Advanced Electric Drives
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Lecture - 31

Hello, and welcome to this lecture on advanced electric drives. In the last lecture, we discussing about the hybrid stepper motor, the objective is to get more torque and a small step size. Now in hybrid stepper motor the torque is produced by the combination of variable reluctance torque and the permanent magnet torque. And the cross sectional view of hybrid stepper motor is shown in the following figure. In this case, we have the stator.

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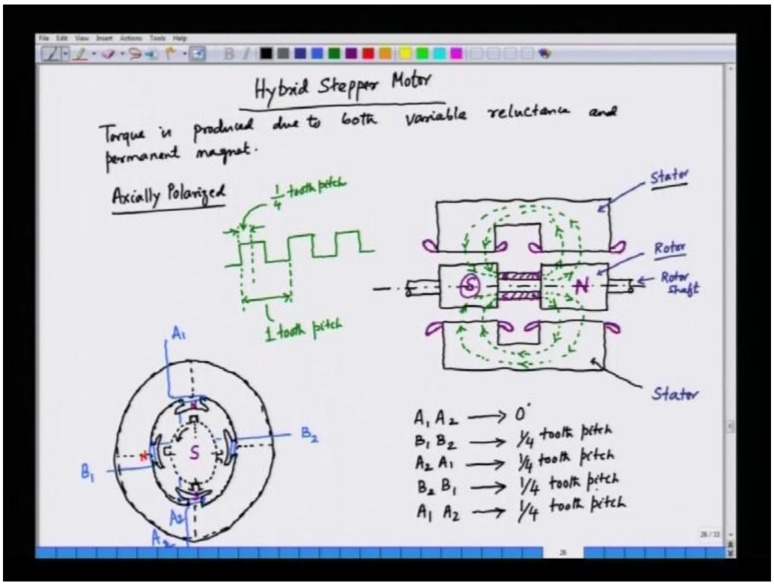

This is the stator section, we have taken a longitude nut section. We have a stator here and the stator has got 2 blocks in this case and these also the stator. So, we have the stator here also. So, this is also the stator and the rotor also has got 2 blocks; One in the left hand side other is the right hand side and we have the shaft this is the rotor shaft and the stator carries winding. In fact, the stator is also having slotted structure, we know that in case of stepper motor there are teeth and slots. The stator has got also teeth and slots the rotor also has got teeth and slots, but the stator carries winding

And in this case the stator carries concentric winding. So, what we have here this basically the winding here. So, if we so, this is the winding, we have this; this is 1 winding. And then we have the winding over hangs here these are the winding over hangs these are also the winding over hangs. And here also we have the winding over hangs in this case and they are call concentric windings. And what we have in case of the rotor; the rotor has got a permanent magnet and it is an axially polarized rotor. So, we can say here this is an axially polarized rotor axially polarized how is it polarized axially? Now, we know that we have 2 blocks of the rotor and if we go on putting permanent magnet across the rotor surface it will be a big task.

So, we do not put timing magnet over the surface of the rotor what we do in state we put bar magnets along the rotor shaft. So, that one side is North Pole, the other side is South Pole. So, what we have done here is this that this is the magnet that we have placed here and this is actually magnet along the shaft of the rotor. So, this side is the South Pole and the right side is a North Pole. And hence we can explore the flux lines, the flux line will come out of the North Pole and enter the South Pole. So, this is the flux lines in this case through the stator yoke. So, this how the flux lines will pass similarly, on the other side we have the flux lines in the South Pole and the North Pole. So, we have the flux lines which is coming out of the axial polarized magnet and here the North Pole is on the right hand side. So, this basically the flux line will come out of the North Pole and will enter the South Pole.

And this enter the South Pole like this similarly, on the other half we have the North Pole the flux lines will be coming out of the North Pole will be like this. So, these are the flux lines and they will be entering the rotor block. And this, how centers as a result, if you see one half of the rotor is a South Pole and other half is a North Pole. Because when the flux is entering the rotor it is the South Pole when the flux is coming out of the rotor it is a North Pole. So, we have not placed a timing magnet across the surface of the rotor we have put the bar magnets. And as a result the entire rotor block in the left side is South Pole and the right side it is North Pole.

We can see here this is the South Pole; we have a South Pole in the left side, because a flux is in entering the rotor. And on the right hand side, we have the North Pole, the flux is coming out of the rotor now, how is the torque produced? Now, let us assume that in this case the stator has got 4 poles is the stator has got a 4 poles we can show the pole structure and. So, the windings and the pole structure is shown as follows. So, we have the pole structures which we can show here that if we show a structure the stator, this is the stator surface in the left side. So, we have 4 poles here. So, this is the rotor. So, 4 pole means we have 4 projections in this case and the projections would be like this. This is 1 pole, second pole the third pole and the fourth pole. So, this is the rotor inner surface as the stator inner surface and this is the stator outer surface.

What about the rotor? The rotor carries slots and the rotor. In fact, carries slots and teeth and the slots and teeth are. So, arranged that sometimes we have slot other times, we have a tooth and so on. And in this particular situation, we can show for example, here we have the structure like this; this is the tooth and this is the slot. We show slot like this and tooth like this and the stator, we have 4 poles and this carry windings and this carry physical concentric windings. And similarly, this is also carries winding and this windings are all connected series connected. So, this is phase A, we can call this to be A 1 and A 2. And similarly, in this case we have the windings here this is B 1 and it is wound like this is B 2.

So, the stator carries concentric winding that we have already shown here and this windings are shown in the following fashion. So, this is A 1 and A 2, B 1 and B 2. And then when we talk about the rotor slots and teeth when we excite phase A 1 and A 2. We can excite in the following sequence we can excite A 1, A 2, B 1, B 2, A 2, A 1 and B 2 B 1. So, in this in this following way we can excite. So, we can excite like this first of all we can excite A 1, A 2 and then B 1, B 2 and then A 2 A 1 and then B 2 B 1 and then it repeats. So, we can starts again with A 1, A 2 when we see the tooth and the slot arrangement we see that this is the phase A is facing a tooth. So, this is a tooth and phase A 2 is facing a slot

And when we excite the particular phase we create a North Pole. In fact, this entire block is actually South Pole. So, we can say that this is the South Pole, the left side of the rotor as we have seen here that the left side is entirely South Pole. So, we are in fact, floating the cross section of the left side of the rotor. So, the left side is entirely South Pole. So, we have shown in the South Pole and in the South Pole when we excite phase A 1 and A 2 we create a North Pole under A 1. So, what we have here is that we have North Pole here and then we have a South Pole here when we excite A 1 A 2 we create North Pole under A 1 and South Pole under A 2. And A 1 is facing a tooth and A 2 is facing a slot what about B 1 and B 2, B 1 is neither facing tooth nor facing a slot. So, we have a situation like this that in this case the tooth is here and the slot in this case is like this. So, if we see the phase B 1 and B 2, B 1 is neither facing a slot nor facing a tooth and B 2 is also neither facing a slot nor facing tooth.

Now, right now when we change from A 1, A 2 to B 1 B 2 what happens earlier A 1 was North Pole. And now when we shift from A 1 A 2 to B 1 B 2 B 1 the phase under B 1 will become a North Pole. So, when B 1 becomes a North Pole, the rotor will try to move and try to move by what angle such that the B 1 phase we will see a tooth. So, in this case, we can see here when it moves towards the, I mean in the in anticlockwise direction like this when we excite B 1 and B 2 we will have a North Pole here. So, if we have a North Pole here this North Pole will attract the South Pole tooth. So, this will be moving in the anticlockwise direction and finally, this tooth will be coming fully under B 1. And hence the movement of the rotor will be by 1 quarter of tooth pitch by tooth pitch we mean; we have. In fact, we have tooth like this and the slot like this basically these are the tooth and slot structure we have so many teeth and so many slots.

So, when we excite phase B 1 B 2 the movement will be by 1 quarter of the tooth pitch. So, this is basically 1 quarter of tooth pitch. What is the tooth pitch? The tooth pitch will have 1 full tooth or 1 full slot. So, this is 1 tooth pitch; this is 1 tooth pitch, 1 tooth pitch is made of 1 full tooth and 1 full slot and when the movement is by 1 quarter this is 1 quarter of tooth pitch. So, this is how the rotor will move and when it moves in the anticlockwise direction when we excite phase B 1 B 2 a tooth will be under phase B 1. And then after that will be exciting A 2 1 A 1, because we have to go in a sequence we are started with A 1 A 2 then B 1 B 2 then we have to again go back to A 2 A 1. So that A 2 will become a North Pole and A 1 will be become a South Pole now, North Pole will always attract a South Pole tooth.

So, if we excite A 2 A 1 after B 1 B 2 will be exciting A 2 A 1 what happens it means when we excite A 2 A 1 this is A 2 and this is A 1. So, we have A 2 phases here A 1 is here when we excite A 2 A 1, this is already move by 1 quarter so. In fact, A 2 is now phasing when B 1 is excited A 2 is basically facing neither tooth nor a slot. It is have the age of the tooth again when we excite A 2 A 1 the tooth will come in and again the movement will by 1 quarter of tooth pitch.

So, here the step size is basically 1 quarter of tooth pitch. So, when we excite say for example, when we started with A 1 A 2 the angle was 0 when we have excited B 1 B 2 it moves by 1 quarter tooth pitch. And then we have excited A 2 A 1 it further moves in anticlockwise direction by 1 quarter. So, 1 quarter of tooth pitch and then we again excite B 2 B 1 it moves by 1 quarter of tooth pitch. And then again by A 2 A 1 it completes 1 quarter of tooth pitch. So, here what is the step size? The step size is in fact, 1 quarter of tooth pitch say for example, in the rotor we have let us say 60 teeth. So, if we have a 60 teeth in the rotor, what is the step size? 360 by 60 by 4. So, say for example, e can take an example here.

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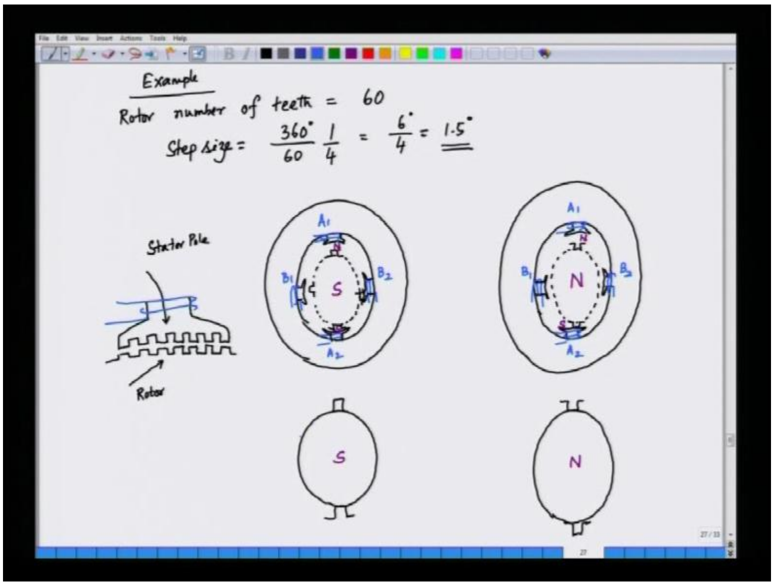

Rotor number of teeth is equal to let say we can say this is sixty. So, is 60 is the number of teeth in the rotor what is the step size the step size will be basically 1 fourth of the tooth pitch and tooth pitch here 1 revolution is 360 degree. So, 360 by 60 is 6 degrees and 1 fourth of that is 1.5 degrees. So, step size here is 360 is the complete revolution 1 circle by 60 is the number of teeth in the rotor. This is the tooth pitch 1 upon 4 is the quarter of the tooth pitch. And that is equal to 6 degrees by 4 and that is equal to 1.5 degrees. Now, it so interesting that without increasing the number of poles, we have only 4 pole in the stator.

We are not entering the number of poles in the stator; we have only 2 phases A 1 phase A and phase B, A 1 A 2 and B 1 B 2. But what we have done? We have placed a magnet in such a way that 1 half of the south rotor is the South Pole and other half is the North Pole. And by doing that and by increasing the number of teeth and slot we are able to have a reduce step size. In fact, the step size can be further be reduced if we increase the number of teeth. So, here we have the step size is equal to 1.5 degrees. Now, we have seen actually 1 half of the rotor, what happen what happens to the other half?

So, we have 2 side, 1 side is in the left hand side and other side is the right hand side. So, in fact, what we can see here that if we see the structure of the stator and structure the stator here they are something very similar. What about the rotor structure? This is the rotor and here also we have the rotor and we have 4 poles here 1 pole, the second pole; the third pole and the fourth pole. And similarly, here also we have 4 pole structure 1 2 and 3 and 4 and this will carry windings. These all will be carries windings here this also will be carrying the windings.

So, in this case, how does these 2 place with a respect to each other. Now, we have a left side and we have right side, because we understand that in this case the rotor has got 2 blocks. The left block is the entirely South Pole and the right block is entirely North Pole and the stators are also connected like this. The stators will be excited in a similar fashion in face when we say A 1 A 2 all the stators are excited at the same time. And when we say B 1 and B 2 the stators the left side and the right side are excited at the same time. So, this stator is A 1 this is A 2; this is also A 1 and this is A 2 have been similar windings we have B 1 here and B 2 here; this is also B 1 and this is also B 2.

The difference comes in the rotor, the rotor left side is entirely South Pole. So, what we have here is that this is entirely south block and then the right side rotor is North Pole this block is entirely North Pole. So, this is call a homo polar structure, it means the whole of the rotor in the left side is South Pole. The whole of the rotor in the right side is the North Pole now when we excite A 1 A 2 and North Pole is created under the stator also. So, the stator is North Pole here now, this is the North Pole in this case when we excite A 1 this becomes a North Pole. This also becomes a North Pole and A 2 becomes a South Pole this also becomes a South Pole.

Now, when we talk about the rotor teeth, the rotor teeth in the left side here we have teeth we have a tooth here and we have slot here. And this is neither facing a tooth nor facing a slot something like this, what about the right side? Right side again this is a north block. So, this should be a slot and this should be a tooth. So, if we see the right side rotor block and the left side rotor block. And try to compare this, the tooth and slot structure they will be of set of each other. In fact, the slot of the left side is align along a tooth of the right side. The teeth pitch of the left side and the right side at the same, but they of set by half a tooth pitch.

It means the slot of the left side is coinciding with the right of the right side tooth of the right side. So in fact, there of set by half a tooth pitch. So, if we are to show the entire structure like this rotor structure. If this is a tooth and this is a slot like this in the left side in the right side, what we have is the following right side, we will have the structure here we have a exactly a slot here and we have a tooth here. So, it means at tooth is matching with a slot of the right side the slot of the left side is exactly coinciding with tooth of the right side. And this is entirely a South Pole block this is entirely a North Pole block. So, if we see the right side once again we see the when we excite phase A and A 2 North Pole is under A 1 and South Pole is under A 2. So, the tooth of this is attracted by the south post object here.

So, that also is conducive for the torque production. So, in this case the 2 blocks are of set by half a tooth pitch. Now, this is how we have the combination of both permanent magnet torque also the variable reluctance torque. Now, to further enhance the torque the stator structure, we have shown in terms of very smooth poles the stator structure. Although we have only 4 poles here the poles sooz are corrugated pole sooz are not smooth as we have shown here they are also corrugated to match with the corrugation of the rotor. So in fact, if we draw the structure of the stator pole, it will be something of this slot. We can drawn a stator pole structure, it is having slot and tooth here we have tooth and slot again tooth and slot tooth and slot tooth and slot tooth and slot like this. And this is how a pole looks like and these are so planned that the rotor will be exactly under this we are drawing the rotor structure.

And hence there is a perfect locking this is the rotor surface and here we have the stator pole. And we have the windings in this case the stators actually carry the winding. But the stator pole is not a smooth pole is basically corrugated having slots and teeth in such a way that a tooth of the rotor is facing the tooth of the stator. And slot is facing the slot and hence they perfect locking. And thus we can have a high detent torque not only that when we excite the stator, the torque production is basically due to the permanent magnet torque also due to the variable reluctance torque. And hence we call this to be hybrid model, hybrid stepper motor, the hybrid stepper motors are very popular, because of low stepping size step size is very very low. Also the torque is also enhance one drawback of variable reluctance stepper motor is that there is no detent torque by detent torque. We mean when we excite the stator there is torque production there is a locking mechanism.

But when we do not excite the torque is 0 and this torque is 0 for a variable reluctance type of stepper motor, but this torque is not 0 for hybrid stepper motor. In hybrid stepper motor, the torque is still present, because for the permanent magnet in the rotor. And hence we have a detent torque Now, these are various types of stepper motor we have studied. Primarily there are 3 types of stepper motor to summarize, we have variable reluctance types stepper motor. We can increase the step size by increasing the number of stuck; we can have the single stuck or a multi stuck motor. Then we can also have a permanent magnet stepper motor where we have the torque produce only by the permanent magnet. And finally, we have hybrid stepper motor where the torque is produce by the combination of permanent magnet and variable reluctance type of torque.

Now, having discuss about the structure and the type of stepper motor, we will discuss about the behavior of stepper motor. Now, let us have a look at the stepping rate now the stepping rate we define as the number of steps for second. So, that is the definition of stepping rate and if we increase the stepping rate the speed increases. And beyond certain stepping rate the stepper motor does not stay in synchronism stepper motor is a very beautiful motor for position control. We do not have to have any position feedback what we give here is the few falsies and the rotor faith fully obese this falses.

And hence the position control is achieve without any close loop feedback. Stepper motor control is primarily full of control and hence it is much more attractive compare to a servo motor. The servo motor we have to have a close loop position feedback, in stepper motor we do not to have a position feedback we apply the false and the rotor follows the number of steps. But if the stepping rate is increased the motor false out of synchronism, it does not faithfully obese the stepping common. And we have to confine the operation within a exceptive stepping rate. And that is how we can determine the operating range of the motor.

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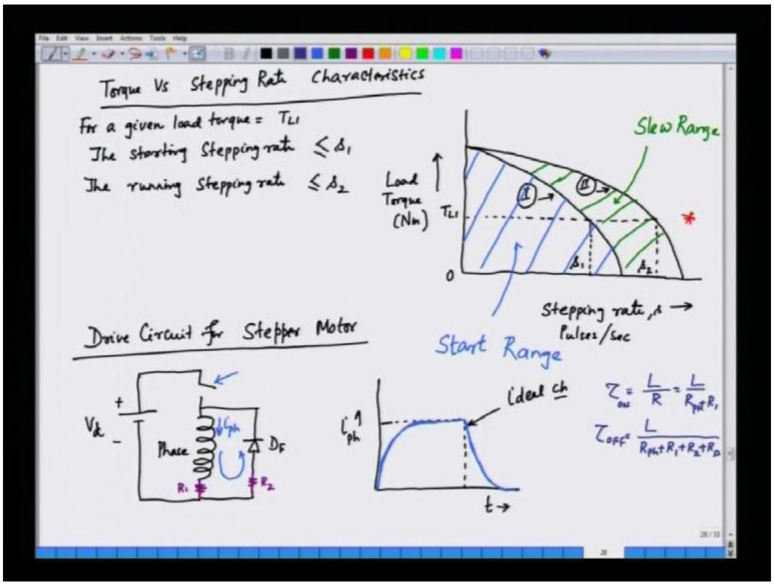

Now, we can draw a graph which will give us the load torque versus the stepping rate in second. So, this is false for second and the load torque could be a Newton meter. And we have 2 types of characteristic, this is basically what you trying to draw here is torque versus stepping rate characteristic. And here what we have here is that we can A 2 types of graphs here 1 is like this other is like this. So, this is the origin we have and suppose we apply a load torque and the load torque here is T L 1. Now, the first curve we can we can show this by 1 and this is the second curve we can show this by 2. So, this is the first curve and this is the second curve. So, we have 2 curves here, curve 1 and curve 2. And if we have a load torque and the load torque is let us say T L 1. We will have 2 stepping rate corresponding to 1 and corresponding to 2 what does it mean? Here we have 2 stepping rates here this will give us S 1 and this will give us S 2.

Now, this S 1 is the stepping rate for which the motor should be starting when the motor under time still condition. We can maximum give a given a stepping rate that is equal to S 1 to start the motor and once the motor starts even increase the stepping rate to S 2. So, the starting stepping rate should be below S 1 and 1. The motor starts up you can increase the stepping rate S 2 and hence we can call this graph 1 to with the start graph or the starting graph and the graph 2 should be the running. So, we can say that the starting stepping rate starting stepping rate should be less or equal to S 1, the running stepping rate should be less or equal to S 2.

So, this is for a load torque for a given load torque for a given load torque what is the load torque here? Load torque is T L 1. So, for a given load torque T L 1 to start the motor, the stepping rate should be less than S 1. What happens you apply more than S 1 say for example S 1 is 3000 pulses for second. If I apply 3 50 pulses per second what happens? The motor will not respond; motor will refuse the start. So, for starting of the motor, the stepping rate should be less than S 1, the motor under tranvil condition it is having some inertia. So, to start the motor the stepping rate should be low 1 and when the motor starts you can apply highest stepping rate that is up to S 2.

So, we can call this to be this to be the slew range. So, this green colored region, we can call this to the slew range. And the region which is left of one which we can show by let us say this blue graph this is call the start range. It means if you want to start the motor the stepping rate should be the start range. So, after the motor successfully started you can increase the stepping rate to the slew range. And it is should be under no situation should be on the right side of second characteristic. If we beyond this suppose we have we have stepping rate which is here and for this stepping rate motor false out of synchronizing.

Motor does not stay in step and the position control is lost. So, we have to very very careful that for starting the motor the stepping rate should be in the start range. And in the motor runs we can operate the stepping rate can be increase to the slow range. So, this is how the stepping rate is determine for a giving load torque Now, when we have a stepper motor drive stepper motor, we need a we require a dry for that we have to want a convertor which can inject current into the various windings.

So, we can have a simple structure in which we can inject the current on to the various phases unless we excite the various phases motor will not start. So, we have to have a converter to inject the current on to the windings of various phases. So, that the motor starts and hence we can have a variety of a convertors which can be used with a stepper motor. So, let us see one type of convertor. So, we will have the drive circuit for stepper motor a very simple drive circuit. What we can have here is the following we have we have DC supply. And then we have switch and then we have the phase of stepper motor the winding of course, we have to have a free bottom diode. So, this is the voltage that we have V d and we have the phase. And we can have the current in the phase there is a i phase and this is the freewheeling diode we have there is D F.

So, this is the simple circuit for a stepper motor drive, we have a DC voltage; we have switch here we have the winding and then we have freewheeling diode. Now, what is our ideal characteristic when we excite a stepper motor the current should rise very sharply and reach the maximum value? Because current determine the flux determine the M M F hence the current should be essentially a rectangular current. So, what we have here is the following that this is the ideal characteristic we want our characteristic to be ideal. So, this is time axis and this is the axis of i phase. So, this should be the ideal characteristic. So, this is the ideal current. So, the actual current; however, does not follow the ideal behavior.

So, the actual current rises like this and reaches the maximum value and then when we close the switch the current rises reaches the maximum value. And it stays there and then when you want the current to be equal to 0, we switch off the switch, we have a switch here this is turned off and when we turn off this phase the current free wheels. So, the diode DF and this decreases in the freewheeling process the current decreases. So, what we have here is that the current false like this. So, this is how the current in a winding changes, but we want to ideal behavior. So, we can improve of an this particular circuit to achieve ideal characteristic and that will be seen subsequently we discussing about the drive circuit of the stepper motor. And we know that we want an ideal behavior of the current wherever we close the switch current.

So, rise to the final value when we open the switch current should come back to 0, but it does not happen in practice. In fact, every winding having some inductance, every winding is having sub resistance. And hence when you close the switch the switch is closed, the current is going to take some time to rise. And this rise time can be reduced if you reduce the time constant of the circuit similarly, when we switch off the switch, the current will fall down to 0 by freewheeling the diode. So, we have this diode here and the current. In fact, freewheels when the switch is off the current freewheels like this. And because of the freewheeling it take some time for the current to come down to 0. So, we have the rise of the current is like this then it stays at the maximum value. Then when you switch off the switch the current comes that to 0 and can this be can this rise time and fall time be reduced.

The rise time and the fall time can be reduced by a simple means insert resistance. Insert a resistance in the winding during the ON state of the switch and inserts some resistance in the freewheeling diode during the OFF state of the switch. So, what we do here is the following we insert some resistance here may be we can call this to be R 1. And we can also inserts some resistance here that is R 2 So, by inserting resistance what we are trying to do effectively we are trying to reduce the time constant of the circuit. If the inductance is say for example, the time constant is given by tau is L by R and that is equal to l by the resistance of the phase plus R 1 in the ON state. And in the OFF state this is the ON state time constant in the OFF state, we have the time constant equal to l by is freewheeling like this is R phase plus R 1 plus R 2 plus the diode resistance.

So, this is the OFF state time constant and ON state time constant is L by R phase plus R 1. So, by introducing resistance in the respective circuit, we can minimize the time constant. And hence we can reduce the ON time and OFF time, this is one of the technique followed to minimize the rise time and fall time of the current in a stepper motor drive very inexpensive. But what is the problem? The problem is that the drive is going to be less efficient. Because whenever we insert a resistance it is going to consume power the overall efficiency is going to come down. So, we can we can of course,, we can increase the fastness of the circuit, the rise time and the fall time can be reduced definitely, but are the cost of the efficiency.

So, by introducing the resistance, we can perhaps increase the fastness; we can say that the rise time improves and the fall time also reduces, but this will be less efficient. So, the efficiency goes down. Now, what is the solution? The solution is to go for an efficient drive in a efficient drive we can apply sufficiently high voltage. So, that the current drive rises to the maximum possible value. Now, in the rise time if we see the rise time is not only function of the time constant, but also function of the applied voltage. So, we can apply little higher voltage. So, that we get a faster rise time and then when we want to make the current equal to 0 instead of freewheeling the current. We feed the current back to the source and that means, the energy of the inductance is not wasted. It is straight back to the source and that is an efficient drive circuit which can be employed for stepper motor. So, we will be discussing about an efficient drive circuit for stepper motor. So, an efficient drive circuit.

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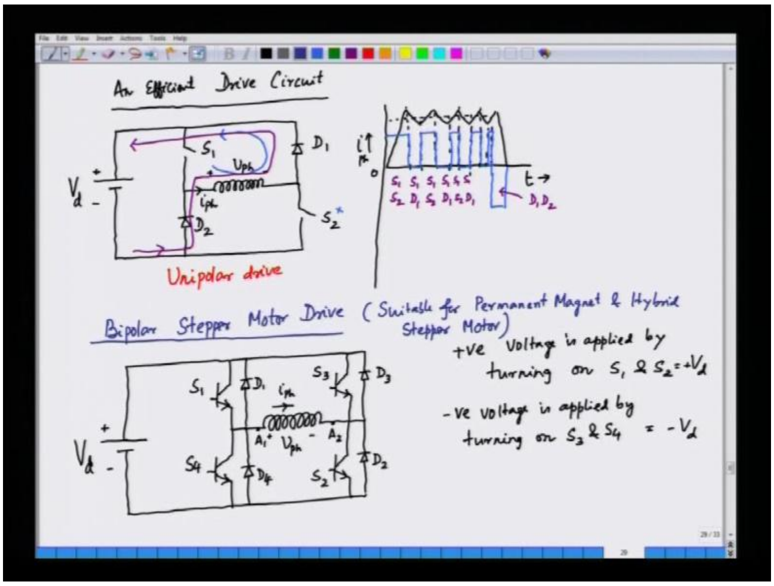

An efficient drive circuit now, what we have in this case is the applied voltage and then we have 2 features here we have the phase in this case we another switch here we have the diode here. So, this is the S 1 S 2 D 1 and D 2; this is the phase V phase here this is I phase. Now, this operates in a in a interesting way when we want the current to be establish in the winding we switch on S 1 and S 2. So, S 1 and S 2 is switched on the voltage across this winding will be V d c of the applied voltage. So, this is V d or V d c this is applied voltage. So, suppose we want the current to follow a particular pattern say this is a ideal current, it should be something like a rectangular structure. And this is the time axis and this is I or I phase. So, we switch on S 1 and S 2, the current rises here.

And then we switch off S 2 one of the switches is turned off. When the switches is turned off the current falls down in this case and then we switch on again S 2 current rises. And then we switch off S 2 and the current goes on changing like this. And finally, when you want to bring the current down to 0, we switch off both S 1 and S 2 and the current falls down to 0 like this. So, this is the nature of the current in the winding of the phase of the stepper motor. So, if we plot the corresponding voltage here the applied voltage in this case. So, when you want to when the current builds up we apply V d we turn. And in fact, S 1 S 2 then we switch off S 2, it freewheels through the freewheeling path is like this S 2 is turned off S 1 is still on. So, this freewheels here the voltage is 0 in this case then again we turn on S 1 and S 2 goes down to 0 again. So, the voltage changes like this

So, this is how the voltage changes. So, here what we do? We apply again positive voltage. And then when you want to finally bring down the current to 0 a negative voltage is apply. So in fact, the conduction sequence is as follows S 1 and S 2 then S 1 D 1 S 1 S 2 S 1 D 1 and so on S 1 S 2 and S 1 d 1. And finally, during this time the conduction is fully D 1 D 2. So, when we turn off both S 1 and S 2 the current is still in the winding and any inductance will try to maintain the current. And when we switch off S 1 and S 2 the current tries to flow through D 1 and D 2 and in that process it is paid back to the supply.

So, the current does not freewheel the current in this case is feed back to the supply like this. So, this is how the energy in the inductance is not wasted any where it is ultimately feed back to the source. So, this is definitely an efficient drive in some situation as we already seen in case of say for example, hybrid stepper motor we need to have a bipolar drive. So, this is an example of unipolar drive by unipolar drive we mean where primarily applying a positive voltage. So, this is an example of a unipolar drive. So, we have primarily this is the unipolar drive when we go for a hybrid stepper motor that is a need of a bipolar drive. In bipolar drive both currents should be reversed we can have A 1 A 2 and then we should be able to have A 2 A 1. So, that can be achieved by having 4 transistor in this case when we have a unipolar drive we have only 2 transistors transistor S 1 and S 2 we have the switches S 1 and S 2.

Now, if we want to have a bipolar drive we have to have 4 transistors S 1 S 2 S 3 and S 4 as follows. So, we can have a bipolar drive bipolar stepper motor drive. So, what we have here is the following we have the applied voltage here and we have 4 transistors. It could be any transistor may be mosfet or V j T this is small drive; this is low power drive. So, we do not have to use very high power devices it could be primarily mosfet although we have shown the symbol of V j T this transistors. And then we have the feedback diodes the diodes inherently present here. They will help us in freewheeling or feeding back the current and we have the winding in this case. This is say for example, A 1 A 2 this is the v phase with plus and minus this is I phase. So, we have S 1 S 2 S 3 and S 4 and we also have D 1 and D 2; this is the feedback diode.

So, we have 4 diodes and 4 transistors here. So, this is applied voltage. So, to apply a positive voltage we switch on S 1 and S 2 positive voltage is applied by turning on S 1 and S 2 so, that is V d. And we can apply a negative voltage by turning on S 3 S 4 and that is equal to minus V d. So, this is how we can apply either a positive voltage we can apply voltage to A 1 A 2 when we switch on S 1 and S 2. And when you want to apply a negative voltage we can switch on S 3 and S 4 and we apply minus V d. So, this is how we can excite the windings of a hybrid stepper motor where we need to reverse. We need to apply positive and the negative both; we have already seen that the sequence of the switching is A 1 A 2, B 1 B 2 A 2 A 1 and B 2 B 1. So, we have to go in that particular sequence. So, if we apply positive voltage for A 1 A 2 for A 2 A 1 we have to reverse the voltage in that is achieved by switching the other pair of transistors.

Now, this is how the winding of a hybrid stepper motor can be energized. So, we have seen simple drive circuit for stepper motor. The drive circuits can unipolar for simple stepper motor and that could be for variable electro straight stepper motor for permanent magnet and hybrid stepper motor where we have the permanent magnet. Whenever we have a permanent magnet current direction mater, we cannot be apply only in one direction. We have to have a facility for bipolar power supply and hence the bipolar stepper motor drive are suitable for permanent magnet and hybrid stepper motor. So, this completes our discussion on stepper motor. We have seen various types of stepper motor starting from variable reluctance stepper motor to hybrid stepper motor and each one is having its own advantages.

So, finally, the best possible stepper motor could be the combination of A 2 that is a hybrid stepper motor where the stepping size the step size can be reduced to a very small value without any difficulty. So, in the next lecture, we will be taking a new type of drive the application of induction motor drive. And how we can have a utility friendly drive which can be applied for high power application like transit? And what is the effect of the drive on the power system? How we can improve the quality of electric power while operating the drive? That will be discussing in the next lecture.