Industrial Automation & Control
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Lecture - 32
DC Motor Drives

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Welcome to lesson number 32 of the course on, Industrial Automation and Control. In this lesson we will mainly looking at not mainly solely will be looking at DC Motor Drives. Now, we have seen that actually drives are very, very important components of automation because they create motion and creating motion is extremely important for industrial operations both in the process industry as well in the manufacturing industry.

For example, if you take the manufacturing industry then you need see the whole of manufacturing operation we have just, we have done in the previous lecture some giving you some exposure to CNC machines which are various kinds of metal cutting machines. You have seen that very precise motion is to be created in those machines either the block or the tool either the job or the tool have to be moved in precise, precisely from one coordinate to the other.

So, that is one kind of example then there is a big example of material handling, so all material handling devices require you to create motion. Similarly in the process industry you require pumps, which will create flow you require control valves. So, for their operation also you need to create motion, so create, creating of motions is very important.

So, we will, we are in most cases motion is generally rotational motion is created by a motor because it is very convenient in a small space you can create that motion and then using various kinds of mechanisms this motion is converted into various other kinds of motions like linear motions etc. So, we are going to look at creation of basically, creation of rotational motion using motors.

And we start with DC motors, because they are still widely used and they are they are the simplest kinds of motors which are used to create motion and lot of application was there, now some of the applications are being replaced by AC motor drives. But still a lot of them exists and it is a proper point to start the discussion on drives, so in this we will mainly be considering.

We will first we have an introduction like we are having now and then we will look at two kinds of you know, we are basically in this lesson we are basically going to see what is the technology, how exactly what is the engineering of these drives, how exactly these motors are rotated. Sometimes they are accelerated, sometimes they have to be decelerated, they have to stop, start they have to move clockwise, counter clockwise, so how all these motions are basically created, the technology part of it, not the analysis part of it.

You have already seen some part of analysis of DC motor control in the context of a CNC machine in a previous lesson, so in this lesson we are mainly concerned with seeing how in a motor you can create various kinds of motion. So, we look at two kinds of this creation of motions, since they are these are electric motors, so they create, so they require various kinds of electronics, power electronic devices and circuits. So, we are going to look at two broad classes of circuits, one are line frequency converters and switch mode DC - DC converters which are, which will show you two different ways of controlling DC motors. Let us look at the main instructional objectives of this course.

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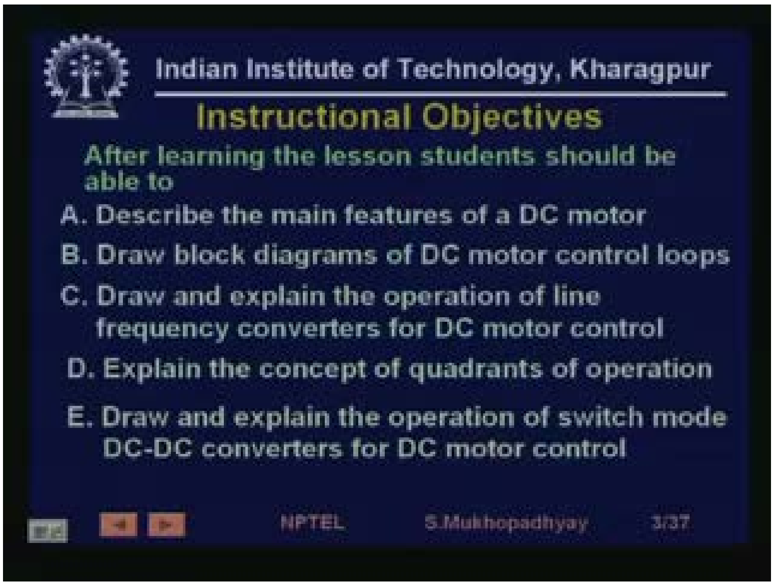

So, after learning the lesson, the students should be able to describe the main features of a DC motor, basically should be able to understand how it works, then should be able to draw a block diagrams of various DC motor control loops to be able to identify how the DC motor is excited, how feedback is obtained etc And then they will be able to explain the basic ways in which a line frequency controlled a basically line frequency AC to DC converters for how they are used for DC motor control.

And finally, they will, they will also understand the except of a you know there is a concept of four quadrant operation of motors, so that is very important in for drives to understand. Then lastly, they will be able to explain the operation of a switch mode DC - DC converter based DC motor control. So, in other words, we will be able to have a basic idea of how DC motor speed is controlled.

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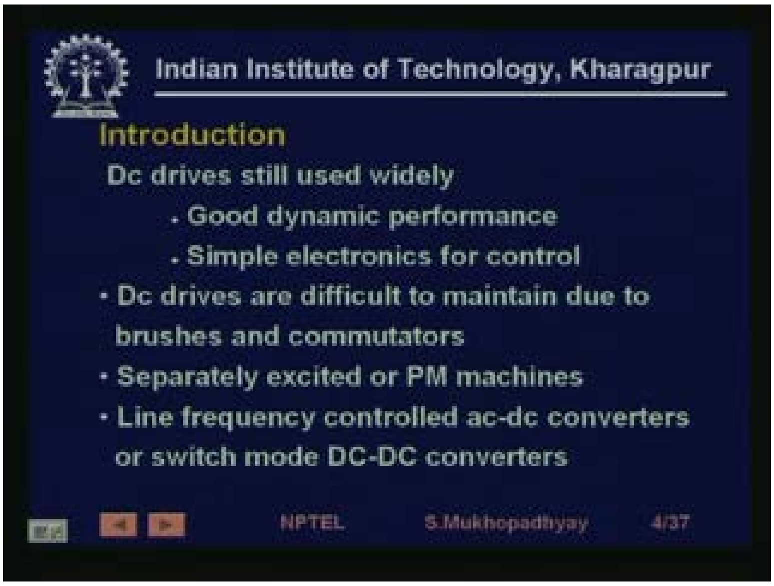

Coming to the introduction as I said that DC drives are still used very widely because initially DC drives, where you know DC the goodness of DC drives is basically derived from two things, it basically derived from the principle of operation of the DC motor. So, in the DC motor as, in fact, the advantages and disadvantages both derive from the principle of operation of the DC motor. In the DC motor one good thing is the flux or the flux created by the armature current and the flux created by the field current are always perpendicular.

So, they are always orthogonal and they generate good the actually the best torques for their values, so what happens is that you get very good dynamic performance. But on the other hand to be able to maintain this torques that way, you have to have a, you have to have a mechanical arrangement of what are known as brushes and commutators. So, it is this brushes and commutators, which on the other hand create the basic disadvantage of DC drives, which arises because of the fact that the sizes of the motor become more and their maintainability becomes bad, especially in industrial environments.

And it is also seen that because of the I mean, it is a DC motor is basically very simple to control, the electronics required, which was a consideration sometimes back was quite simple compared to AC motors. Now, this situation as we will see in the subsequent lectures have changed and now you have other kinds of motors which essentially operate like DC motors that is they can they also inherit that goodness of DC motors that the fluxes are always at always perpendicular or nearly perpendicular.

But they do not have this disadvantage of the brush and compared to that they have more complex electronics which is becoming more and more acceptable with the developmental of the field. So, basically these are you know in a, so in a different way we will see that drives which require good dynamic performance must essentially behave like conventional DC motor drive, but without some of its disadvantages. But still even today we you have a good amount of DC drives here.

So, they are as I mentioned that they are difficult to maintain due to brushes and commutator especially in the industrial environment and they also create electromagnetic noise because of sparkings sometimes, which may not be acceptable. Typically people use separately excited or permanent magnet machines, permanent magnet machines are used because they are lighter and because of the fact that there is a lot of interest permanent magnet machines.

Now, because of the advent of good, very good quality magnets, it is now possible to use rare earth magnets like cobalt samarium and get very good torques in very small and volumes and light weight, so permanent magnet motors are of interest. So, either we use separately excited or magnet machines for these drives and generally line frequency controlled AC –DC converters as we have seen that there are two kinds of drives.

One are called adjustable speed drives, where speed adjustments are necessary, but essentially the steady straight performance is of concern, transient performance is not of concern as we have seen in our previous lessons, where we saw that a very considerable energy savings are possibly if you use an adjustable speed drive for things like pumps, fans, blowers etcetera. On the other hand, there are other kinds of drives like we have seen in the case of CNC machine controls that you need very good performance to ensure exact manufacturing dimensions.

So, for those kinds of drives you need exact position control and transient responses of great importance, so these are called servo drives. So, for different kinds of electronics are used for this kind, of this kind of machines they are, so we will see two typical kinds of electronics or power electronic converters used for DC motor control in these two applications. One are called line frequency control AC –DC converters or switch mode DC - DC converters.

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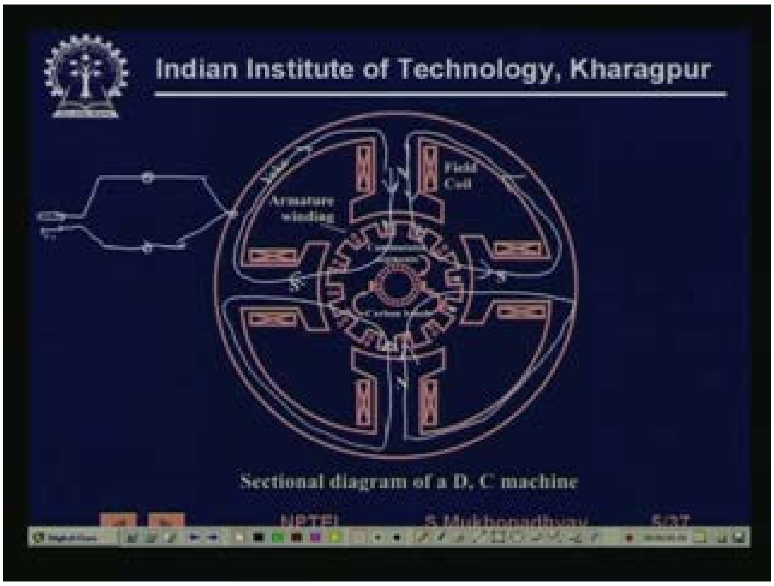

So, as I was saying that let me begin with this is a cross section of a motor, you can see you can see this yoke on which there are poles. So in this machine there are two pole pairs one this north, so you have this is and flux will flow typically like this, so these are typical flux lines in the motor. Similarly, and so this is a two pole pair motor, this is the armature and from the armature you get a cylinder out, which is the set of copper strips called commutator segments each of this commutator segments are actually connected to these coils, these are the coils.

So, you have long coils which are one side connected to the commutator on one end and on the other side you have the coil overhand, so the coils, so may be this coil is actually connected to depending on the kind of winding pattern and this coil may be connected to this one, then this coil may be connected to this one and so on. So, they are connected at one end, so it looks like if you look at a coil, it will look like this.

You know these are the, if you take a cross section these are the sides that you are seeing on both sides then they go to one end of the motor and this side is connected to the commutator segments, simple copper strips on which some moveable brush rotates. So, if you want to see understand the operation then we should see the next diagram, which is this.

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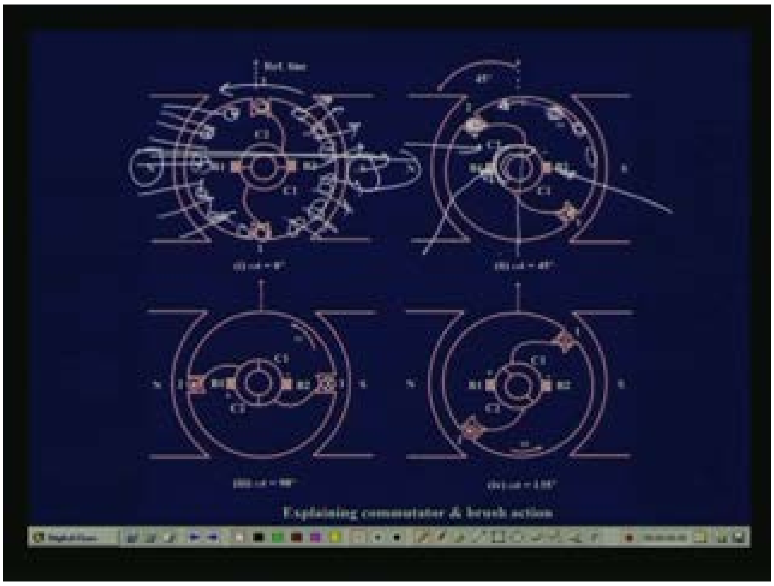

So, you see what happens here, so you have, say we are just for understanding simplicity let us look at the… So we have a two pole machine this is north this is south. So, the field flux flows like this let us say actually it will be you know they will perpendicular and then they will going like this, if you take the net axis the field flux axis is like this. On the other hand look at this set of coils, so you have a set of coils here and a set of coils here. So, it turns out that these coils, here may be the current convention is all dots we have a…

So, what happens interestingly, you see that this suppose, this turn this motor is rotating this way right, so first from here one, this the next picture is the next picture is forty-five degree here, so it has now moved in and depending on the flux direction this is has. In this case we have shown this has this has dot current means coming towards us and this is cross current. So, going, these are the current and or if you have connected the positive terminal to this one and the negative terminal to this one, if it is acting as a motor then you are connecting supplies to these.

Then, all the commutator segments which are connected with this brush segment are going to be positive, so therefore, all of them will have dot current here and cross current here. So, you see that on this side of the commutator segment, so this half everything is going to be dot currents and this half everything is going to be cross currents, even if the rotator is rotating. So, the current magnitude will actually the current magnitude will change polarity as it comes to this side, so what happens as a result of this is that.

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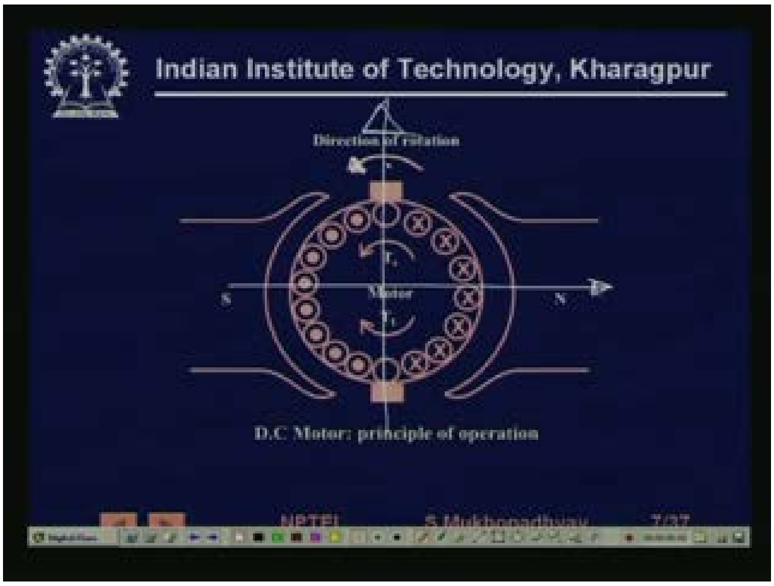

This will make that on one side of the brush you will always have, so you see that if you have this sort of a coil then the armature that is the flux, which is created due to the armature current is actually aligned along this direction always even. If the rotator is rotating and the flux due to the field coils is aligned along this, so this is, so you know this is, so therefore the torque is along this and the and the motor rotates and as it rotates.

So, for a normal DC motor the field flux is actually the direction of the field flux is actually fixed in space and the direction that is very easy to achieve because the field coils are fixed in space, they do not move. But on the other hand the armature flux is also fixed in space, in spite of the fact that the armature is rotating this is the beauty and to ensure that, so that to ensure that the armature flux remains perpendicular to the field flux, well they can be moved little bit by moving the brushes, but that is a different thing we generally do not do it.

So, what happens is that we in general if the brushers are in there, so called neutral position then the armature flux is going to be perpendicular to the field flux irrespective of the fact that the motor is rotating. And this gives maximum torque and gives good dynamic response, best possible dynamic response for a given you know current driving capability and for a given mechanical property of the motor. This is why the DC motor is considered to be good.

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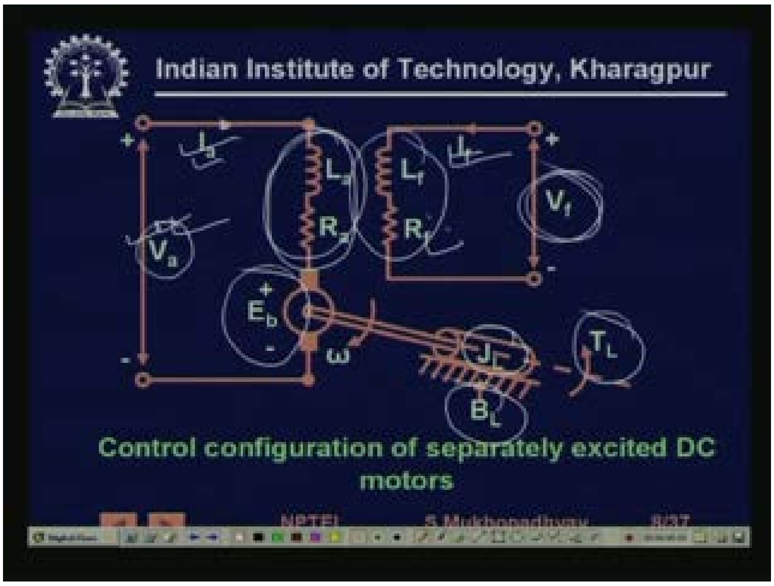

So, basically this is the control configuration of a separately excited DC motor, we call a DC motor separately excited, when the field is excited from a different source and the armature coil is excited from a completely different source and they are not related. You know sometimes there are other configurations in which DC motors are run for example, series, shunt etc, but in this case they are separate and this is the configuration which is used for control drives.

So, what is happening here is that, so we have the armature coil this is the armature coil which is excited by the armature voltage, there is some armature current flowing, there is some back EMF. And this is the field coil, which is static and which is excited by another source of voltage called the field voltage and this is the load that the motor is driving. So, including the load and the motor, the total load on the motor shaft including its own friction or any other friction or inertia that the load may be having.

So, that is all that is replaced with the by this JL and BL TL is the load torque requirement, so this how it is to be controlled, so on you need to have one voltage supply which will control the current in the armature and you need to have another supply which will control the current in the field for creating the kind of motion that you want to create. Now, the whole question is that how do you control these voltages or these currents. So, the whole question of drive is to create a source of energy, a controlled source of energy, where we will be able to control these Vs and Is on the field of the armature point that will create the desired kind of motion.

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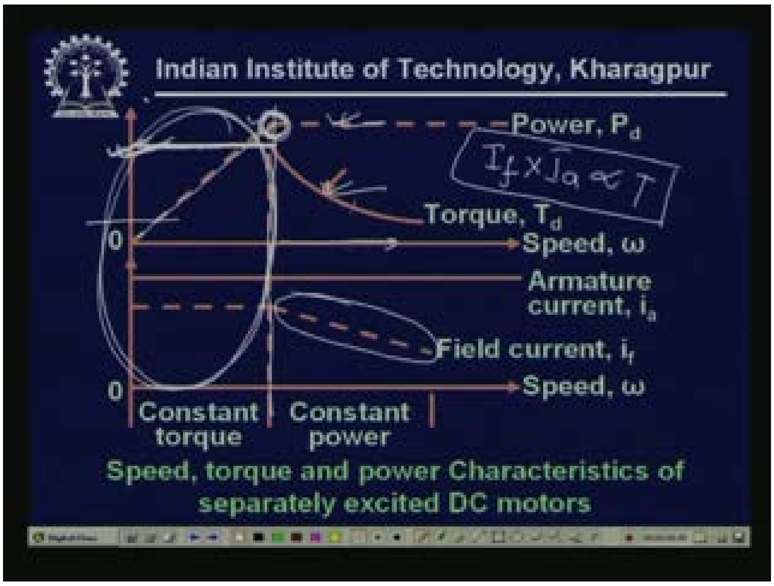

So, this is the well know torque speed curve, in a torque speed characteristics actually it gives what is known as the you know the operating region of the motor. So, as we have seen that we can either, we can either control the armature or control the field or control both of them theoretically speaking. Actually they are actually either the armature or the field is generally controlled that is there are two modes of control and in this mode you have, in this is the mode, this is the zone where we are having armature voltage control.

So, if you have armature voltage control then your torque remains constant, if you have that is that is the maximum torque which is achievable at different speeds remain constants right. So, why is why does that happen because we are not doing field control, so we are doing, so the field current is constant right. So, If is constant, similarly the maximum armature current is also fixed, because the field current is constant.

So, what will happen is that if the voltage is increased to the maximum value then for a given, for a given maximum armature current, If into Ia which is proportional to the torque is going to be fixed. So, therefore, you have a constant torque region, so you can, so as the speed increases; obviously, if you have a constant torque then as the speed increases the power that you can achieve will increase upto a certain level, where you have come to the maximum power that the machine can deliver.

That is your torque, this maximum value of torque and the corresponding to the maximum value of armature current and the corresponding value of speed. After that one cannot get, one cannot get more power out of the device, but one can still increase the speed if it is desired to do so. So, then if you want to increase the speed further at the cost of torque because power has to stay constant that is the maximum, which we can deliver then we can one know what is known as the field weakening or we can weaken the field.

Then what will happen is that we can go to higher speed region, but the torque will fall, so that the torque and the speed will product which is power will remain constant. So, the operating region can be divided into two parts, a constant torque region and a constant power region. For industrial drives this is the region which is of more concerned, and so we will mainly be looking at armature voltage control of separately excited DC motors.

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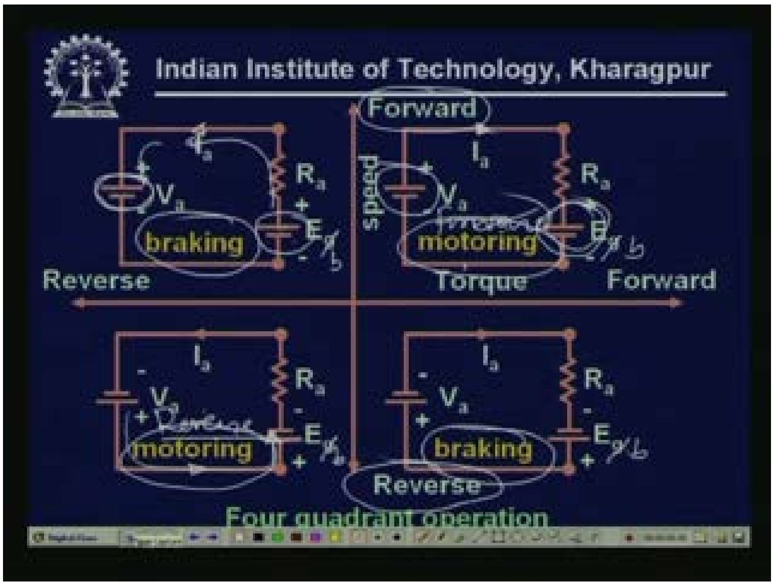

Now, while the motor is moving, several modes of operation can exist for example, so we have two things one is torque another is speed of the motor right. So, depending on the speed we have two directions, so this is the speed can be positive or negative, depending on whether it is rotating clockwise or anticlockwise, now arbitrarily we call one to be forward and the other to be reverse.

So, depending on whether the speed is positive or negative we have in this case we have chosen to call positive speed has forward then negative speed becomes reverse, so either the motor is in the forward rotating mode or in the reverse rotating mode. Now, while it is rotating forward, if we have a we generate a torque which is also in the forward direction in the same clockwise or anticlockwise direction then the motor will accelerate will try to drive the load more and more in the forward direction.

So, in that mode where the speed is forward, where the speed and the torque are in the speed direction we call it up the motoring motor, so these two. Here the speed is forward and the torque is also forward and here the speed is reverse and the torque is also reverse, so sometimes we call it forward motoring and we call this reverse motoring. Compared to that there is another mode call braking, so what happens here is that the speed is still forward, but the torque has reverse, so actually what is happening torque creates acceleration.

So, if the torque is reverse then there is net reverse acceleration, so the speed is, so the speed is coming down, so the speed is forward still moving, but it is slowing down because of the negative acceleration right. So, that mode of operation we call braking. And this basically shows that under what kind of conditions these you know the supply voltage polarities and the back EMF this is should be b. So, the supply voltage and the back EMF polarities, how they are related.

So, in this case you know, in this case what happen let us take the lets take motoring, the back EMF is created because there are some coils which are which are rotating within the field flux, so there is some induced EMF. So, in this case when this motoring, the power source is actually delivering power into the motor, so that can be seen that if current direction is like this then this source is actually receiving power this back EMF source is receiving power which is being delivered by the external source. So, that is why it is motoring.

And that power which is absorbed, which is seen, I mean seen to be absorbed by the back EMF is actually causing, is actually re representing the conversion of electrical energy into mechanical energy, which is creating the speed which is creating the back EMF. So, that power is going to create the speed, which creates the back EMF, so that is why you are motoring similarly here also the look at the current direction, the current directions like this. So, the external source is delivering power into the back EMF source, so the motor is receiving power.

Exactly the opposite happens, here the back EMF source is delivering power into the external source why, because this is maintained smaller than the back EMF, so the moment this is maintained smaller the current direction will change. Actually there are going to be some inductances and this change will involve some LDI by DT effect, but generally if that LDI by DT effect, we do not consider. Then the current will eventually reverse, if this is maintained less than this and there, then you can see that it is the back EMF source which is delivering power into the external source.

So, we are actually getting back some power from the motor, actually this power is coming from the kinetic energy of the motor, so this is and while the motor gives up its kinetic energy to give back electrical energy into the source it is; obviously, slowing down because it is losing kinetic energy. So, therefore, the speed is coming down therefore, it is braking, but because the loss of the kinetic energy is actually being converted to an electrical power and being fed back to a source therefore, it is called regenerative way.

This power, this kinetic energy could also have been you know wasted in things like resistances that is possible, so in which case it would still be braking, but it will be a different kind of braking as we shall see. So, you see that depending on the torque and speed quadrants, we can have four different kinds of operation one is forward motoring, so forward motoring, then forward braking, then reverse motoring, then reverse braking.

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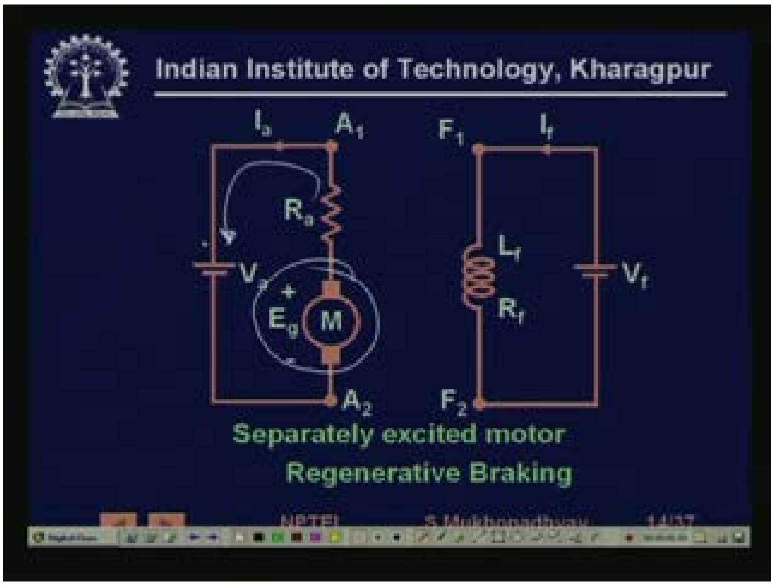

Now, so we see there are three kinds of braking that we are talking about here what happens is that you see this source, this back EMF source, so this back EMF source which is the motor is delivering power into the external source which is the battery the field is just connected. So, this is here this is the regenerative braking situation.

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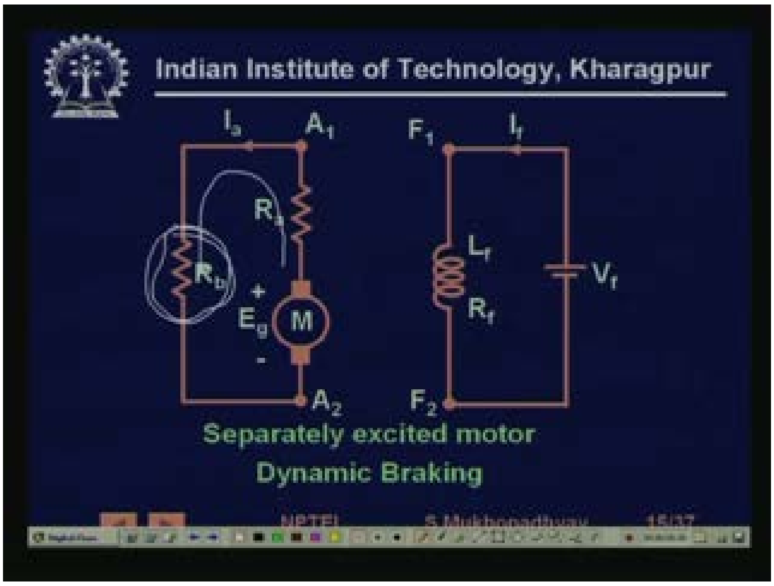

Alternatively, we could have what is known as the dynamic braking, in the sense that in the sense that we could at any point of time we could disconnect the source and then connect what is known as a resistance, a braking resistance here then this current would have been dissipated in this resistor as heat. So, that is there you are not gaining the power, but you are actually wasting the power as heat, anyway this is called… Therefore it is not regenerative it is call dynamic braking.

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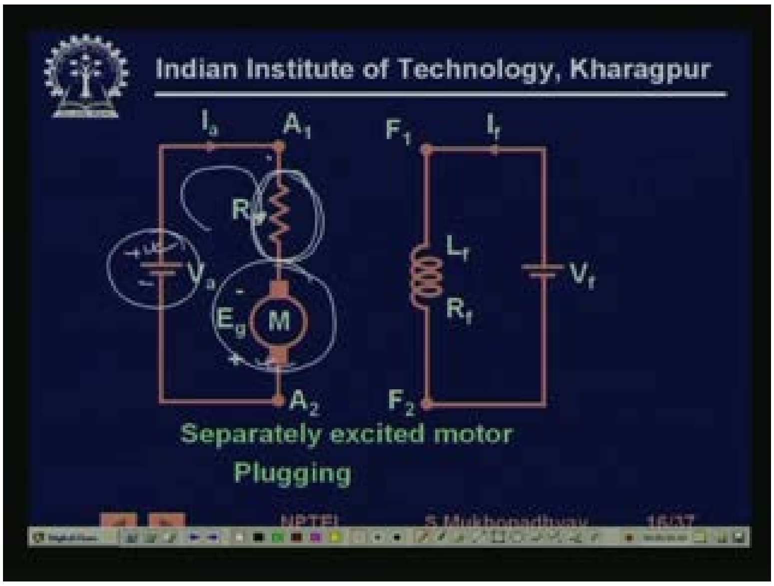

Next we could have if you want very rapid braking, then we can use a method called plugging, where not only is the voltage kept in degenerative braking the voltages are still opposing, but the supply voltage is less, therefore the back EMF source drives power into the supple voltage. On the other hand here you see that the supply voltage look at the polarities plus minus, minus, so plus minus plus minus, so therefore, these two, this EMF source and this EMF source are actually adding, so therefore, a large, huge large current will flow.

And, so this is also delivering power, look at the current direction and this is also delivering power and all that power will result in a very high sudden peaky current, which will, which will actually. ((Refer Time 31:22)) So, the energy is going to be dissipated within the winding as heat. So, the motor is going to since the current is see the remember that the flux direction is different, but the current has completely reversed, so therefore, there is and there is a large current. So, there is a large making torque and the motor will come to rest very fast, but that a lot of heat will be created in the winding.

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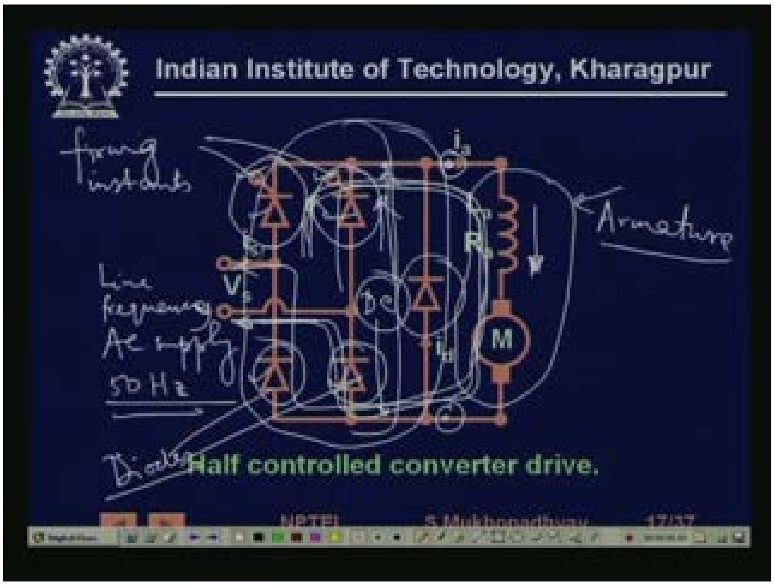

So, now, let us come to the point that how we can, so we basically want to drive the voltage source Va, so sometimes we want to keep it more than the back EMF source. So, that it drives current in to the motor and the motor accelerates. Sometimes we want to reduce that and so that the motor can decelerate and it can I mean give back its kinetic it is mechanical power to be converted the electric power and sometimes, so we want.

So, in other words, we need to have a method of controlling the supply voltage to the motor armature how do you do that, so there are various ways of doing that, so we first look at some you know what are known as line frequency converter drive. So, what do we mean by line frequency, so what we mean is that here you have line frequency AC supply say 50 hertz. Now, and we have see the, we have connected a basically this is a rectifier, this is a rectifier this is what is know as the freewheeling diode and this is the armature, this is the armature.

So, what we can, what we are going to do is, we are going to take the AC here and then rectify it to be a DC, so here it will become a DC at this point and not only that because it is half controlled, so the magnitude of this DC can be controlled by controlling the firing instants. In this case we are demonstrating through what are known as thyristors, so or rather to put them on, so firing instants, so by controlling the firing we can control the supply voltage to the motor and we can vary it.

But note that we cannot have in this case, first of all in this kind of these are these diodes and thyristors, they are all as far as current is concerned they are unidirectional devices. So, here current cannot be reversed right, so therefore, the current is always passing like this, you know the current in through this devices are always in this directions. So, in the positive cycle it is passing like this, in the negative cycle when this voltage becomes negative it may pass like this.

So, you see that the supply current is sometimes going, supply current as far as the supply is concerned the current is switching,, but as far as, but the current direction through the switches can never change that is because of the basic nature of the switches. So, what happens is that the current through the armature coil that direction remains fixed, although the terminal voltage, the terminal voltage across the armature can become, in this case they actually cannot become negative because of the fact that these two are diodes. So, is here is a source in which we can have a positive voltage applied along with a positive current and the magnitude of the voltage can be changed.

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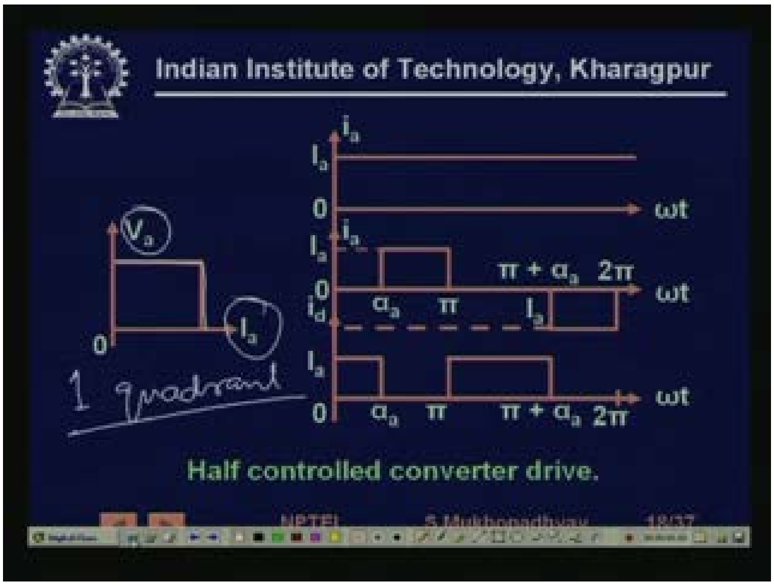

So, we essentially have we can have only have positive current and we can only have positive voltage, so it is a one quadrant control, but within this quadrant we can, so we can only do motoring here that to in one direction, but by controlling the voltage we can change the amount of the torque and the speed always same in the same direction, but there magnitudes can be controlled right. These are you know some of the current waveforms which we can skip for now.

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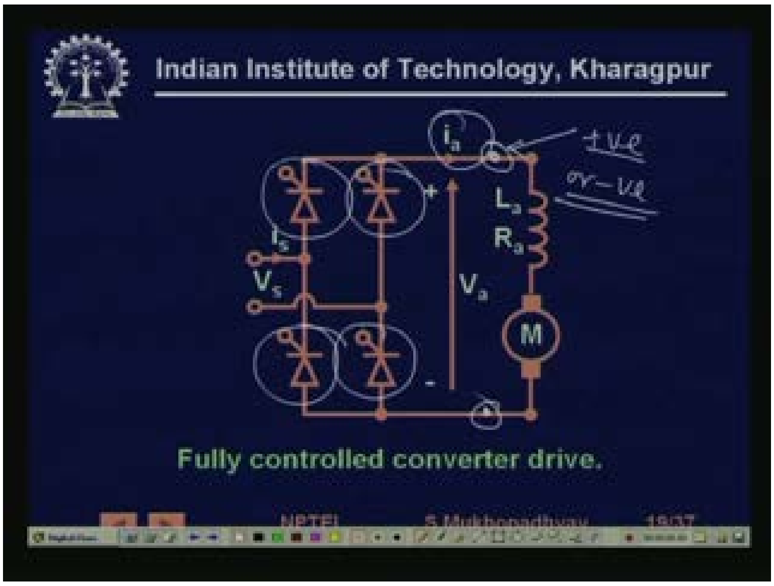

Then we will have what are known as fully controlled converter, so here now you will notice that all the four devices are active, which means that now current is still unidirectional because current through this devices can only move in one direction still. So, still current is unidirectional, but now because of the inductance if we it is possible that the current will remain in this direction as mentioned while the terminal voltages will change they can go negative, they can go positive or negative. So, now voltage can be voltage across the motor can be reversed, but current cannot be reversed ,which means that we have a two quadrant control.

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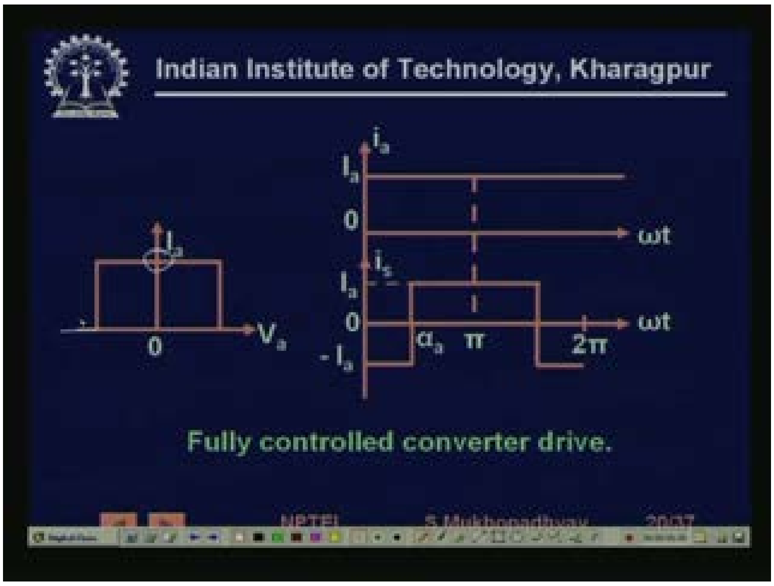

So, we have two quadrant control, where we have the current is still always positive, but the voltage is sometimes positive and sometimes negative. So, you have, you know what is known as two quadrant operation.

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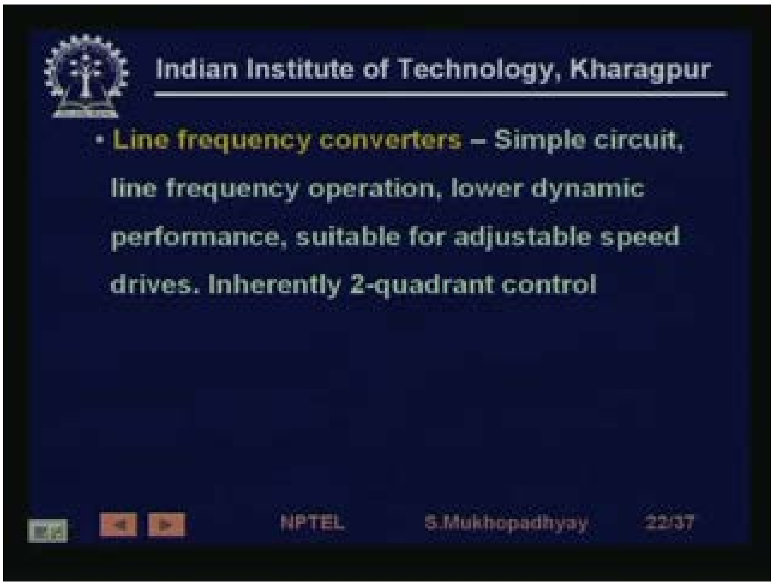

If you want to have four quadrant, now this is, so you see that you have used all four as, we have used all four we have used a fully converter drive, but still we cannot basically achieve better than two quadrant. But if with only one converter, now it is possible that we connect two converters and then achieve.

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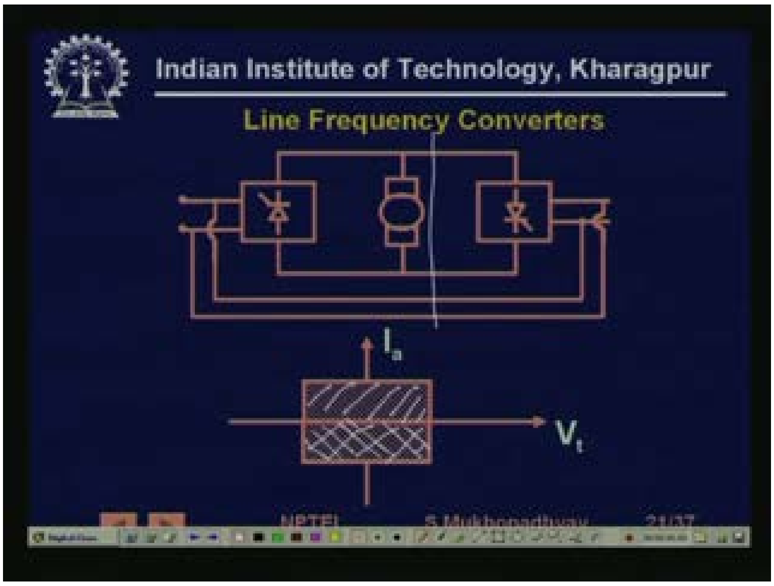

So, you see what we are essentially doing here is the fact that we have connected two converter, so we previously we had seen only this part of it, so one converter connected to a motor, all four are active or rather fully controlled. So, then one converter gives you on this one quadrant, the Ia is positive. Now, on the other hand if you put another converter with the terminals totally with just the opposite polarity then you will get another two quadrant operation, which is in this quadrant.

Now, if we connect them in parallel and then sometimes whenever I want, depending on which quadrant operation I want, I use either this converter or this converter. So, in this way it is possible to achieve it is possible achieve four quadrant operation using line frequency converter. But only thing is to be remembered is that though it is quite simple to its quite simple to use this line frequency converters, but they are, but because there frequencies are low.

Sometimes they give rise to you know, what is known as torque ripples because when you are going to switch on switch one side of switches on and then switch another side of switches off, but you cannot very closely maintain the current, but the pulsation of the current is actually determined by the frequency of the supply. So, sometimes this may result in unacceptable transience in torque and speed, so in such a case we have to use other kinds of converters.

Before we see such converters in the next lesson, let us look at typical control loops that are used to have, you know adjustable speed drives using this kind of line frequency converters.

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So, line frequency converters to puts simply are rather simple circuits, which operates at line frequency which means that they are basically AC to DC converters, so the AC line frequency 50 hertz is their operational frequency, their dynamic performances are not that stringent basically because of the fact that their frequency is low. So, therefore, there is some amount of current pulsation and therefore, torque pulsation, so this gives rise to a little bit of poor dynamic performance.

So, they are they are widely used for adjustable speed control because in adjustable speed control we anyway do not have dynamic performance requirement, so the simplicity comes as an advantage and inherently these converters have two quadrant control. So, if you want to have four quadrant control then you have to have two converters in you can say in anti-parallel as we have seen, contrasted to that we have, we have switch mode converters, which are much more complex we will see them in the next lesson.

They have higher frequency of operation and therefore, they are they have dynamic performance and therefore, they are generally used for servo drives and inherently used they actually use a kind of form called switch mode converters or basically PWM inverters used for DC to DC conversion. So, they are they are used for four quadrant controls, which are typically required in servo drives, so in anyway let us we let us look at the control architecture now.

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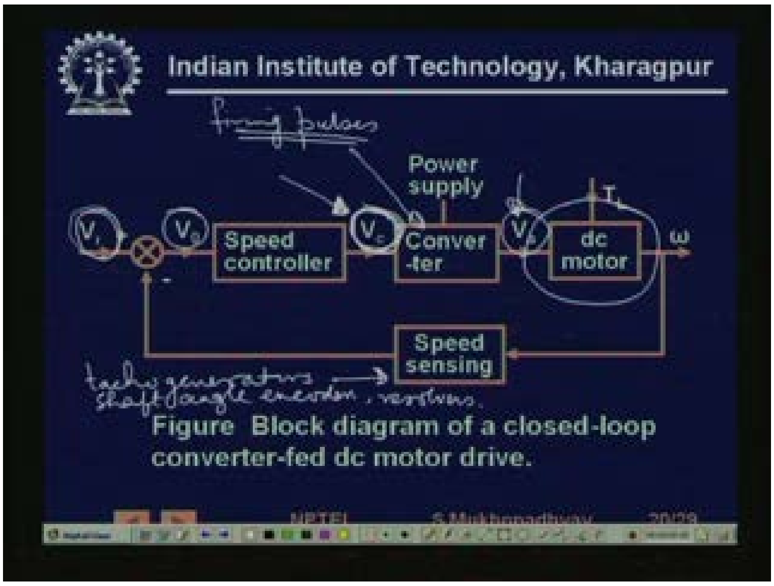

Now, that have you have seen that what is the basic power electronic circuit that can create a variable voltage source, let us see how we can use that in controlling the speed. So, here we have the standard control loop, so we have this is the motor, which is the plant and we have this is the reference input, so this is voltage input which says what is the speed that we want to have and; obviously, it is a since, it is a feedback configuration. So, therefore, the speed is sensed.

Speed is sensed using various kinds of sensors they could be tacho generators or they could be shaft angle encoders or they could be resolvers various kinds of sensors are used here for speed sensing, this is compared and this is the error voltage, this is the error single which is fed to the speed controller. So, based on the error voltage the speed controller according to it could be PI controller, so the speed controller generates a command signal for a certain armature voltage.

So, this commanded armature voltage signal is now realized this is the actual armature voltage, average armature voltage which is applied at the armature and this is the commanded armature voltage by the speed controller So, the internal this converter electronics actually generates this firing pulses, which decide the times the time durations for which these switches are going to be on and off. So, based on this command they actually generate some firing pulses. And once these firing pulses are applied, so the switches become on and off and therefore, a particular armature voltage gets applied to the DC motor. So, this is a very simple way of controlling a DC motor for an adjustable speed drive.

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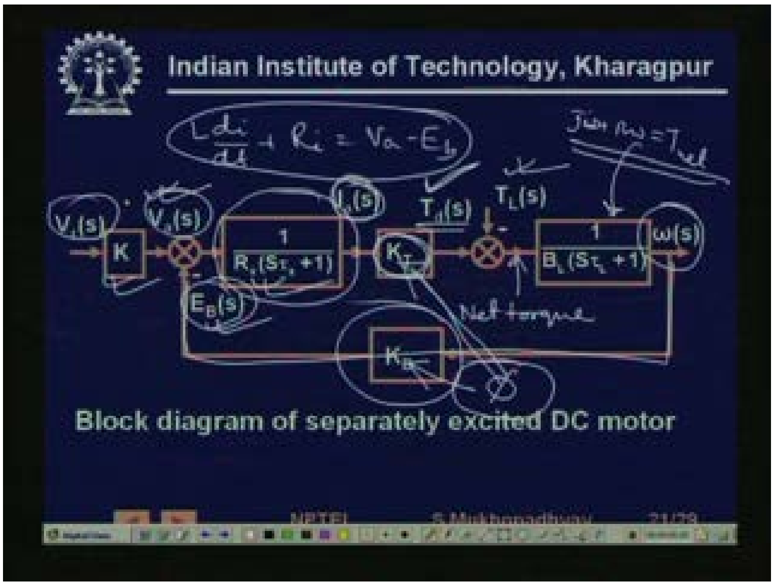

So, we move on, if we, so since is a it is a control system, so it is nice to look at the basic block diagram, so first we look at how the plant transfer looks like. It is actually very simple to understand and this will show why a DC motor is so preferred for control, so the simplicity that a motor basically you know to we want to have see, we want to control speed, so speed is our output. Now, what produces speed, torque produces speed, so what is the relationship between torque and speed.

So, if you see from this side, so this is my output quantity, so there is a electromechanical torque or develop torque and there is a load torque. The difference between the two is the net torque, this is the net torque which is going to accelerate or decelerate the shaft. So, the relationship between that is given by a linear transfer function which is given by its moment of inertia, so we have you know J omega dot plus B omega is equal to T net this sought of an equation we have, so this part is linear.

But remember that the torque generation itself, we are trying to control the armature, but the torque generation itself is torque is flux into current. So, it is basically these the flux or the field into the armature current, but the beauty of the DC motor is that is because the by its construction and by its by its brushes as we have said the current the armature current and the field current are always orthogonal. So, therefore, even if we vary the armature current, the field axis flux remains constant because it is perpendicular it has no component on that side.

So, therefore, we need to for control, we need to only, we need to only control the armature control and the control law will be linear. This decoupling of the armature and the field axis because of their perpendicularity is the reason why DC motor based control is so simple and preferred. So, this is the armature current and this is the torque constant, which includes the flux, so in this constant we have absorbed, so the torque developed is actually proportional to the armature current because the field current is constant and orthogonal.

Now, how do you get the armature current, so the armature current is again the net EMF net EMF is applied armature voltage minus back EMF flowing through and Rl circuit, so therefore, we have Ldi by dt plus Ri is equal to net EMF which is Va minus back EMF. So, this equation is basically realized here and this back EMF is in turn proportional to the speed by this constant KB which again depends on the flux, so it is constant, so in this KB we also have the flux.

So, the fluxes are included in these two relations, so and this is the reference voltage and this is the depending on the reference voltage we can give the armature. So, you see that because of the construction of the DC motor, the DC motor can be very easily described as a linear system and therefore, it is control is very simple and can be easily realized using things like PI controller.

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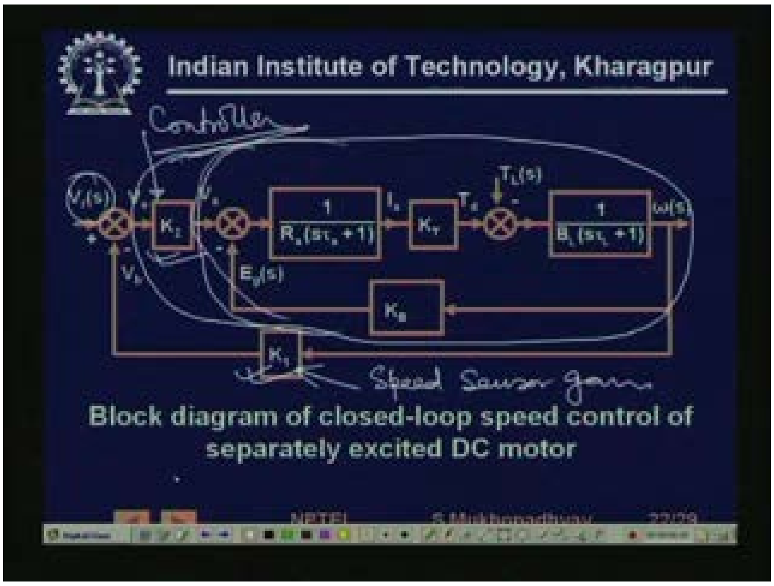

So, this is the plant transfer function, so if we want to have a close loop system then this is the plant transfer function, remember that we have just seen. And we have taken the plant transfer function, actually not bad this is the plant transfer function, this is the controller in this case we have taken a proportional controller, we can also take a PI controller. And this is the feedback loop, so this is the speed sensor, this is the speed sensor gain and this is the reference voltage.

So, this close loop is just the open loop plant and the controller in the forward path and the feedback path transfer function, as we have seen many controller loop, so it is easy to understand. So, you see that what we are trying to control is that we are trying to control the applied armature voltage based on the speed error that is what we are doing.

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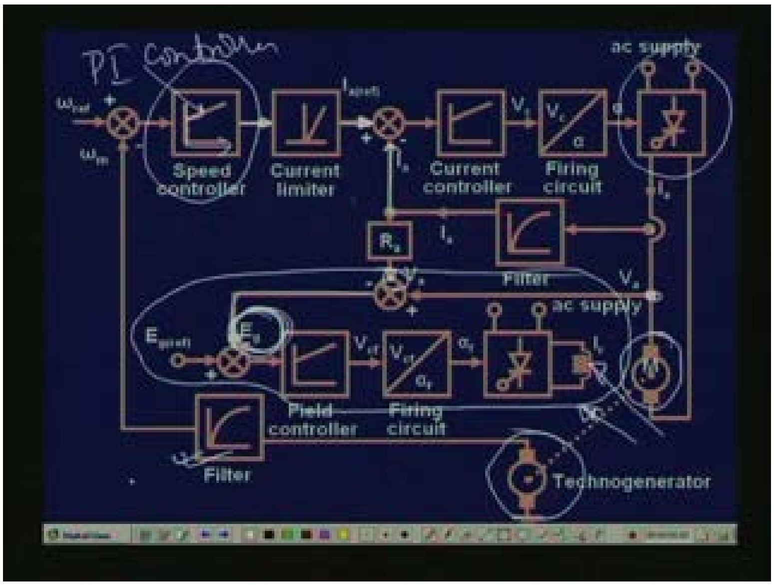

So, if you look at a total control loop then it will look this, see this is a these are overall control loop, so this is the armature, this is the techno generator or the speed feedback, sometimes you use a filter here to get rid of noise, this is a real implementation. So, here you have speed controller this is a typical symbol which is used for PI controls because this picture gives the error versus time characteristics of PI controllers, often you have inside the speed control loop, you also have a current control loop because you sometimes you want to control the torque itself.

So, therefore, you will have a current limiter, so this actually gives a current reference and that goes to a current controller that is applied as the current reference. So, if you give too much current command then that will be limited. Now, you see that this is the converter which is supplying to the motor the converter current is tapped here either using a hall effect sensor or using a resistor, so this current is being compared.

So, this is an inner current loop just like a cascade control, this is the outer speed loop inside you have a inner current loop, this will give much more stiff control, transient response with improve On the other hand the field is also being adjusted such that the IRa drops see this is this is Ia, so this is Ira, so the excitation to the field winding, which this is the field winding is adjusted such that this IRa drop is actual compensated, so this Va this is minus Ia Ra , Ia into Ra.

So, that is compared and such that this is the, so the equivalent amount of EMF is, so in the steady state the flux will be such that there is no variation in the speed due to this Ia Ra drop right. So, this is I mean some amount of field controlling in that sense, so this looks like a, this is a you know slightly more complex current loop, so we will.

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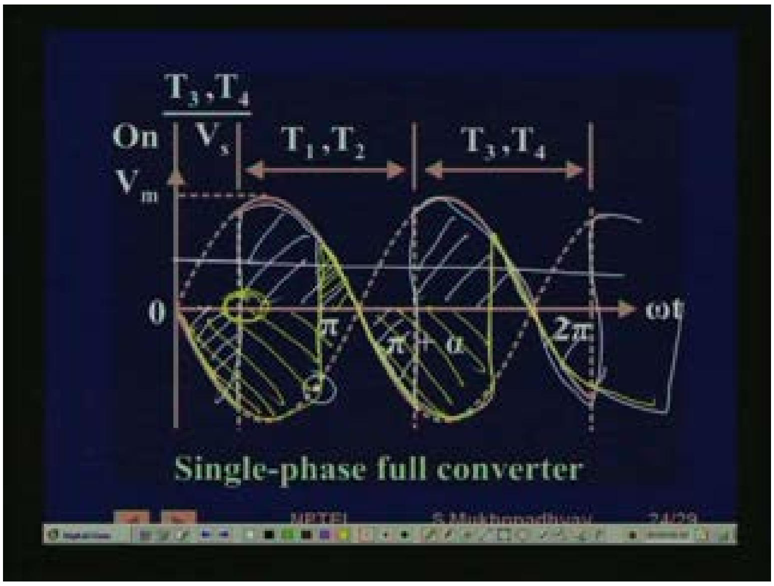

This picture shows that how voltages can be varied, so if you have a full converter which we had previously seen then you know depending on, this is the point, these are the points of time where these, so the switches are being put on. So, the voltage across the armature is actually of this form, follow the white marks, so you see that if, so the voltage across the armature is this, followed by this followed by this, followed by this, so you see that the average voltage is somewhat positive here.

On the other hand, if these would have been, would have fired at this point that is switches then we would have got this, so then I will draw it with a different color that then the voltages would have been the voltage across the armature would have been this. So, you see that it would have had a the average value of the voltage would have been negative do you see that, so this is what I was telling that if you have a full converter then by changing the switching instant. If you switch here, you get an average value which is positive, if you switch here you get average value which is negative, but the current remains unidirectional, so therefore, you have either braking or…

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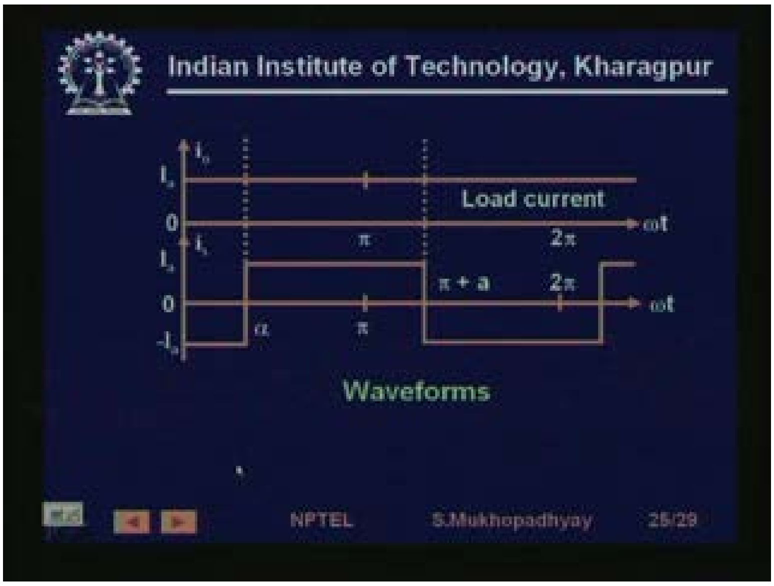

So, these are the current waveforms will not.

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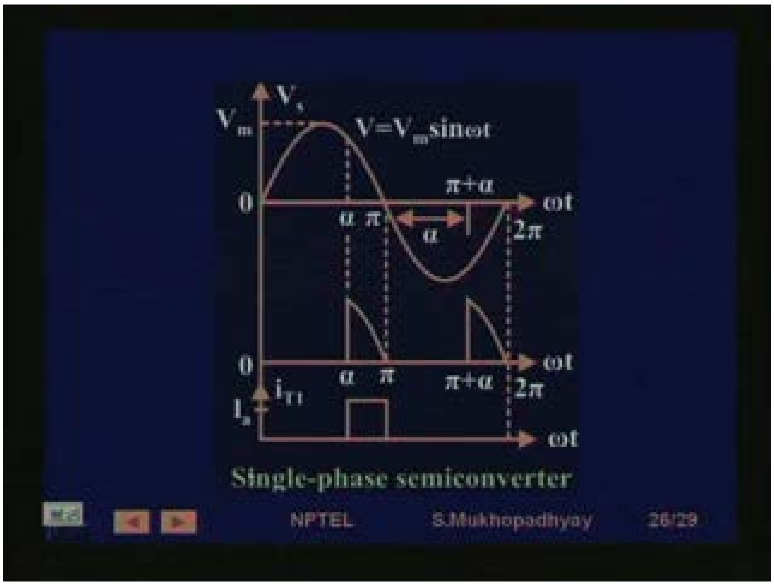

This is a semiconverter, In a semiconverter because the diodes will switch off the moment the voltage crosses zero, the diodes which are there in the semiconductor in the semiconverter are going to switch off. So, therefore, you cannot have negative voltage, so therefore, you can only have positive voltage from the max to zero. So, therefore, you have single quadrant operation, this we have mentioned.

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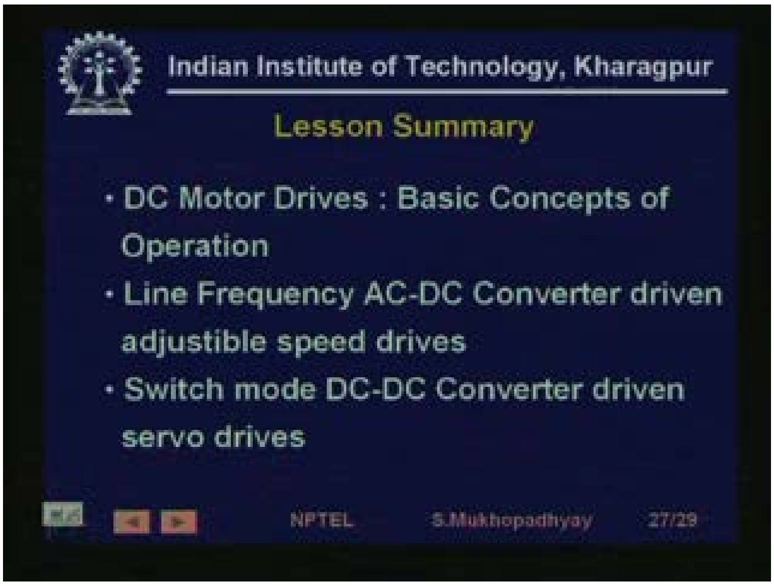

So, we come to lesson summary, so what we have seen are basic concepts of DC motor drives and the basic reason why DC motors are considered good and this wide popularity. We have seen the basic line frequency AC –DC converter, driven adjustible speed drives we have seen various quadrants of operation. We have not seen the switch mode DC –DC converter driven servo drive, which will see in the next lesson.

But we have seen how the four quadrant of operation what they mean and how braking and motoring can be achieved by reversing the voltage in that in the converter driven drives. So, thank you very much, in the next lesson we are going to look at switch mode converter driven DC and BLDC drives.

Thank you very much.

Welcome to lesson 33 of the course on industrial automation and control.

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So, in this lesson, we are going to look at DC drives we will continue with DC drives, but we will look at DC drives, which are supplied by a different kind of power source called switch mode converters. And then we will once we do that and we understand how it works, we are going to extend the DC drives to what are known as brushless DC drives, which are very popular nowadays.

So, we are going to first look at DC – DC converters and their operations then we are going to look at these DC – DC converter fed DC drives, we are going to look at their single quadrant, two quadrant operations. And finally, we are going to take a look at BLDC drives or brushless DC drives, so our instruction objective for today are the following.

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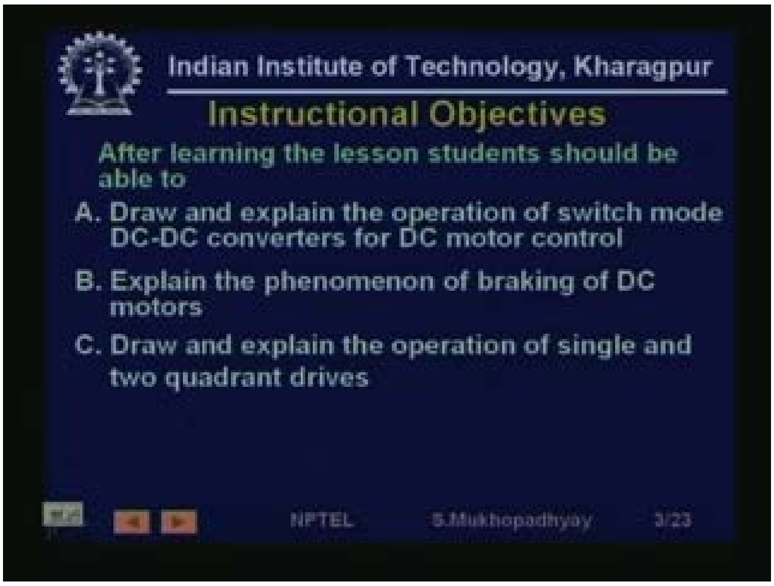

So, first we will after the lesson the student will be able to understand the basic concept of how a switch mode converter works, what sought of a power source it is and if it is connected across the armature of the DC motor then what happens during its operation this is the first instructional objective The second is that, so once these various kinds of switchings go on, so we will see how the DC motor can be made to motor or it can be made to brake, so that we will understand.

Next is, we will also see that you know there are some kinds of drives, which do not require which may not require all four quadrants and so they may be a single quadrant drive requirement or there may be a two quadrant drive requirement in which case it is not really necessary to have a four quadrant drive and we can simplify the circuitry. So, we will see them.