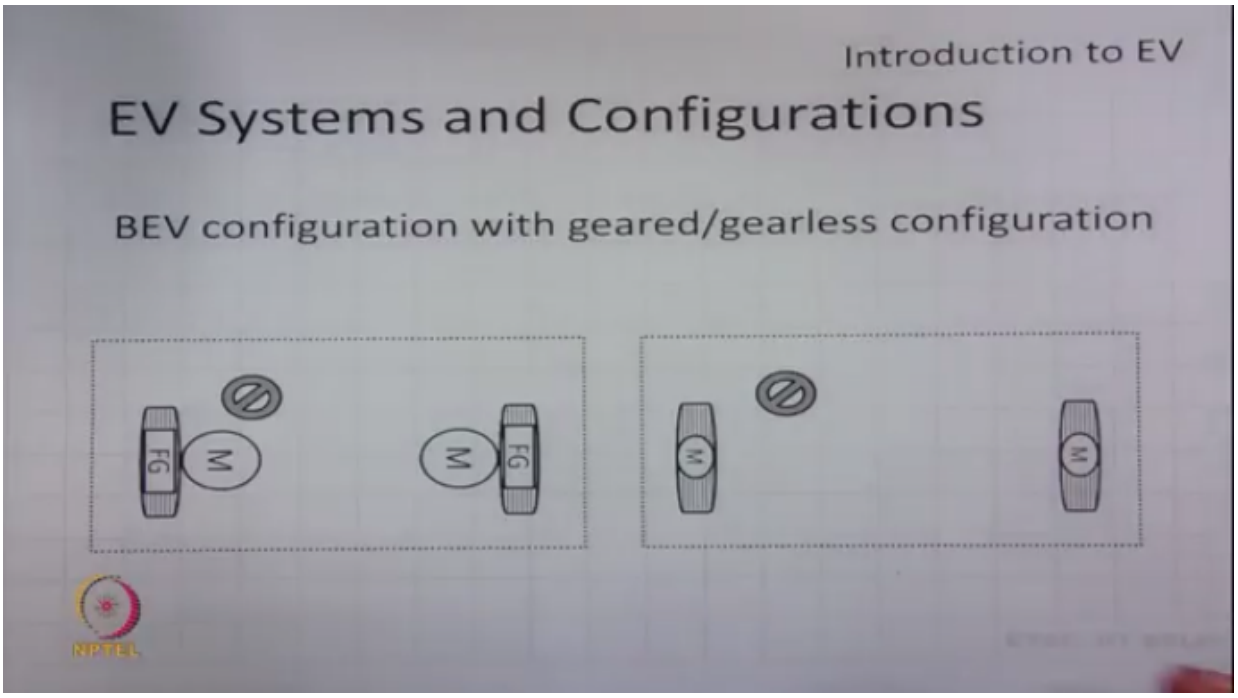

So if you compare geared versus gearless system, so we are talking about inbuilt drives where there is no differential, there is no clutch and there is no driving axle, so we have two kind of systems which we have seen earlier, so one system uses a motor which is embedded in the wheel and the rotor is inside the wheel, and in gearless configuration the rotor of the motor itself is the driving wheel such that the gear can be eliminated.

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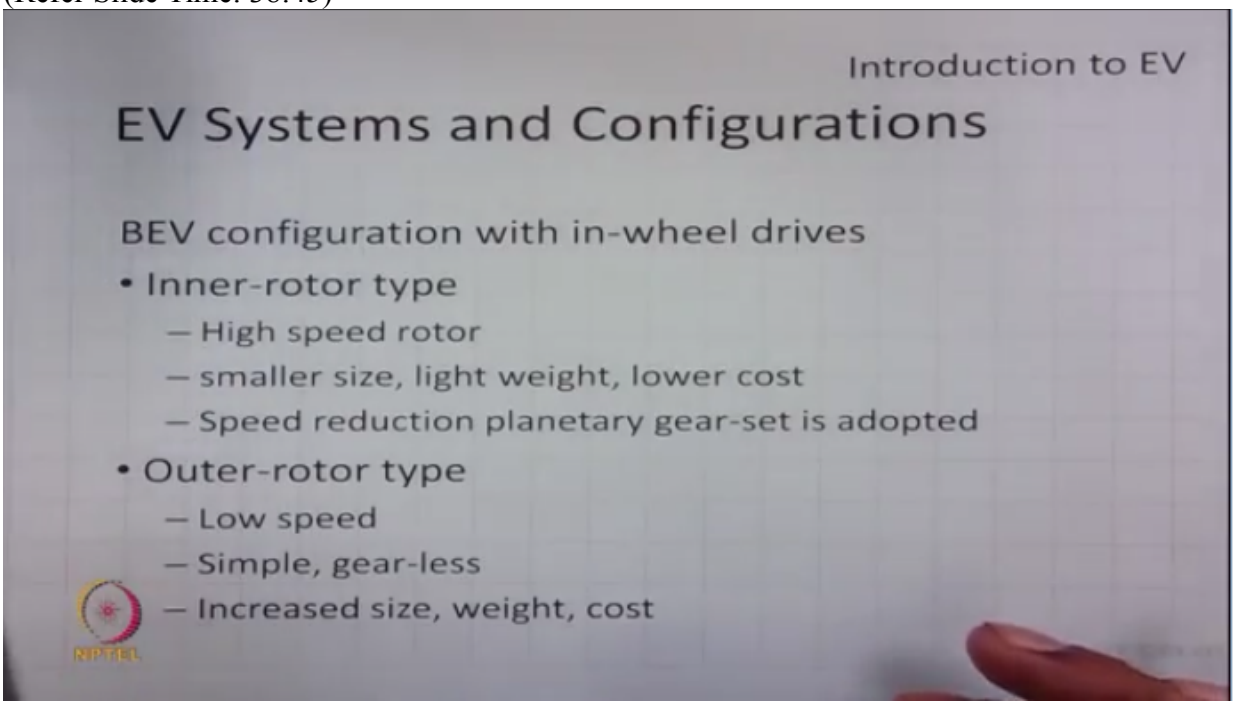

So if you see these two systems the first type of in-wheels system is in a rotor type, means it can be a conventional motor with a high speed rotor, and the speed reduction is obtained by a

complex planetary gear which is embedded within the wheels, so system is smaller in size, it has less weight and lower cost.

On the other type which is outer rotor type of in-wheel drives, the rotor itself is a mechanical wheel, so it's a low speed system because now the motor has to be a low speed design, it is slightly bulky and more size, cost is also higher it is simple in a way that it doesn't have any gears, but today with the development of a high efficiency gearing systems possible this system is preferred in high performance electric vehicles, while this type of in-wheel drive is popular in low power segments such as two wheelers and three wheelers where we all know that we use something similar which is known as hub motors or which is generally BLDC type.

So in BEV configuration how to decide the system voltage,
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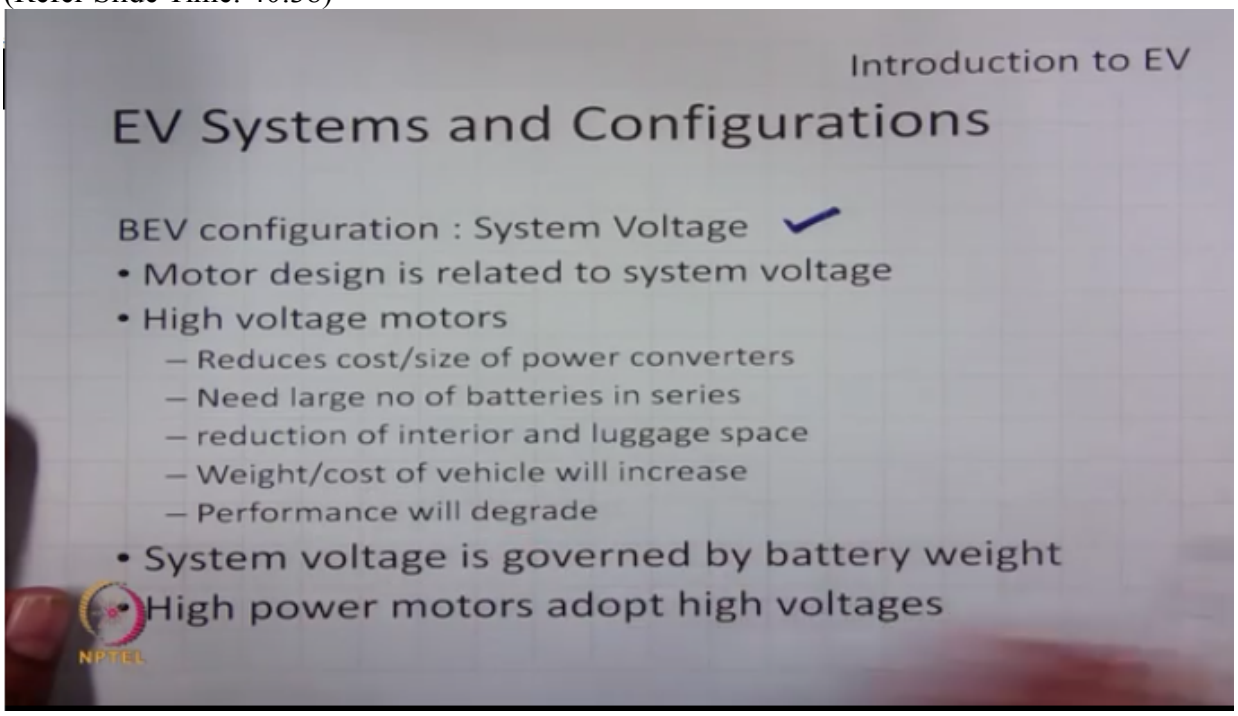

so the system voltage can range from in a 24 volt system, 12 volt system, 48 volt system, 96 volt systems or it can go even higher to 300 volts and 600 volts, so what decide this system voltage? So if you use a high voltage motors for any application it means reduce cost and size of power converters, because high voltage allows low current design means the torque requirement can be obtained by low currents or low physical connector size of the windings, but when you use a high voltage motor you should have a high voltage of the DC link or high voltage of the battery tank, so we need large number of batteries in series to obtain this high voltage, so if you use large number of such battery cells it requires lot of space, so there will be reduction in the user space because it will occupy most of the luggage space and the interior space.

Also the weight and cost of the vehicle wheels also increase because of the battery cost involved, performance will degrade because of the weight, so while deciding the voltage of the motors or the battery bank the optimization has to be done such that the performance of the

vehicle versus the efficiency drop in the power converters or the motor size weight as it has to be concerned such that you know we get the better performance in terms of cost and operation, system voltage is normally governed by battery weight, but another thing is that when you go for high power motors let's say if you are going for 100 kilowatt motors, this motors cannot be designed at very low voltage, so high power motors has to go for high voltage design, so that is all in the discussion of EV's systems and configurations.

And we will start discussion on our next topic which is HEV systems and configurations in our next interaction. So thank you all for listening the lecture.

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