Industrial Automation and Control
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Lecture - 33
DC and BLDC Servo Drives

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Welcome to lesson 33 of the course on Industrial Automation and Control. 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 today are the following.

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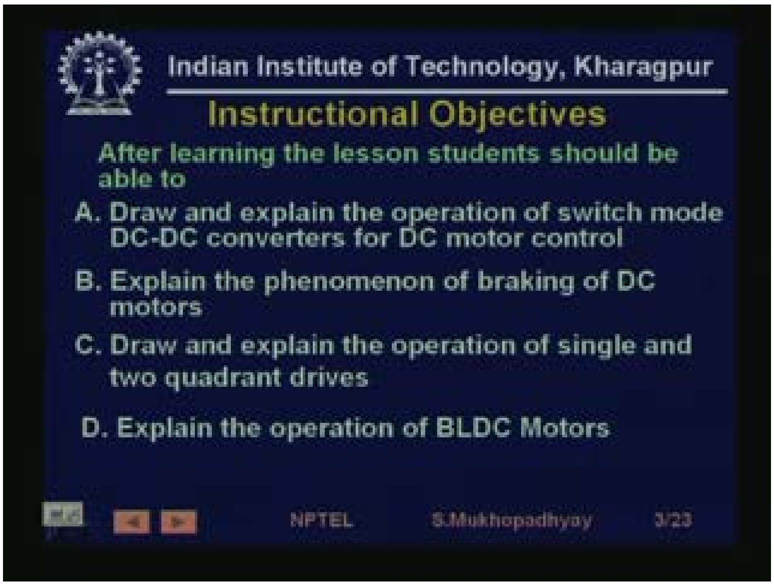

So, first we will after the lesson the student will be able to understand the basic concept of how a switch mode converter works, what sort of a power source it is and if it is connected across the armature of the DC motor then what happens during its operation. This is the first instructional objective, the second is that, so once these various kinds of switching's go on, so we will see how the DC motor can be made to motor or it can be made to break, 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 there may be a single quadrant drive requirement or there may be a two quadrant type requirement in which case it is not really necessary to have four quadrant drive and you can simplify the circuitry, so will see them.

The next one and then finally we will extend the concept of BLDC these DC drives and to a new kind of motor called brushless DC motor, which does not have the disadvantage of the brush, but has the advantage of the DC motor, which is that the armature. And the field fluxes are perpendicular, which leads to a very simplified control structure and also very good control sensitivity. So, we will see that how we can have the best of both worlds; obviously, at the cost of increased electronics.

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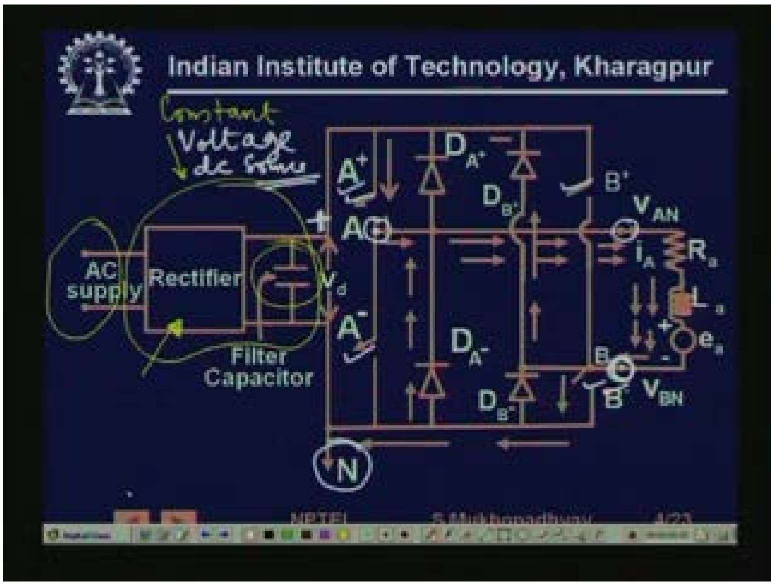

So, now we look at first, we first set off to understand this switch mode converter circuit and here is a single phase switch mode converter. Sometimes it is this same circuit topology is also called a PWM inverter, because the same topology can be used to generate in this case what we are doing with this circuit is that, we have an AC supply which is our normal AC supply line frequency, then we have a rectifier. So, a normal rectifier, constant it is not a variable voltage rectifier, this is the constant voltage rectifier.

So, some diodes, a bridge rectifier along with a capacitor, a large filter capacitor which, so these two together is basically constructs a constant voltage DC source, let me choose a slightly thicker pen and white, so constant voltage dc source. Now, this phase controlled rectifier is this not phase control rectifier, this switch mode DC-DC converter is actually produces, in this case it produces the variable voltage DC, which can the either positive or negative and apply this variable voltage DC, bipolar DC to the armature depending on the requirement of motoring or breaking as decided by the speed controller.

So, as we have seen that in a speed control loop, we are going to determine what sort of armature voltage we need to apply, depending on our load disturbance or whatever and these are typically used for servo drives. So, even if there are load disturbances, we want the speed to be constant or we want the position to be exactly accurately reached these are the kinds of drives which are used in, let us say CNC machines.

So, we need to have a good control loop, which will quickly accelerate and decelerate these machines, so that it is going to do by controlling these switches and why it is called it is the same topology which is used in PWM inverters because of the fact that it is a bipolar topology. So, we can also we can always generate positive and negative voltages. So, if we give our reference commands in a suitable sinusoidal manner, we can also get an AC out of it.

The only advantage is that we can get variable frequency AC out of it, if you use it in that mode it will be an inverter, inverter generates AC from DC, but in this case it is being used as a variable voltage bipolar DC source remember. So, first of all let us look at it, so we have four switches, which I have termed A plus and A minus and B plus and B minus and with respective to and for in parallel with each switch there are four diodes.

So, we have DA plus which is in parallel with the switch in A plus, DA minus in parallel with M minus and similarly DB plus and DB minus. This DC source has this terminal as positive, so this is the positive terminal of the DC source and this is the zero voltage terminal, so we are assuming that it is plus and zero. So, and these are the terminals which are connected to the motor armature, so this A and B, here is the motor, so we have the back emf source, which depends on the solely depends on the speed of the motor then we have the armature resistance and inductance.

So, as we can see, that if at any time, this switches are operated in pairs, so we have either A plus and B minus on in which case this terminal A is positive and this terminal B is negative or we have B plus and A minus on in which case, we have the terminal B as positive, it is positive connected through this positive terminal. While this terminal A gets connected to zero or ground or neutral whatever you call it.

So, you see first point to be noted is that by making the switch is on and off, we can apply either positive terminal voltage or negative terminal voltage to these to the armature, so the voltages can be reversed, now comes the question of the current. Now, suppose what is going to happen, so now, before the understand what is going to happen, we are going to see that in some detail, let us take a look at the control law that we are going to using and then come back to the circuit and see how what sort of voltages and currents will result.

So, let us first see the switching law that is used and then we will see that what kind of voltages and currents are produced in the motor, in response to that switching law and what will be its impact on the motion of the motor. So, that is we are going to see that, so let us go little bit forward and then come back to it, so first of all some simplifying assumptions, first is that the switches are ideal, so we are going to we are going assume that there instantaneous turn on and off.

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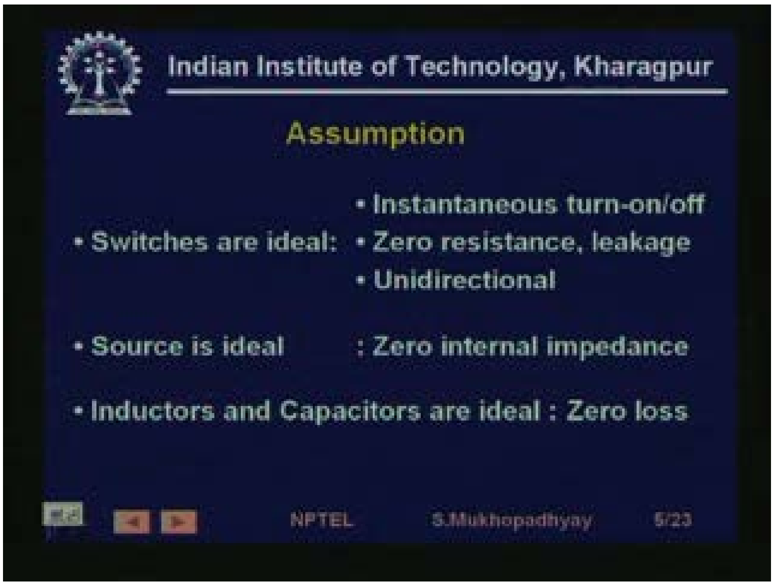

There is zero resistance, but the switches are unidirectional you must remember that in all other respects is like a switch, but expecting for the fact that we cannot have a current flowing in the opposite direction in the switch, these are the properties of this electronic switches. We will also assume that the source is ideal that is the DC source is ideal, it has zero internal impedance and if it has zero internal impedance that is, it has zero regulation.

So, whatever current is drawn it is a constant ideal voltage DC source, which can source enough amount of current that the converter may need, we are going to assume that and it is to you know such that the source, real source actually approximates that we actually put all those filter capacitors, large capacitors. We will also assume that the inductors and the capacitors are ideal, so there is no loss.

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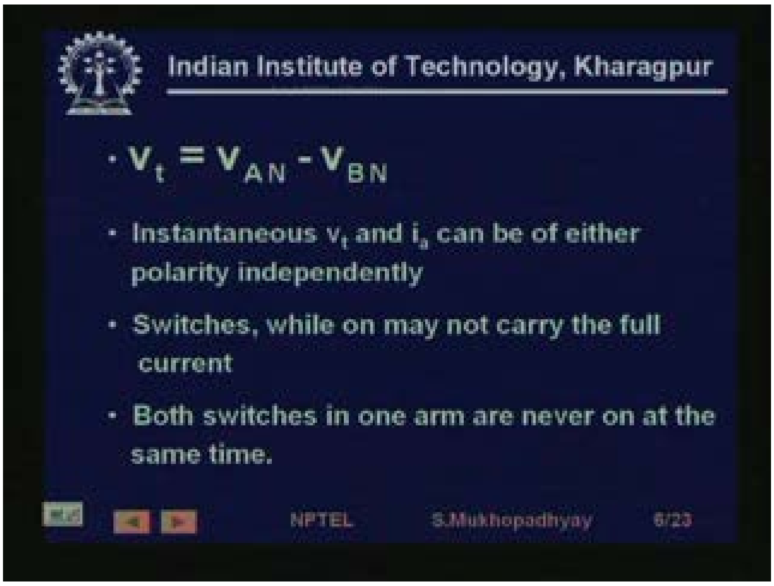

So, having said that we will first note that the terminal voltage across the armature voltage is basically VA minus VB, so we note that and as we will see that in this circuit, the instantaneous terminal voltage and currents can be of either polarity, you can have you can have positive positive, positive negative, negative positive and negative negative. So, they can be changed independently, it is not necessary that if the voltage is positive current has to be positive.

So, there will exists instants, where all four kinds of combinations will occur. Sometimes you may also find that even if the switch is on, because of its unidirectional property. It will not carry any current, so while it will set the voltage it will not carry the current and we must remember that the both switches in one arm can never be on, because if it is on then the DC supply is going to be shorted by zero resistance. Even if it is not zero, in practice it is going to be shorted by a very a low resistance and it will cause damage to the supply certain, so we obviously, cannot have that as existing. So, now let us look at our first, let us look at our control law is that let us go back.

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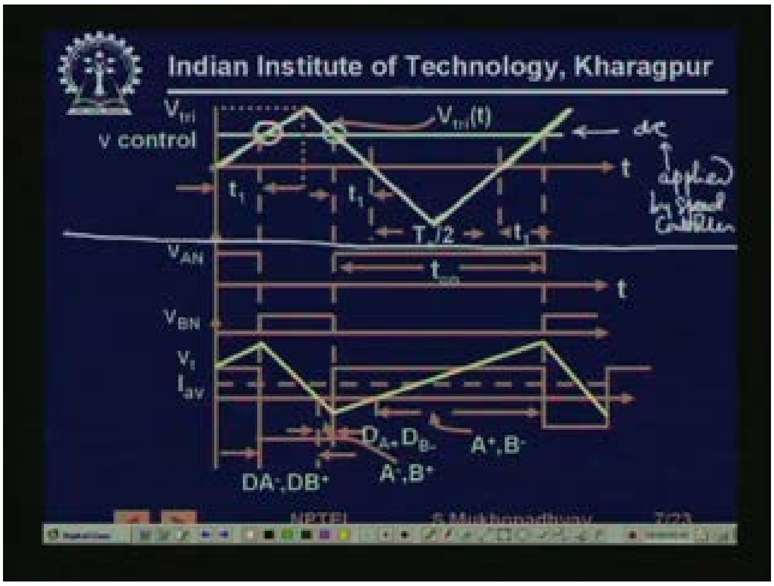

So, first of all do not look at the rest of the diagram, so first of all let us look at the diagram up to this, so only look at the top part of the diagram, so what do you have, we have a triangular wave, so this yellow triangular waves. This V, this is a wave of a certain fixed frequency of rather high frequency this much we remember that the if that this is the major difference with the line frequency converters, the line frequency converters always switch the switches become on and off at line frequency which is 50 hertz in our case.

But here as we will see that the frequency of switching will be determined by this triangular wave frequency, which is generally much higher than the line frequency it is of the order of several kilo hertz, it could be 50 100 kilo hertz, it is not I means in some smaller converters or IC converts, but it can easily be 10 20 30 40 kilo hertz. So, it is about a thousand times higher frequency than you have in line frequency converts that you have seen in the last lesson.

Now, we have a triangular wave, which is of that frequency and we have a control voltage which is a DC voltage, so this is a DC, but this is the voltage that my controller keeps changing. So, this is applied by the speed controller, applied by speed controller, so now suppose this voltage is at this level, so what is our control law, our control law is that wherever the control voltage will be less than the triangular voltage value, triangular voltage is continuously changing.

So, at this point, the let us say before this the control voltage was greater than the triangular voltage, while from here up to here the control voltage is less than the triangular voltage. So, our control law is based on this relative comparison and the control law says that.

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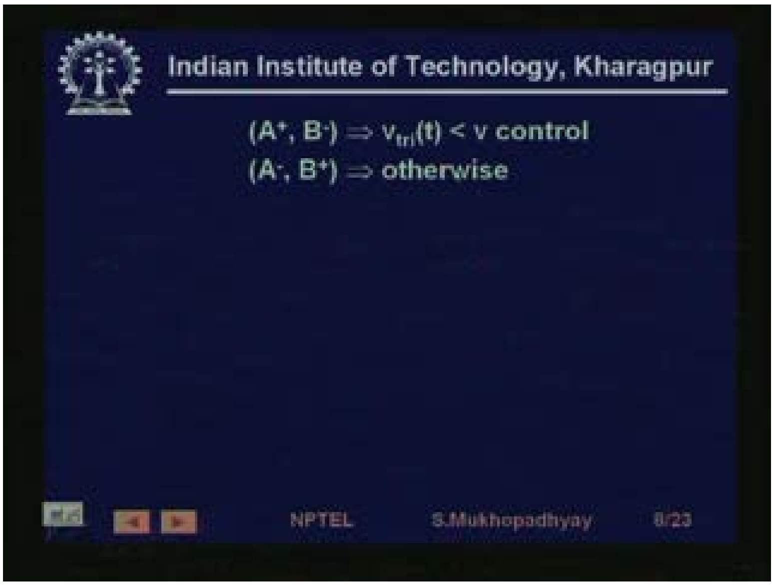

If the triangular voltage instantaneous value is less than V control then we are going to have A plus and B minus as on and if it is not then we are going to have A minus and B plus as on, so let us see what happens. So, now we go back to our circuit, so this is my triangular wave control static.

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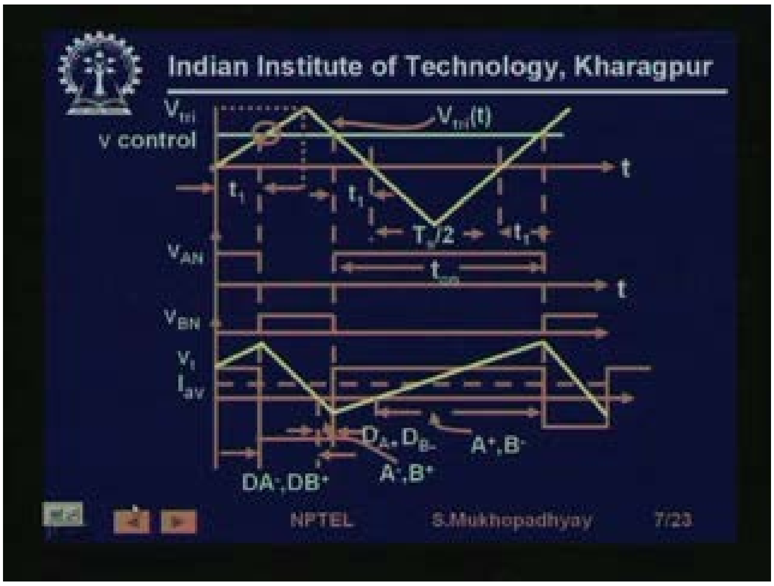

So, you see that as we vary, let us note this, why it is called it is also called PWM control is because of the fact that as you make the control where either speed controller makes the control voltage level go up and down. So, what happens is that you see that during this time A plus and B minus rather A minus and B plus are on and during this time A minus and B plus are on, so whenever, so you see that this voltage pulses.

So, whenever A minus and B plus are on VB become goes to positive because B plus is on, so VB will go to positive, while here A plus and B minus are on, so VA will go to positive. So, by moving this we can vary the width of these voltage pulses and therefore, that it is called a pulse width modulation control. So, if we do this, then we can vary the average value, remember that this is happening at a very high frequency, so therefore, since the motor is a low frequency device you must remember that the motor is a low frequency device.

So, a very high frequency voltage input is not going to have any impact on the motor, only the low frequency part of the applied voltage is going to produce some motion. So, therefore, we need to consider the average value of these waves and by changing this pulse widths, we can make this average values go from a positive to a negative. So, this is what we are going to achieve that is why is called a pulse width modulated control, so now let us see that how the voltages and the currents actually vary, if we switch those make the switches on and off like that, so that is look at the circuit.

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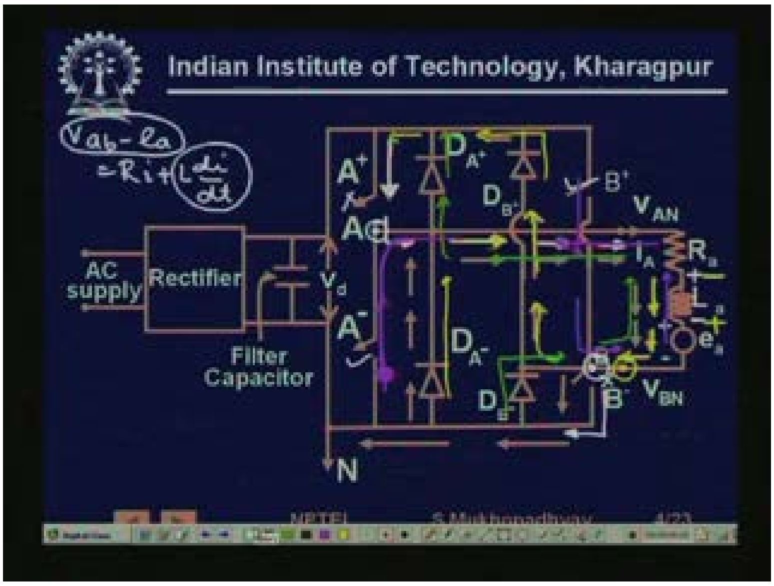

So, now we are ready to see the voltages and current, so initially suppose A plus and B minus where on, so you the current was, so the voltage was positive, the armature voltage was positive. And current was also flowing as positive, so the moment, so you what, so what you what happens is that the current is positive and suppose also suppose that the motor is now rotating in such a direction. So, the suppose the motor is motoring, so if it is motoring then we will typically have the back emf opposing the motor will be motoring with the average value is positive.

So, for most of the time, the pulse widths will be such that on an average for more time A plus and B minus will be on, so suppose that then the motor is rotating in a positive direction such that the polarity of the back emf all as shown. In the motoring mode it will be it will be opposing the applied voltage and it will be lower than that, so there is a net current flowing, and the difference between VAB and EA is being dropped in the R and L So, basically the equation is VA ab minus ea this is the net emf is equal to Ri plus Ldi by dt.

So, since this is positive, so therefore, Ldi by dt is likely to be positive and the current generally keeps increasing, so when the current is increasing then the current is as shown by the white arrows and the voltage across the inductor is also this is positive and this is negative. So, it is opposing the correct by Lenz's law, it will always oppose the current.

Now, at this point of time right, so it this is going on for some time and then in the mean time V triangular T has crossed V control level.

So, at that point of time this will open, so this will become open and this will become on and this will become on and this will become off. So, suddenly the now the voltage is reversed, so now, this is negative and this is positive, but as we know that current through an inductor cannot be instantaneously reversed. So, therefore, the inductor for a short amount of time the inductor will now what the inductor will try to do is, it will try to maintain the current and it will instantly switch off its, so change its polarities.

So, it will now suddenly see the back emf, see the still the motor is rotating in the same direction rotation cannot be changed, so fast at kilo hertz frequency because it involve inertia. So, the motor is rotating in the same direction therefore, the polarities of the back emf are the same, but this inductor will now suddenly switch its voltages, voltage across the inductor will instantaneously change such that the current is maintained. And it will still for short duration it will use its magnetic stored energy to drive the current in the same direction.

So, the current through the inductor will keep flowing in this direction, so it will go here now this switch is off, so therefore, you previously it was flowing, previously if you have noticed it was flowing through this path, but now it cannot flow through this path. So, therefore, it has to, so what will happen is that because of the inductor will generate enough potential such that this diode will become forward biased and the current will start flowing in this path and similarly the current it cannot come through this path, now because this switch is open.

So, therefore, it will to start flowing through this diodes, see that, it cannot flow through the switch because this switch is unidirectional, so in this switch current cannot passed through. So therefore, even if the switch is on the current will flow through the diode and now to be able to sustain this inverse voltage and sustain the current now the di by dt is it has to have a very large di by dt, so the current is falling very sharply. Now, at one point of time when the current falls sharply then what will happen is that this current will actually fall to zero.

Now, after the current falls to zero then what will happen is that you see still this is negative, this is negative, so after the current start following to zero this VA minus ea, ea we can assume that at the, as for as the switching frequency is concerned. Since the motor cannot accelerate or decelerate, so fast, so we can assume that at that switching frequency is if you consider one cycle of switching then the speed of the motor remains unchanged.

So, therefore, the ea polarity is going to stay same, so ea is the neither will the speed for appreciably over one cycle it will fall a little bit. So, we can assume that that this back emf is also a constant voltage source, it remains un change in polarity and in magnitude. So, now once this armature, once this armature inductance source has die down because a current has reached zero, now this VA minus ea will take over. So, this VA minus ea would now the current will reverse, so now the current will start flowing through this switch.

So, we can use, we can use this one, so now the current will reverse and it will start flowing through this or rather no it will actually start flowing through this path. And the current will reverse and it will sorry it cannot it will flow through this path. Similarly, exactly the similar thing will happen again when V triangular T will become less than V control, at that time again this will off be off and these two will become on and then again for sometime the inductor will try to maintain the current in this direction.

So, now the currents will the switches will be on, so the voltage will terminal voltage will again be positive, but the currents will continue to flow through the other branch that is the current will continue to flow, it will start flowing through this now. So, in that mode again the current will start flowing through this it will still following the old path, but it will now flow through this and will flow through this path, even if the switch is on.

So, these are the situations that occur continuously at that 10 kilo hertz or 20 kilo hertz frequency, so now we are once, we have understood that such a see that there are situations where voltage is positive, but current has not reversed because of the inductor magnetic energy. If we watch it after some then current will also reversed, so we have V negative, I negative. Similarly, we have the other situation, so the it is for this reason that we said that all kind of combinations are found and what will be the average effect of all these combinations entirely will depend on the pulse width.

So, for how long which combination stays, we are going to have the net torque, the net voltage and the net current, so everything will have to be averaged over long time to get the effect. So, now we go back to our waveforms, you have already seen these, so now we come to the waveforms.

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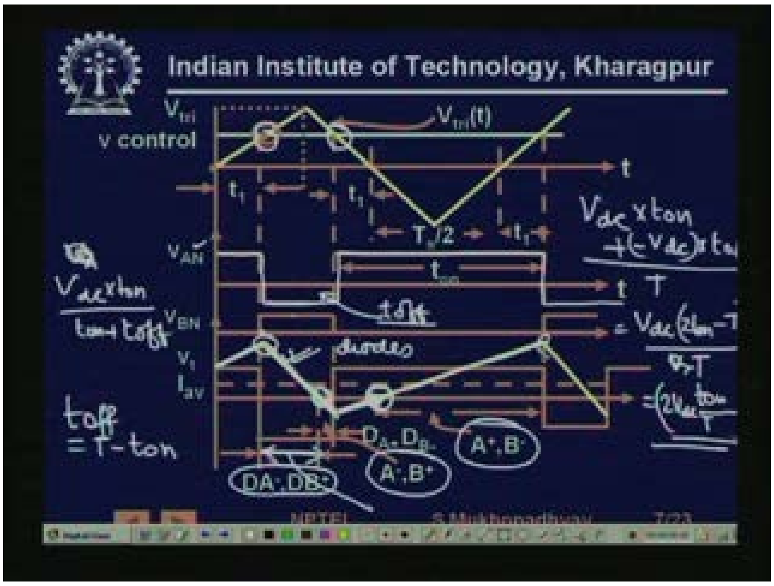

So, this is what is happening, so the movement V control is as long as V control is less than V is control is greater than V triangular, we have A plus and B minus on. So therefore, voltages VAN is positive and VBN is zero, B is at the neutral voltage. Similarly, the movement it crosses this VAN goes to zero and VBN goes to positive, so if you see, if you want to draw the terminal voltage then it will look like, so initially it will be VAN minus VBN, so it will be positive VBN.

So, VAB if you want to plot VAB then VAB will go negative here, because there is VAN is zero and VBN is positive, so VAN minus VBN is going to be negative. So, now this white mark that I am drawing, so the terminal voltage VAB across the motor is going to be like this white mark. So, you see that what is the what is now the average terminal voltage VAB; obviously, it is VAN minus VBN is V which is the Vdc. So, it is going to be Vdc, average is going to be Vdc into t on divided by, so basically t on by t on plus t off.

If I call this as t on and this as t of, so it is going to be Vdc into t on by t on plus t off, no now t off is equal T minus t on, so it is going to be Vdc into t on plus minus Vdc into t off divided by T, so it is going to be Vdc t off is T minus t on. So therefore, into two t on minus t by T. So, it is 2 Vdc into t on by T minus 1 this is the voltage expression, average voltage right, so what happens is if t on is t on by t is half then we have exactly zero voltage, if t on by t is one then we have a positive Vdc voltage, if t one by t is zero, then if then we have negative Vdc voltage, so this is the picture.

Now, what happens to the current, so look at this that, so the current was increasing during this time because of the fact that Ldi by dt there was there was some net voltage which is applied voltage is positive, opposing back emf is ea. So, VA minus ea is the net voltage, which is which is being draft across ra and ia, so if, so whatever is left is being consumed in the Ldi by dt, so the current keeps increasing. So, the current keeps increasing at this point of time, suddenly the switch is off, at this point of time.

So, immediately what is going to happening is now the inductor is trying to drive the current in the same direction, so the current is still in the same direction, it is still positive, but it is rapidly coming down, because the inductor is trying to a large Ldi by dt is being created. So, di by dt is very sharply falling and it is overcoming the applied voltage and the and the back emf, so it will sharply falling at this point of time it has crossed 0.

So, during this time the diodes are conduction, so during this time DA minus and DB plus are conducting, during this time, during this time, this time. After that for some time here A minus and B plus are conductor because current has become negative and after that they are again being switched off. So, the moment they are switched off now the current from negative it is coming, it is now rising, it is now rising.

And you see that the two rates of fall and rise are actually different why, because of the fact that that in one case the di by dt has to be so large in the during this time the applied voltage and di by dt are actually of the same polarity. So, there has to be a such a large di by dt then it can overcome that while in during this time, the applied voltage and the di by dt are not of the same polarity. And then the current is at this point of time, now the current is I mean, here they are aiding and here they are opposing actually.

There of different they are aiding during this phase, so a large voltage has to be current has to be driven against a large voltage therefore, di by dt is falling sharply, on the other hand here di by dt rises slower. So, the current rises at this point of time again from here the MOSFET or IGBT whatever switches you have or thirstier they will take over and from here these thirstier conduct on the current again rises. So, this is the way that the current changes.

So, what is now again you have to find, if you want to find the torque, you have find the average armature current and you can easily find out from that this is the zero line, so you can easily find out that the average armature current is actually positive. So, you are going to have a positive torque, that is because of the fact that A plus and B minus are actually on for a large larger duration, so current is positive.

If you had made A minus and B plus on for a larger duration that is if you have change the pulse width t on by t off if you are played with you would have got a negative current. So, here the current can be reversed and the voltage can be reversed and that is why you get a four quadrant control. So, this is the way these drives operate and remember that these current switching's are actually occurring at, there are some other modes of the circuit, which we have not discovered like a which we are not discussed.

Like, we have you know, current controls switching which we are not considering even within one mode, but even then the switching's are occurring at very fast frequencies and therefore, the current ripples are really high frequency ripples. And therefore, they do not have impacts on the motor, dynamic that is the motor motion, so therefore, the torque ripples are much less, so this is the way, that what is the matter.

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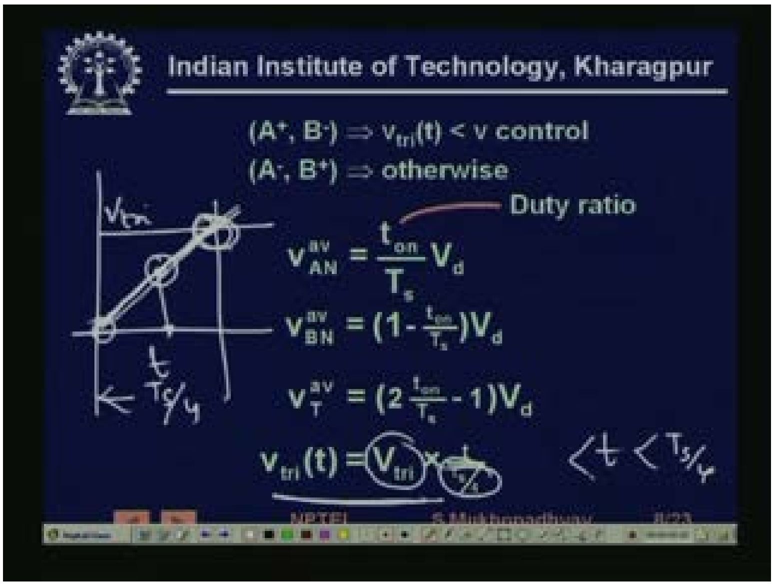

So, now there is also another interesting thing that we want to mention that is the it turns out that is the armature voltage is actually proportional to the control voltage that is very interesting. So, we as we have said that V average AN is t on by Ts into Vd, Vd is the DC voltage, similarly V average BN is t off by Ts into Vd, so t off is 1 minus t on rather T minus t on, so you get this one.

So, Vav the V average across the terminal is 2 t on to by Ts minus 1 into Vd that is we have to derived just and now let us what is the triangular volt wave, a triangular wave, let say the any first part is nothing, but. So, there is a suppose the pick value is V triangular this is Vtri, so what is the time domain, what is the time function. So, the time function up to this it is a triangular wave, so it has four legs, so we have to describe them by four different time functions.

So, during this straight did the time function is Vtri, this Vtri into at any point of time t and this is Ts by four, so it rises from zero to Vtri in time Ts by four. So, therefore, this is the time function for the triangular wave during the period. t less than Ts by four greater than 0 during this time this is the time function, so I do not know why it is getting locked, now suppose will be will see this.

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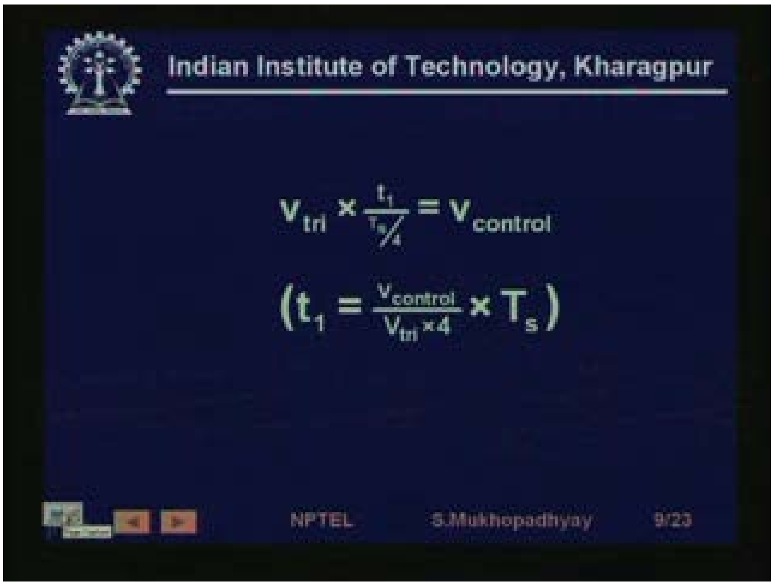

So, suppose a time t 1 the triangular wave becomes equal to V control, so therefore, this equation will hold and therefore, this time once you are given V control and we are given

V triangular then this t 1 can be solved from it, it is like this. Now, what will happened at if the if this is t 1.

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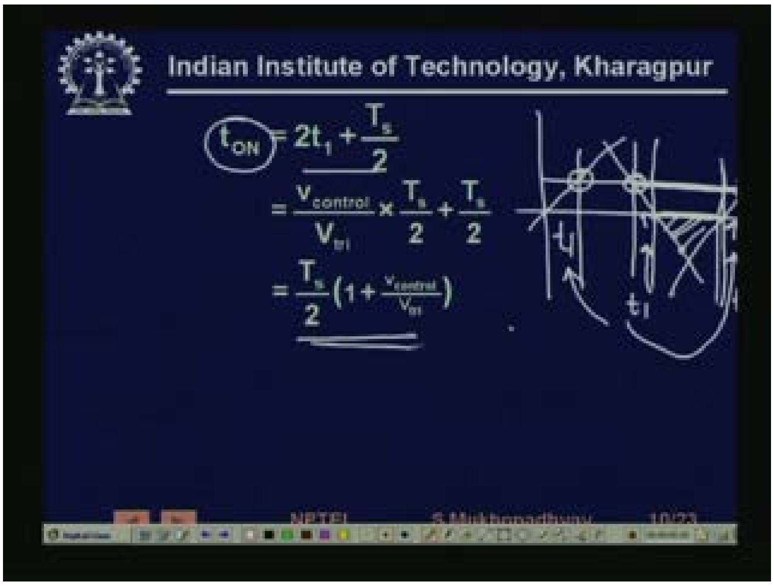

So, now what is t on, you can actually, if you actually see So, this is t 1 and this is t 1, this is also t 1, this is also t 1, so what is the time during which so the time during which this stays on see this t on is, this is t 1 this is Ts by 2 half of the triangular wave. So, this is Ts by 2 plus t 1 plus t 1 this is the duration. So, the switching occur here, here and here again, so it is 2 t 1 plus Ts by 2 and we know what is t 1 is. So, we put just substitute t 1, so we get this is t on, so if this is t on then what is t off.

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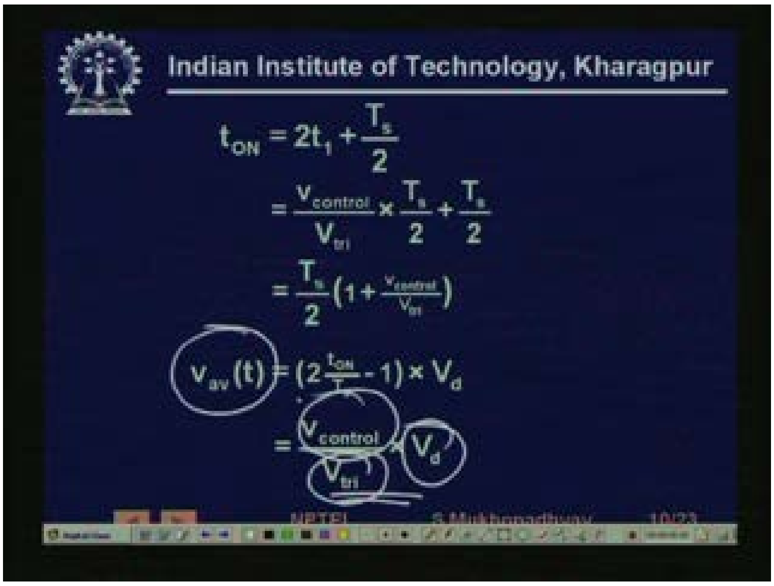

So, now V average t, we know what is the average t, so we just substitute this value of t on, so t on which I substitute, if you substitute we will get this expression. So, you see the in that V triangular is a constant, it is a design constant you have chosen, Vd is a constant it is a DC source. So, this is that V average t which you apply across the motor is simply, the simply proportional to V control, so just by switching up and on and off this DC voltage, you can apply a proportional average voltage to the armature, which can turn positive and negative, so it is that is why the circuit is, so popular.

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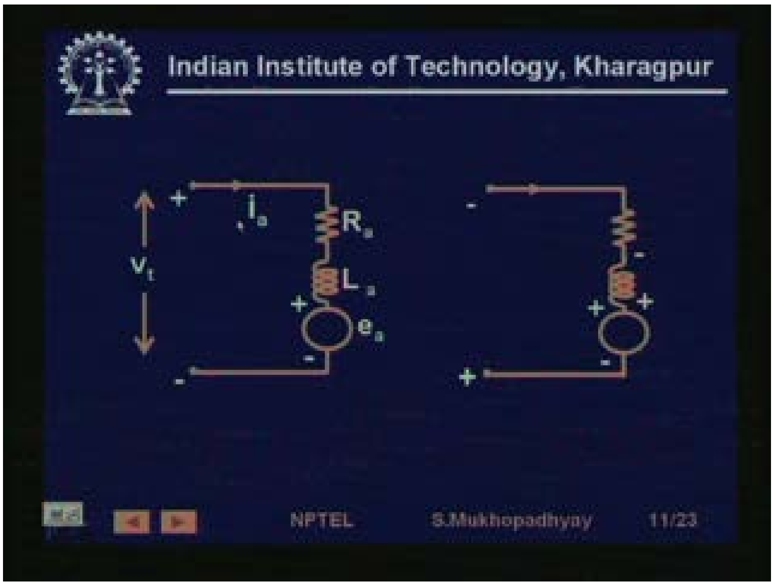

So, having said that, so this is the diagram that you are seeing that if current reverses what will happens, so we have already explain that and these are the equations.

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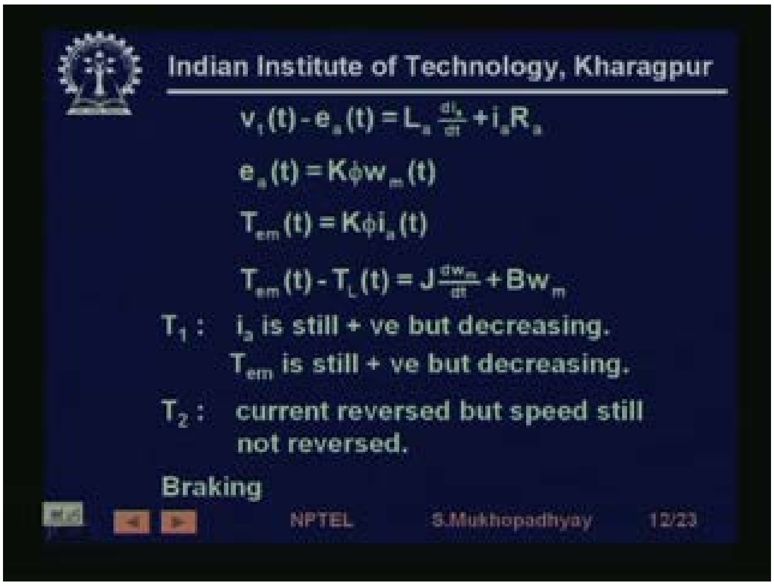

So, ea is K phi omega m, torque is K phi into ia and finally, speed will be given by solving this differential equation J d omega m, these are the equations of the motor standard separately excited motor equation, fluxes assume constant and unchanged with the variation of armature current. So, the equations are, so simple. So, there are situations, when ia is still positive, but decreasing then it is still accelerating ia is positive means, it to torque is still positive right and depends on the net torque can be negative also. Similarly, if current is reverse, but speed is still not reverse then we are having for the temporary duration we are having deceleration.

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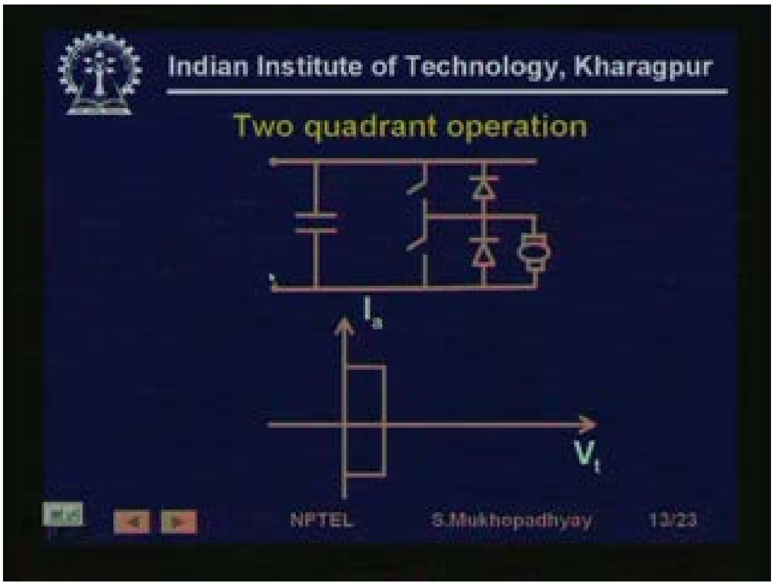

Now, this is the basic four quadrant operation, now we look at simpler versions of this for example, we look at two quadrant operation, If we have two quadrant operation then we have only this circuit. So, you see that we are only using one arm, the previous circuit that we have seen this is the DC source, we are using only one arm and we are correcting the motor across this across this arm, the other arm is fixed to the ground, so then what happens is that, now with this circuit.

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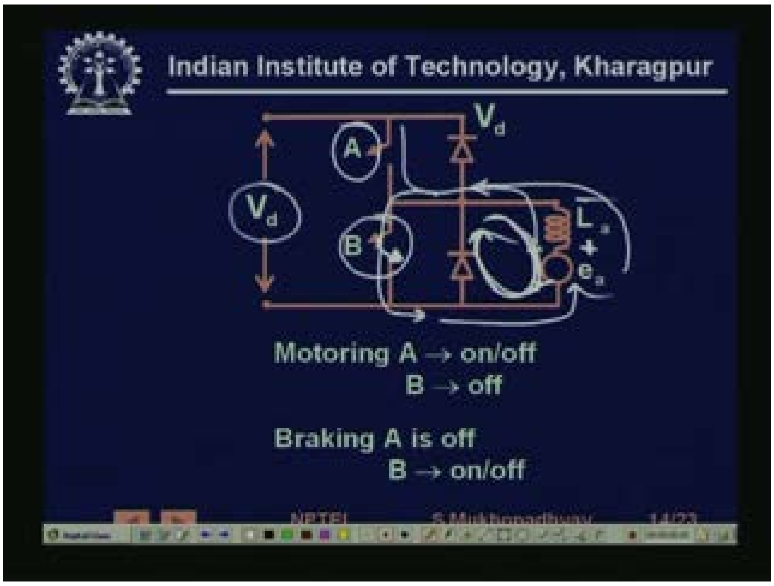

If you want to do motoring, so we do A on off and B off, so B is off all the time, so when A is on the current passes through this, so terminal voltage is positive and current is positive, so motor is, so it is, it will be motoring. If we if we put A off when what will happen is that the current will still circulate through this for some time, so we can control the, it will be falling because now the Ldi by dt will change terminal and it will start driving the current in the same direction against the armature back emf.

So, the current will be falling, but it will be still be in the same direction, so by, so by controlling this how long you are keeping it on and how long keeping it off, this current can be make fall and so the average value of the current can be controlled. Similarly, when you want to have breaking then A is on A is off and B is on or off, so when you have B as on, so then what will happen is that when you want to have breaking then A is off and B is on or off.

So, if B is off and A is off, then it is still circulating, but the movement this is off actually this then what will happen is that, so when B is on. So, after sometime what will happen is that this current when B is on then what will happen is that for some time the armature inductance will drive against ea and the current will start falling, but it will still fall in this direction.

After that when the current comes to zero at that time or the when the, when the current becomes when this current comes to zero, then this Ldi by dt effect will be not there and then the motor emf will start driving current through this path. So, then the motor emf will be driving current through this path and it may drive current through this path or depends on this voltage.

So, what will happen is that the motor electromechanical energy will get spent, because this is basically this voltage source is generated by them by the motion of the motor, so the, so the motor will start slowing down. So, therefore, it will be breaking, so you see that, so you can see that it will you can still do motoring and breaking in one direction right, but you will not be able to change the direction of rotation of the motor and therefore, it is a two quadrant control. So, in one direction, you can do motoring and breaking, on the other hand if you still simplified the circuit, you could have a single quadrant operation.

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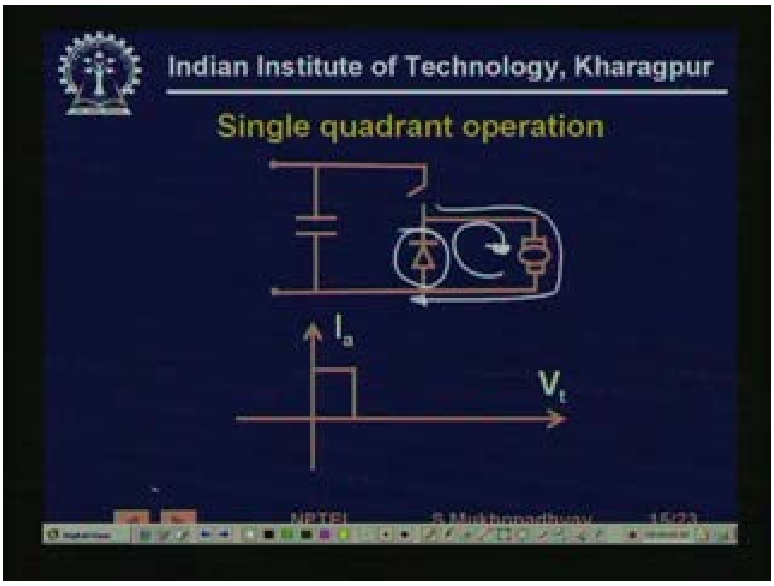

So, for example, this is a very simple one, in which you cannot even break so you can only, if you switch it on then the current will be flowing in this direction, if you switch it off. Then there is no way that this there is, so if you switch if off then it will current will circulate, but still current will be in the same direction. Current cannot reverse in this case because you have not provided that switch, so therefore, since this is the unidirectional switch therefore current cannot reverse, so current can only be positive and therefore, voltage can also be only positive.

So, you have a single quadrant control, so these are you know simpler versions of these converters, so now we will quickly see, we have seen single quadrant operation and two quadrant operation. So, now, will see another we will see the extension to what are known as brushless DC motor, which are actually which have permanent magnet rotors.

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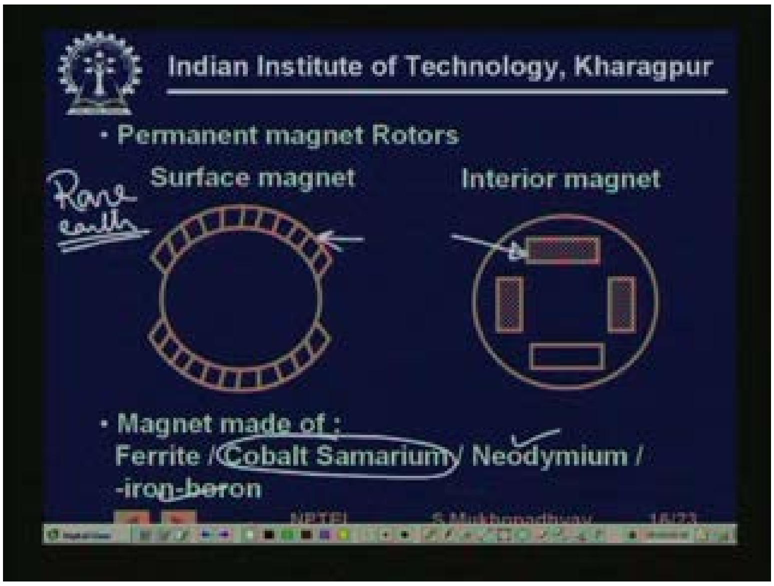

So now the armature is now, so now the field has come to the rotor the DC field, see why brushes were required because you wanted to feed armature current into the rotating. Whenever you have a, you want the feed current into a rotating body you have must have either a brush or a slip ring kind of arrangement, which is difficult to maintain, so therefore, what we do is we change the places where we want to give supply.

So, what we do is, we now create the field in the rotor, so we have permanent magnet rotors and this will become highly popular after there are some materials have been discovered, which can create which in a very, which can have very high, very high magnetic intensities can be created by these magnets. So, you know, so previously people use to use want, so there not iron, they are actually made of some special kinds of material called rare earth in the periodic table you have some rare earth elements.

And these are made of these rare earth magnets are made of this rare earth and they for example, a typical one is cobalt samarium and sometimes you have, there is another version which is neodymium iron boron. So, these magnets can create fields, which are order of magnitude larger than what can produce with different grades of iron. So now you have you fix this magnets on the rotor either as a surface magnet or which is on the rotor or you sometimes when you have very high speed motors, then these magnets fixing the magnets become very difficult and they tend to you know fly away.

So, therefore, sometime you have interior magnet designs, where the magnet is inside the rotor body, so now imagine that these magnets now you have a rotating field as the rotor rule rotate, you have a rotating field in the rotor. You will probably notice, later on we are going to do this, that is why there sometimes, it is sometimes said they are like synchronous motors because in the synchronous motors like what we have all these power generators that are used in the generating stations, we have we apply DC field in the rotor.

So, since we are also doing that using permanent magnet, so they are sometimes called you know there, it is said that they are really synchronous machines. So, now what is the problem, so now the problem is different the problem is if you want to generate good torque then the field in the rotor and the field in the stator must be perpendicular. Then they will generate good torque and if you want to have a simple control strategy then they should stay perpendicular all the time and the DC motor there this brush commutate arrangement, the fields are fixed in space. So, the rotating field of the rotor in the DC motor by the brush commutate arrangement is kept fixed in space and here just a reverse happens, here what we do is here we have, we do not use a brush.

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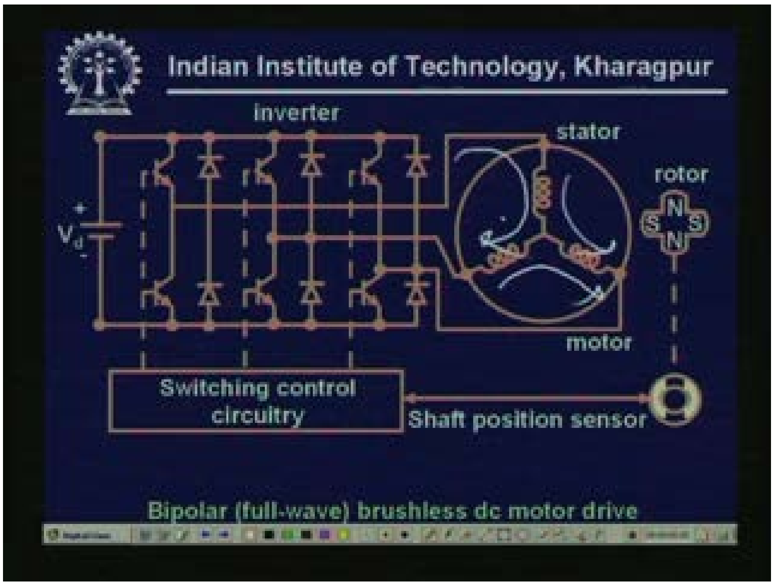

So, when we do not use a brush, our field in the rotor is rotating, so what we do is by complex electronic switching and by sensing the rotor position, we also keep rotating the stator field. So, now both are rotating previously in the DC motor the stator the field was both the fields were fixed in space, they were not moving even if the rotor was moving. Now, the both the fields are rotating, but by cleverly rotating the stator field, I am always maintaining that perpendicularity.

So, while they are rotating they are always remaining perpendicular and therefore, that that basic property of the DC motor is being satisfied. So, this is essentially what are then why they are called brush less DC machines, so seen this diagram, we have this rotor which is rotating and there is a sensor which is sensors the rotor position and we have the stators. So, the deduction of the stator fields, now which stator we now you can see that you if you controlling the switching's, we can send current through these two or we can send current through these or we can send current through these two.

So, by controlling the switching as we have seen, we can send current through different combinations of stator fields and therefore we can orient the stator fields in space also. So, as the rotor is rotating if you keep on changing the orientation of the stator field to maintain that perpendicularity then we will get a control like that of a DC motor, so this is the principle. So, you see that the various emf's which are induced in the stator fields.

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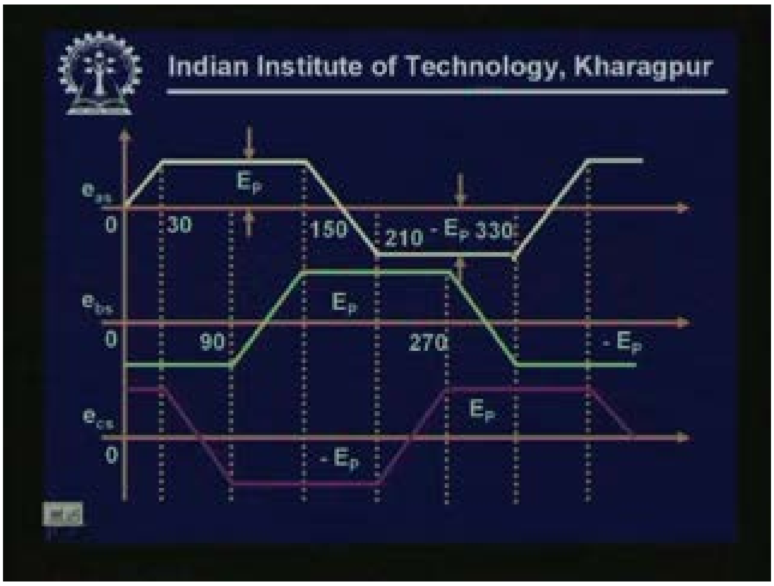

Now, by construction they are very trapezoidally, because the rotor is rotating, so first the emf in one stator winding, there are three stator windings, so there you see that they are 120 degree phase difference apart. So, as the rotor is rotating, first this emf is, so the emfs across are actually varying with rotor angles like this. Now, naturally now if you switch your currents with refers to these emfs then you will get the DC motor like action.

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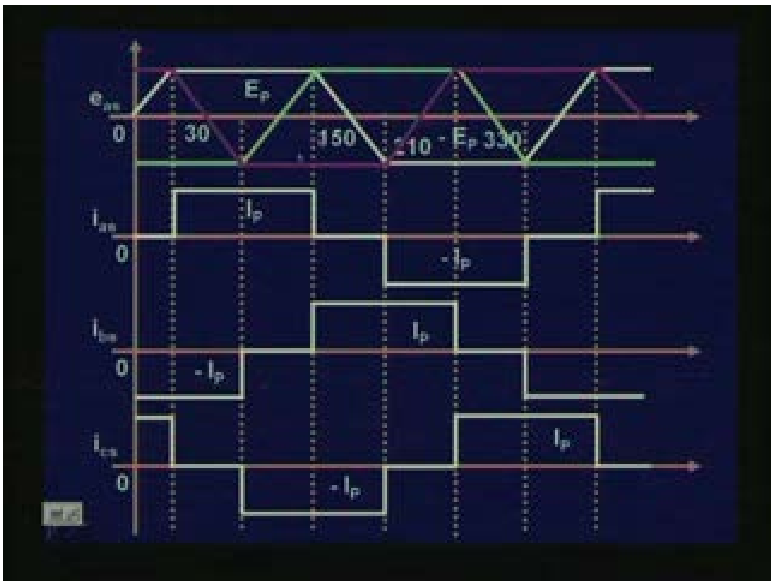

So, you see that the currents are switch for example, when is the a is current switched when the a is emf is full when is the b phase current switched when the b phase emf which is green is switched. So, you see that you are always if you see in the next diagram, so you see that during this is the back emf, this is the current even driving again and look at the other one. So, at any 60 degree interval this is the current entering and this is the current going out this is 0 and so during when a phase is positive. So, positive, positive while this is negative, negative. So, you are always delivering power into two windings, so if you see the next diagram.

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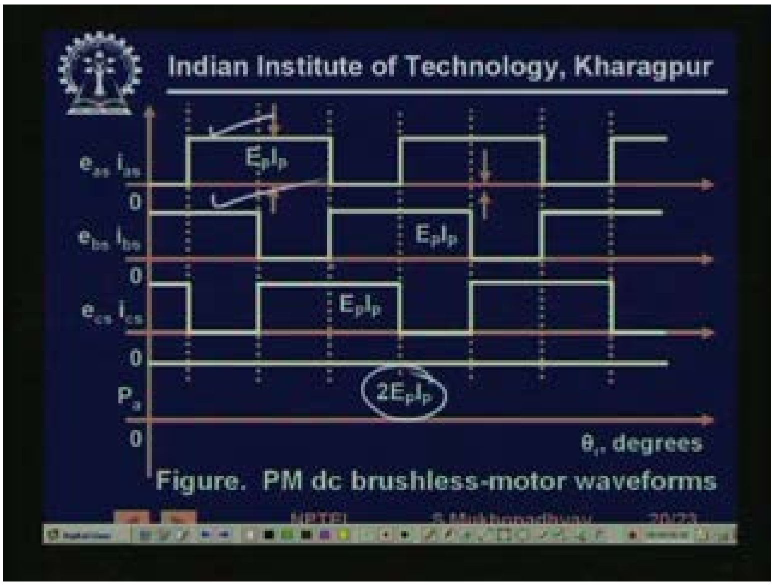

You will find that at any point of time, you are delivering power E into I which remains constant into two windings, so you see take any point of time the total input power is always 2 EPIP. So, here it is the EPIP, EPIP here it is EPIP, EPIP, so your constant power is being delivered, mechanical power is being delivered into the motor and there is no variation in that even if there is switching. So, the motored motion is very smooth, so this is what is happening, this is the way the PM is controlled. So, depending on the rotor position you will have the switch on the corresponding currents and then you will get torque, so this brings us to the end of the lesson.

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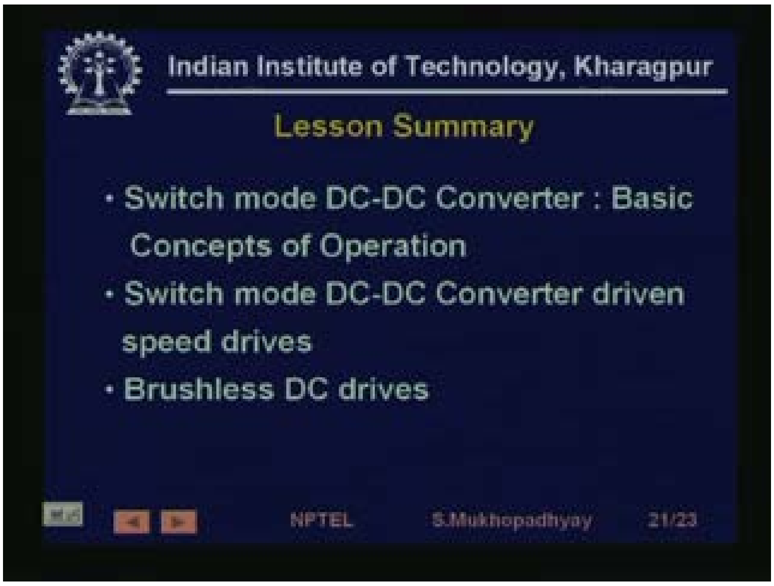

So, what we are seen are basic operations of switch mode converters and we have seen that how they can be used in drives, one quadrant, two quadrant, four quadrant and finally, we had seen the extension of these drives. So, this can how this concept can be easily extended, we have not gone into of course, how the switching are realized and there analysis, but that will be too involved, but we have seen that how even without having a brush, we having a permanent magnet rotor and by reorienting the stator flexes in space.

In synchrony with the rotor motion, we can get a DC motor like operation without brushes, only thing we have to remember that the price that we are going to pay for these are two fold, one is that we are going to have more complex electronics to be able to rotate the stator flux and second is that we are going to require a position sensor. So, our rotor position sensor is necessary for this, there are of there is of course, a lot of research for other things, but as far as we know a position sensor is required. So, that is all and in the next lesson, we will be talking about AC motor drives.

Thank you very much.

Industrial Automation and Control

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Lecture No - 34

Introduction Motor Drives

Welcome to lesson 34 of the course on, Industrial Automation. Today we are mainly going to talk on, not mainly solely going to talk on induction motor drives, so we are going to talk on induction motor drives.

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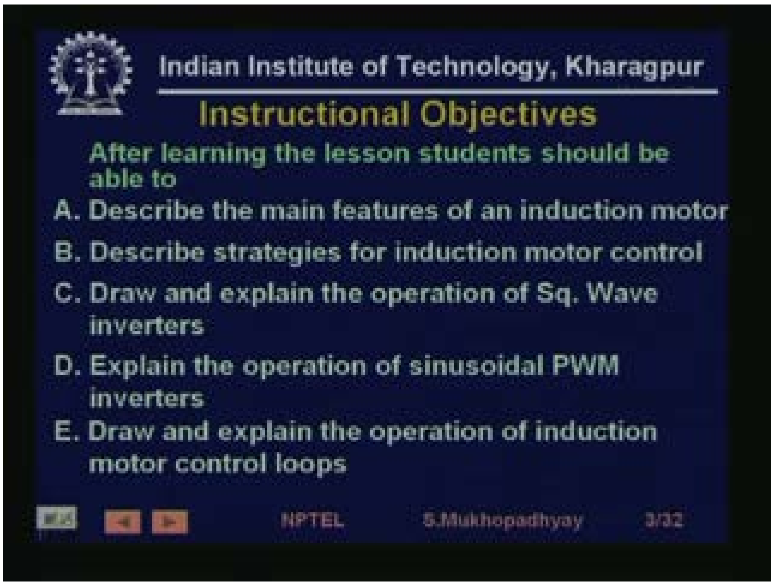

The instructional objectives are the following, first we will briefly see how an induction motor works and we will try to see the principle of operation and the basic equivalent circuit etcetera. So, the student will be able to explain how an induction motor works, then then we will see that if once we know what the induction motor is we will see what are the basic strategies of induction motor control that is how we can speed it up, how we can break it, etcetera.

Having done that, we will see how, we will go to the technology side and see how there are two kinds of induction motor reason AC machine, so it uses inverters. So, we will see actually it can be it can use various other things, but we will look at inverter driven induction motor drives and we will first look at the square wave inverter, which is a simple inverter. And then we will look at the PWM inverters, which are more complicated devices, but have advantages. And finally we will see how an induction motor, what are induction motor control loops looks like.

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So, to this end, first let us see what are the advantages of an induction motor, see these advantages, we are considering against what we are considering visa V, typically visa V DC motors. So, what did we see in the DC motor that DC motors have higher weight, their armature cost waves more, cost more, basically because of the brush commutator arrangement and so the induction motor has lower cost and lower weight.