Advanced Electric Drives
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Lecture - 23

Hello and welcome to the lecture in advance electric drives. In the last lecture we would discussing about the unipolar brushless D C motor drives, where only one winding is excited at a time, as the regent the top production is less. So, let us take a look at the unipolar drive.

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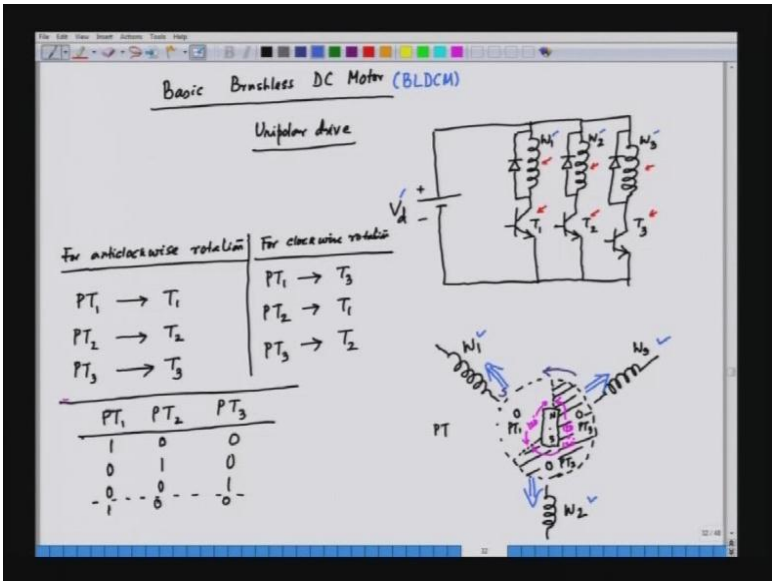

Now, here are you can see that, we have a brushless D C motor, where we have three winding w 1, w 2 and w 3. And these three windings are exciding form a single disease source that is v d.

And the three windings are connected to T 1, the transistor T 1, the transistor T 2 and the transistor T 3 respectively. So, at any given time, only one of the transistors will be on and hence only one of the windings will be exited. So, we have the three windings w 1, w 2 and w 3 and the rooter in this scale that, we know there is brushless D C motor the rotor is essentially a permanent magnate rotor which is may be two pole or any even number of poles. And in this case for a simple brushless D C motor, we can switch the windings in sequential fashion to make the rotor rotate either in clock wise direction or in anti clock wise direction. Now, here to make the rotor rotate in anti clock direction our

sequence of fetching will be w 1, w 2 and w 3 and this three windings are swifts based on a optical encoder which is house in the rotor and fix to the rotor.

We have an optical encoder, which have the three part of sensor, P T 1, P T 2 and P T 3 are the part of sensors, if signals like 1 0 0, 0 1 0, 0 0 1 and so on. And as a regent one of the windings will exited and hence we have a contentious rotation. On the other hand, you have a possibility that, in a motor we can excite more than one winding at a time and that case the top production will be better, will be more in fact. So, we will see a drive is where more than one winding exited and that drive is call a bipolar drive. So, will now discuss about a three face bipolar brushless D C motor drive.

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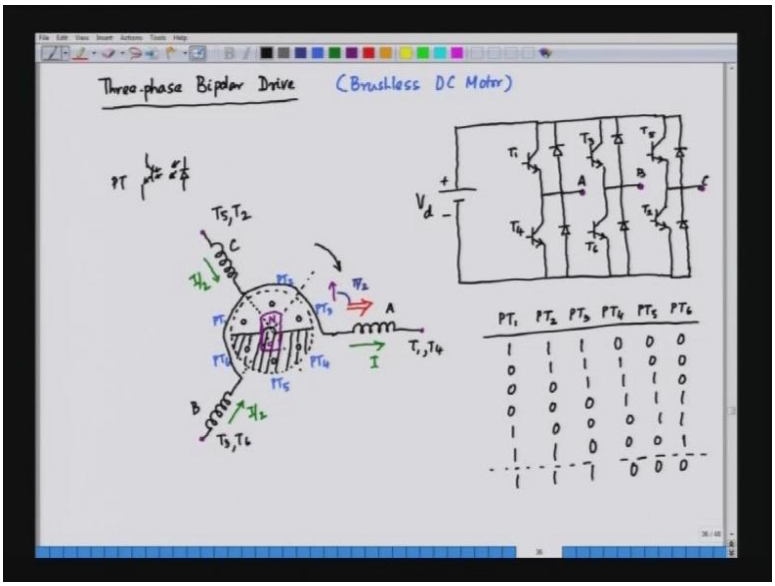

Where we excite this winding from a three phase in water and each phase can have both positive current and negative current. So, this is the important structure, we have two transistors for a phase, this for one phase, this for other phase and this is for a third phase.

And here, we have the feedback diode. The diodes from facilitates by decimal current flow for industry winding and the current can be maintained either feedback diodes and we can name the transistor as T 1, T 2, T 3, T 4, T 5 and T 6.

And we will be supply with three phase winding and three phase winding is supplied from, this is the point it supplies phase A, this is the point it supplies phase B and this is

the point it supplies phase C. Now, how are the phases arranged? The phases arranged inside the motor we have the stated here the phases are stated difficult. So, we are exiting the stated and the rotor is essentially a permanent magnate. So, we have three phase winding on the status in a brushless D C motor the rotor is the permanent magnate and we can assume latter say rotor has got only two pole. So, here these are the various phases here phase A, phase B and phase C.

What about the rotor? the rotor is a and the rotor is house with again and optical encoder as you already seen here also you have and optical encoder the optical encoder is arrange like this. So, we have all this 60 degree regions and for the optical encoders you have six photo transistors, these are the poles.

In fact, this is the photo transistor and we can call this transistor as P T 1, P T 2, P T 3, P T 4, P T 5 and P T 6. The photo transistor as separated from each other by 60 degree where as six photo transistor we have involved revolution 360 degree. So, the photo transistors are phased in 60 degree interval and the optical encoder is constructed by having a disk, which is having 180 degree transparent and 180 degree optic material.

So, this part is an optic region the lie does not pass this region, this is the optic region. So, when the photo transistor comes in the optic region, they are basically covered they do not give a signal has 1, when the photo transistor encounters a transparent region. That is not has the hast region are achieve the optic region and the optic region the transistors gives a signal equal to 0 and in the transparent region the photo transistor gives a signal that is equal to 1. So, any given time because, of the encoder arrangements this basically an optical encoder because, of the typical arrangements of the encoder or any giving time the three of the photo transistor will be giving 1.

Now, here we can very clearly say that P T 1, P T 2 and P T 3 will be giving signal 1. In fact, if we try to a right down the signal C as, P T 1, P T 2, P T 3, P T 4, P T 5 and P T 6, these are the photo transistor. For the present situation, the photo transistor one will be giving high here, because it facing the transparent region, photo transistor two will also be giving a signal is high. This also the transparent region photo transistor giving three will be a signal high and photo transistor four, five and six will be giving signal 0. Now, if the rotor rotation the clock wise direction, the clock wise means rotate like this.

If the rotation is clock wise, we can say that after sometime P T 1 will be 0, P T 2 will be 1, P T 3 will be 1, P T 4 is 1, P T 5 will be 0 and P T 6 will be 0. And similarly we can write down the sequence, after that we have three one feature shifted here. And then we have this state after that we have P T 1 becomes 1, P T 2, P T 3 and P T 4 are all 0, P T 5 and P T 6 are 1. After 60 degree we have 1 1 here and then we have 0 0 0 for P T 3,4 and 5 and P T 6 is again equal to 1.

Then after 60 degree of this, we have 1 1 1 then 0 0 and 0 so, it is same as the starting sequence. So, what you have told here, basically six state and the state changes after 60 degree because, photo transistor are kept in 60 degree intervals and they have strussenery, the photo transistor has strussenery. The photo transistor receive the light advance side, we have a photo transistor like this. The photo transistor and on the other side we have lights off.

So, the photo transistor will give a signal one, when it is phases of transparent region. So, like, this is the sequence, when it rotates in clockwise direction and the state change in every 60 degree interval. Now, suppose we have the rotor and the rotor here is a permanent magnate rotor. And later say the rotor have only two poles, the north pole and the south pole. And the rotor as is place with respites the photo transistor and the encoder in the following fashion. We have the rotor; the rotor is a permanent magnate. So, here is equalent permanent magnate we have and which is our north pole and this is the south pole. So, the rotor is place like this and it is glue to the disk.

The disk which is having optic and transparent region it is glue to the rotor and the disk rotates along with the rotor. The photo transistors are have be fix your location 60 degree in phase, but the disk is rotating along with the rotor in the clock wise direction. Now, let us say that bound to make the rotor rotation in the clock wise direction now, to do that we have to excite the windings to be excite the windings we have to see the transistors. Now, this winding A is connected to A of the inverter and this is phase B. So, we can say this is the phase B here, and this is of C.

And the phase b here is connected to phase B of the inverter, phase C here is connected to phase C of the in water. And we can see here, that in the inverter the D C source is V d and in every phase we have two transistors. So, for example, in phase A we have T 1 and T 4 so, phase A is connected to in fact, T 1 and T 4. Similarly phase B is connected to T

3 and T 6 and similarly phase C is connected to T 5 and T 2 so, this is T 5 and T 2. When we excite this various pages we should make sure that for optimal motor production the angle between the rotor field and the status field should be 90 degree, just like a D C machine,

If you observe a D C machine the field m m f and the armature m m f are in quadrature, the 90 degree for optimal motor production. So, we can have the similar condition here. So, we will assume that for this particular situation we will excite a phase A, phase B and phase C is such a fashion that the fill direction is orthogonal to the direction of the rotor filter. In fact, we are ending at a field which is in this direction and the rotor field if in this direction and the angle between the two fields is 90. So, when we excite phase A, phase A will be carrying current in this direction. This is the direction of the phase A current.

Let say it is carrying a current I. So, we have applied a positive voltage to phase A and phase A is carrying this current I in this direction. Let us say and the phase B is will be connected to negative bias we can assume that, if the negative voltage is applied this will carry current in to the rotor so, it is I by 2. And phase c is also apply the negative voltage so, this will carries current here in this direction and this magnitude is I by 2 and since we have a three phase windings we can connect this winding in star. So, if we connect the winding in star what we have the future will be this windings are all connected. So, phase B phase C and phase A are all connected. So, we have star connect stated.

So, in a star connected stated I A plus I B plus I C is equal to 0. So, in this case phase A is carrying I in the positive direction, phase B and phase C will be carrying I by 2 and I by 2 in the other direction. So, let us see how exactly the m m f is produced.

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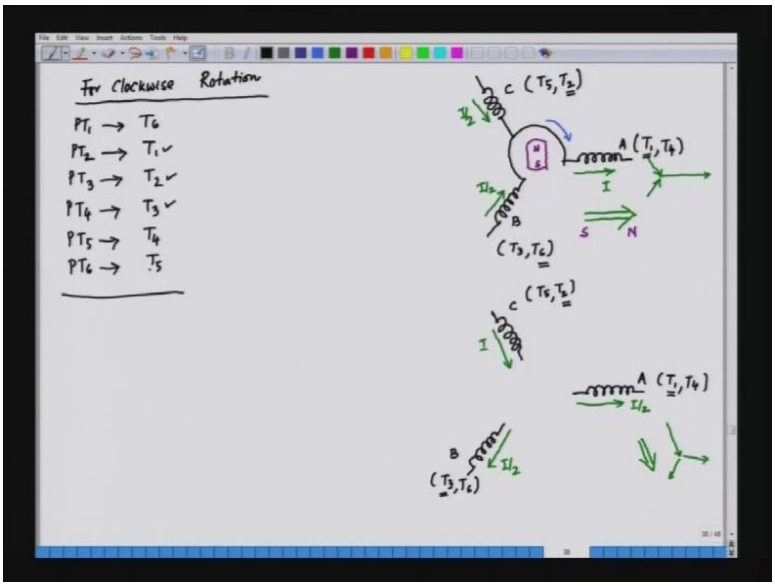

So, we have three phases here, phase A, phase B and phase C. So, this is phase A, we have phase B here and we have phase C here and these are star connected. So, phase A is applied with a positive current. So, it means the current is like this.

So, it is I and phase B current with the other direction I by 2 and it is I by 2 here. So, when be excite the windings like this, the m m s will be the vector form of the three m m f. We have phase A is excited, phase B is excited, phase C is also excited. So, the resultant m m f has to be the vector form of the three m m f. So, we can say that the resultant of this three would be in this direction, is the resultant of the three m m f. We have one m m f in A, other m m f along B axis and the third m m f along C axis. So, if you try to find out the resultant of this three will get a vector which is along the phase A axis having an amplitude which is 3 by 2 times the m m f of phase A.

So, this is the m m f and when the m m f is produce like this. What we have here? We have south pole produced here and a north pole produce here by the definition south pole receive the flux north pole gives the flux. And what is the direction of the rotor? The rotor direction was perpendicular like this. So, this is the south pole, this is the north pole we have and the torque and then here we have the south pole. And south pole a flux the north pole to that the tendency of the rotor rotate in the clock wise directions. So, when the rotor rotates the encoder position also get changed. You can see here, that we are talking about bipolar drive. So, in the encoder position is changed initially what we had?

We had P T 1, P T 2 and P T 3. So, P T 1, P T 2 and P T 3 were giving all one, we are in this particular situation now, if it rotates by 40 degree right now. We will be in this particular state 0 1 1 1 0 and 0. So, in this state P T 1 if covered P T 2, P T 3 and P T 4 all of they will be facing light. So, P T 2, P T 3 and P T 4 will be 1 and P T 5 and P T 6 and P T 1 will be 0. So, we will be in a different position. So, in that case what we have a situation we can say that for clockwise rotation.

For clockwise rotation, we have to feed the photo transistor in the following fashion. So, we have the photo transistor is P T 1, P T 2, P T 3, P T 4, P T 5 and P T 6 and how are they connected? They are connected in the following fashion P T 1 is connected to T 6. So, we have the transistor in this case so, we have the six transistors. So, P T 1 is connected to T 6. So, we will see here, P T 1 is connected to T 6, P T 2 is connected to T 1 in a sequential way.

Then P T 3 will be connected to T 2, P T 4 is will be connected to T 3, P T 5 is connected to T 4 and P T 6 is connected to T 5. Now, when we excite the winding, the winding say for the example, phase A is excited either by T 1 or by the T 4 we can see here that phase A is excited either by T 1 or by T 4. So, T 1 will be giving a positive current and T 4 will be giving a negative current. Since whatever saying here, that is every winding though current will be bidricks now. By apply the positive volts you can positive current by apply the negative volt then we can have a negative current.

Similarly for phase B, phase B can have a positive current, positive current means, current coming out here, by apply T 3 and we have a negative current by applying T 6. Similarly in phase C by apply phase C, if you want to have positive current, you can trigger of switch on T 5 and we want to have a negative current you can trigger T 2. So, you see what happens in this case? That we are in the clockwise rotation. So, for P T 1, P T 2 and P T 3, T 6, T 1 and T 2 are on. So, T 1 is connected to phase A and for phase B we are connecting T 3 and T 6 and phase C is connected to T 5 and T 2.

So, in this case T 6 is on, T 1 is on and T 2 is on, T 6 is on so this is on, T 1 is on this is on and T 2 is on this is on. So, here we can assume that, the current in phase A in this direction. The positive current let say and phase B and phase C are connected to the negative bias. So, this is connected to hence, this current is I by 2 and this current is I by 2. So, the rotation of the rotor is the clockwise direction. After some time we will have a

deferent situation. So, you will have T 6 will be covered T 1, T 2 and T 3 will be on. So, in that case, what is the position of the m m f let us find out. So, we phase A here, we have phase B in this case and here we have phase C.

And the switching having change so, this is connected to T 1, T 4, phase B connected to T 3, T 6, phase C is connected to transistor T 5 and T 2. Now, we have T 1, T 2 and T 3 three transistors we have now on. Now, in this case T 1 is on, T 2 is on and T 3 is on. So, it means phase A and phase B will have a positive current and phase C will have negative current. So, it means phase A current will be positive, phase B current will be positive, but phase C current is negative.

So, this is current. And this will be I because, it is entering here, this will be I by 2 and this will be I by 2. And hence we have a situation, where we have a vector like this, vector like this, vector line this and the resultant of these three will be the in the vector which is like this. So, for the previous position so, we can have this is the south pole and this is the north pole. So, we have the situation like this so, it means the vector in rotate in the clockwise direction all right. So, this is how the vector is rotating and after some time the vector will again in rotate and doc what will have here, this continuous rotation and the rotor will try to catch up with the status field and hence will have a continuous rotation in the clockwise direction.

So, this is the connection for clockwise rotation. So, if it can connect the photo transistor one to the base of transistor six, photo transistor two to transistor one, photo transistor three to transistor two, photo transistor four to transistor three and photo transistor five to transistor four and photo transistor six to transistor five we have the continuous clockwise rotation up the rotor. And here we can see that, any deferent time all the three winding is exited and hence the top production is more compare to unique electronic drive. Now, what about the counter clockwise rotation.

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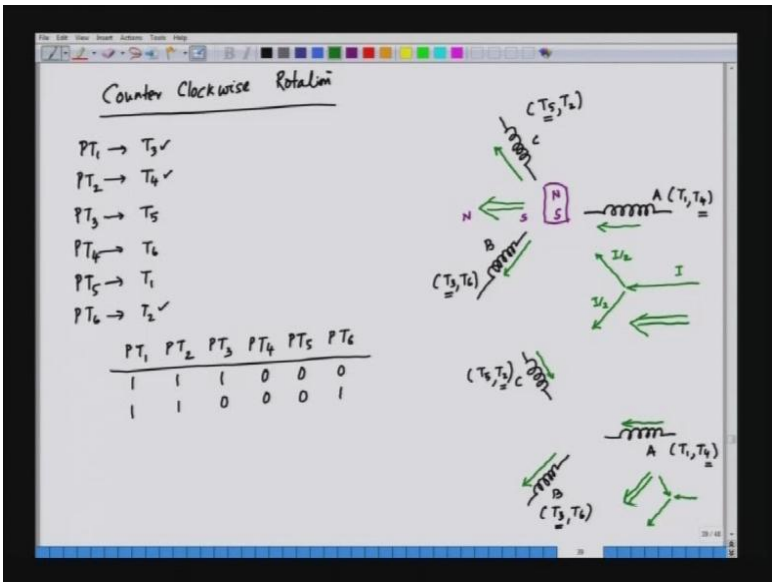

So, we will see how we can up a counter clockwise rotation. Let us again these are the windings, this is phase A, this is phase B, this is phase C here, now phase A is again connected to T 1 and T 4, phase B is connected to T 3 and T 6, phase C is connected to T 5 and T 2. Now, here at this instant the rotor originally well are these positions, this is the north pole and this is the south pole. .

So, here we would like to have the rotation in the anticlockwise direction or counter clockwise direction. So, in that case we expect that, the stated m m f should be in this direction with this south pole and this north pole. So, that the south pole here will attract the north pole of the rotate and hence the rotation will be in the counter clockwise direction. So, how to achieve that? Now, to achieve that you will have the current in the windings in the following fashion. So, this winding will acquire like this, this winding will acquire like this, this winding will acquire like this. So, essentially what we have, you having three vectors here, one vector is like this, the other vector is like this, the third vector is like this.

So, if this is let say I, this is I by 2 and this is I by 2 and the resultant of this three will be in this direction. So, what we have to do here is that? We have to switch in such a way that the current in the three windings will be I, I by 2 and I by 2 respectively, if one current is positive other two currents will be negative. So, here we switch in the following fashion, we switch here T 4 and then this current is negative. So, we switch T

4 of phase A then for phase B we switch T 3 and for phase C we switch T 5. So, this current coming out by convention we have assumed to be positive let say.

So, if the current coming out of the winding as for convenes is positive you can also assume the other way round, but here at we have assume that the convention of the current is positive when it is coming out of the winding. So, in that case phase A should be applied with a negative voltage. So, phase B should be applied with a positive and phase C should be applied the positive voltage. So, here we can have the photo transistors like this, P T 1, P T 2, P T 3, P T 4, P T 5 and P T 6. So, they should be connected to the respective transistors and what are the video transistors. Now, you say that we have T 4 is on, T 3 is on and T 5 is on. So, we will say this is connected to T 3, this connected to T 4 and this connected to T 5.

And similarly you will see here, we have T 6 here, T 1 here and T 2 here. So, this is how we can connect the various photo transistors to various transistors and this will results in the counter clockwise rotation. After sometime we minute to safe this m m f vector of the stated. So, initially in this case, if you see the photo transistors P T 1, P T 2, P T 3, P T 4, P T 5 and P T 6, these were initially 1 P T 1, P T 2, P T 3, P T 4 was 0, P T 5 was 0 and P T 6 was 0.

Now think the rotation is counterclockwise direction. There is a little change in the post pattern now here this will shift left. So, what we will have here is, if that after sometime P T 1 will remain 1, P T 2 will also remain 1, P T 3 will be 0, P T 4 will be 0, P T 5 will be 0 and P T 6 will be 1. Now in the second step, the first step is complete. In the second step let us see, what is the direction of the m m f, whether the m m f is rotating in the counter clockwise rotation or not. So, P T 1 is connected to transistor 3, so, this is on, P T 2 is connected to transistor 4 that is on, P T 6 is connected to transistor 2 that is also on. So, here what you have transistor 2, 3 and 4 are on. So, if 2, 3 and 4 are on what is the state of the m m f.

So, we will see that in the second situation we have three phases here again, phase A phase B and phase C this is connected to T 1 and T 4, B is connected to T 3 and T 6, C is connected to transistor T 5 and the transistor T 2 of the inverter. And what do you find here is that, T 2, T 3 and T 1, if T 2 is on this is on, T 3 is on this one is on and T 4 is on means this is on. So, it means the phase B is connected to the positive and hence the

current will be positive and by definition the positive current is coming out of the winding.

So, we can say that, this is the current here and T 3 is negative so, this is the nature of the m m f here and T 2 also negative so, we have the nature of a m m f will be like this. So, here what we have in this case is that we have three vectors one like this, other is like this and the third one is like this and the result that of this three will be like this. So, we have still that the resultant of m m f in this case will be here right. At this m m f it shifted from the original m m f by 60 degree and this means the m m f is moving in the shape of 60 degree. So, from the first position to second position the m m f has rotated by 60 degree in the counterclockwise direction.

The rotor will also try to catch up with this m m f and hence the rotation of the rotor will be also in the counterclockwise direction. Now, let us see again what about the torque pulsation and the torque production here now, if we see the structure of this encoder and the rotor we will see we have three windings in the stator phase A, phase B and phase C.

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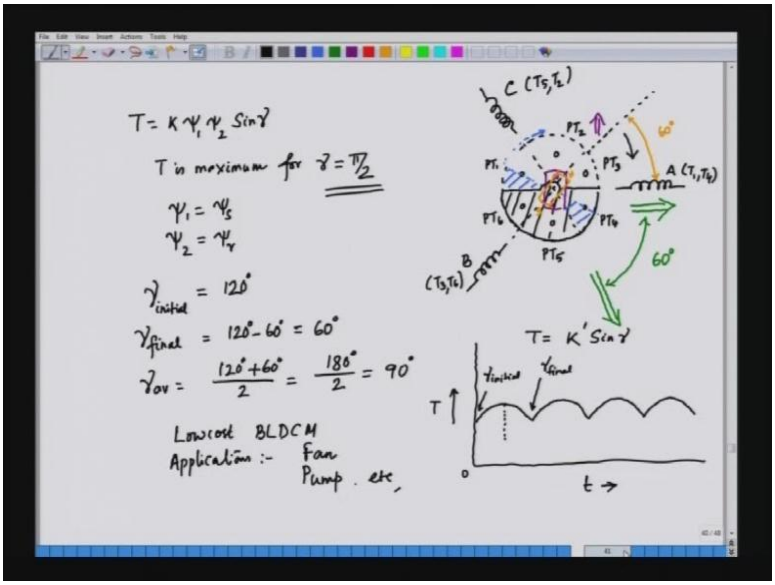

The rotor is at this moment is vertically aligned. The disk is fix to the rotor, the disk can the rotors can basically bloom, the rooter is right now in the upward direction north pole, if phasing up and then the disk is fix to the rotor. Now, at this instance the m m f are you have seen is along phase A because, the angle should be 90 degree. So, this is the m m f of the stator and the rotor m m f is vertically upward.

And hence naturally the stator m m f and the rotor m m f are the aligned with each other at an angle equal to 90 degree and this angle 90 is conducive for maximum torque production. Now, after 30 degree from this the encoder is continuously moving in the let us say clockwise direction. So, after 30 degree the encoder will be occupying this position ok. So, this will the occupying this position. So, this will be the operating region right and will have this region as stance for enthusiasms.

So, this is the situation that we have that P T 1 is getting covered and P T 4 is getting uncovered. So, P T 2, P T 3 and P T 4 will give us high signals and as this instance the m m f will be sifting by an angle that is equal to 60 degree. The next position of the m m f we have already seen will be along the direction ok. And this angles between this m m f it is 60 degree. So, the m m f changes in the stapes of 60 degrees and in one evolution there will be six changes of the m m f and hence we are expecting some torque ripples here. Now, what is the nature of the torque ripple?

Now, at this instance, if you say that the rotor has already move. What about the stator I mean the rotor poles the rotor poles we will also be moving to this location it is new location and the new location will be like this. This is the north pole and this is the south pole. So, right now, the rotor axis is align along the stator m m f not at 90, what at 60 again 60 degree. So, this angle if we see next position gives, the position of the rotor right now, after the disk has shifted soon under 30 degree from the previous position. The rotor is also shifted along with the disk by the same 30 degree angle. So, this angle between phase A and the rotor this angle is also 60 degree.

So, at the commencement of the next switching, the rotor is align not at 90, but at 60 plus 60 equal to 120. And we know that equation for the torque production T is equal to k some constant psi 1 psi 2 and the sin of the angle between them. Psi 1 is the rotor flux, psi 2 is the stator flux and gamma is the angle between the rotor and the stator flux. So, if the angle is 90, the gamma is 90 the torque is maximum. So, we say the T is maximum for gamma equal to pi by 2. So, we can say that, I mean one of the fluxes will be say for example, if psi 1 is a stator flux, psi 2 is a rotor flux.

And are this instant when the stator changing, what is the angle between the rotor and stator m m f that angle is 120. So, we can say that gamma initial is equal to 120, gamma is not constant, here gamma is changing, gamma is changing due to position because, the

rotor is not stationary. Rotor is moving away and the rotor is gradually moving away and after again 60 degree because, this is the position of the current position of the disk. Now, when the disk when come to this position T 2 will be covered and T 5 will be uncovered. So, the disk would have to travel trough 60 degree for the next switching.

So, hence if gamma initial is 120, gamma final is equal to 120 minus 60 degree because, the m m f will be stationary till the next switching and the next switching will occur only after 60 degree. So, up to the next 60 degree the m m f will be stationary here, the stator m m f will be stationary. So, gamma final will be 60 degree and hence we can say that as the rotor rotates gamma is continuously changing from 120 to 60 again jumping to 120 to 60 continuously like that. Off course it obviously is 90, 120 plus 60 by 2. So, we can say that gamma average is here is 120 plus 60 by 2 that is 180 by 2, that is equal to 90 degree and that is conveniencely for maximum torque production phi by 2, but while the rotor is rotating gamma is continuously changing.

And hence we have a torque ripple, how does the torque change? The torque changes in the following fashion. We have the equation for the torque, we can say that T is equal to some constant k 1 prime sin of gamma and with time gamma is also changing, we have this torque axis in the y axis so, 120 to 60. So, in fact, the torque is changing as a sin waves, but it is changing like this.

So, this is gamma equal 120 sin when it decreases become 90, where the torque is maximum this correspond to gamma equal to 90. So, we can say this is for gamma initial and this one is for gamma final and since it is periodic it is constantly changing. So, this is the nature of the torque pulsation and here will have six safe torque repul. So, torque repulse is six times the frequency of revaluation. So, every midvika revaluation will have six times the torque pulsations. So, sometimes not acceptable, but this kind of brushless D C motor drives are not used for very high performance applications because, of the torque repulse in the torque ripple there are only limited to fan type of application.

So, whenever we have a fan we can go for drive like this and the torque ripples which is inherently present in this kind of drive does not do any harm for a fan drive, but for a drive like automobile or a tracksim application we cannot have this kind of torque pulsation they will create vibrations and discomfort to the passengers. So, we can say

that physically a low cost that is the D C motor applied application in this case fan applications and other applications could be a pump application and so on.

As we know that in any drive would like to control the torque and the torque is basically controlled by controlling the current. Now, here we do not have any mean in the current because, we have applied a fix D C voltage. say for example, let us take a small fan a closed old fan, we have applied a battery and we are not controlling the current. Now, if we want to control current we need to have a mechanism for current control and this kind of drive are not current control and hence and they are applied only for fan and pump type of application warning essentially at constant speed.

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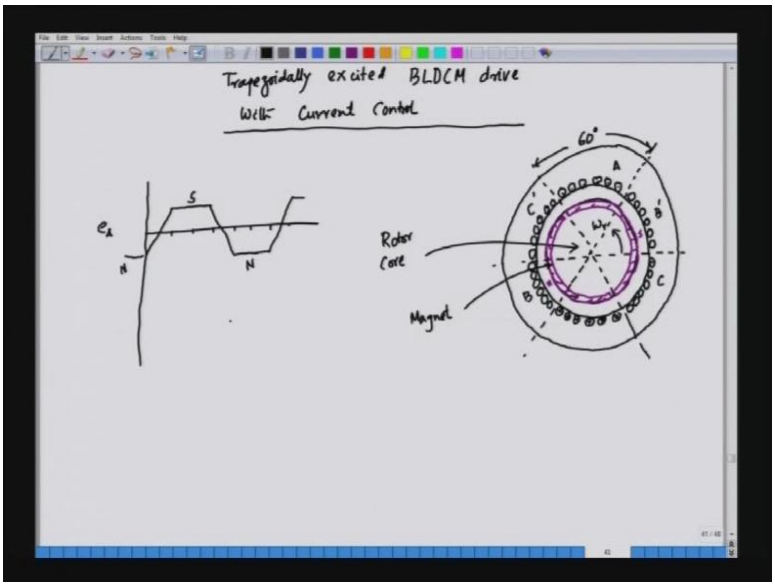

Now, we will take little advance drive. Let us see that we will take classified and excited brushless D C motor drive with current control. Now, let us understand what is the tropical excited brushless D C motor, in brushless D C motor, the stator windings could be constrict the stator windings could be distributed. I will show you some picture of. So, we have this is a brushless D C motor drive, this is a internal structure of brushless D C motor. In this case we have the rotor; in this case we can see that they lay on the permanent magnets.

We have in this case one, two, three, four and then other four pole sets eight pole rotor and a state having a windings and this windings are constrict windings and constrict windings are used for low cost brushless D C motor, which are used for fan application,

pump application and could be for any actuators for electro mechanical actuation system. We can have further type of structures now this is a structure of a brushless D C motor the stator winding in this case you see here there is a stator structure the stator code is laminated and these are the windings of the stator and the stator winding in this case is distributed. This is not constrict as we have seen in the previous case this is little more expensive brushless D C motor, where the windings are distributed this D C motor winding.

Were flux in this case and a windings are similar to that of three phase synchronous motor these are the over hand structures. This is the slot opening and these are the stampings and this concentrate the stator core. These rotors of a typical brushless D C motor drive which is little more expensive and this can be applied for toxin application and automotive application and we have the magnets. The magnets are inside the rotor that is inside the rotor having a interior permanent magnet structure. This is how the magnets are buried here these are rotor core the rotor core is also laminated and this is a magnet one side could be a south pole, other side could be a north pole and the fluxes will be coming out of the north pole and entering the south pole.

And here the current within the rotor and hence we can call this rotor to be interior permanent magnet rotor. This is a assembly of the rotor and the stator the rotors are having the four magnets here, it is a four core structure and the stator is distributed winding and this kind of windings are applied for high perform application that we were discussing right now. So, coming back to our original discussion on a tropically excited brushless D C motor drive now, let us discuss a tropical excited brushless D C motor drive. What is the meaning of tropical excited system? In tropical excitation the back aim of the motors are tropical in nature. Now, this is produced in winding how to distribute a structure as follows.

The rotor in this case say, here we have the rotor and then we have the stator. So, the stator core structure is like this. So, we can divide this into six segments and the magnet is arrives in the following fashion this is the magnet. So, other side also we have a magnet here. And in this magnet we have two poles, one is a north pole and the other one is a south pole. So, this is a rotor core and here we have the magnet, this is structure. So, we can show this magnet in a hast fashion

The stators will be having three phase windings and the windings are distributed over the stator structure, the stator inner surface is a cylindrical surface. So, we have the slots and in the slots we can have the windings and the windings are in the following fashion we have the windings and we are not seeing the cross section of the conductors this is a phase A and phase A return path is here. So, if we have dots here the current is coming out in this case, here the current is going into cross. This was phase A and phase B shifted from phase A by 120. So, we can have this structure of phase B, phase B is here.

Phase B and we will have the B prime and similarly we have phase C and we have the C prime. So, the windings are distributed over 60 degree we can say this angle here is 60 degree. So, as a rotor rotates suppose the rotor is rotating in the counter clock wise direction this is the direction of rotation we can say this is the omega r and as the rotor rotates the induced e m f in a phase will trapped in a nature.

Now, if we see the nature of the induced e m f, you see that induced e m f is phase A will have a structure like this. This will have the structure so, this we can say phase A, when the magnet is entering the winding the induced e m f is gradually increasing. So, here the winding were influencing let say north pole phase A winding and gradually the north pole is going away and south pole is entering the winding. So, the e m f is gradually changing the polarity.

And then the winding is purely under the influenced of the south pole there again the north pole is entering and the polarity is gradually reversing and here we have full north pole. And that is we say that the induced e m f in each phase is not sinusoid, it is basically the tropically structure and hence we call this to be a tropical excited brushless D C motor drive. In the next lecture we will try to see how we can have current control for this tropically excited system and how we can also dynamically model a brushless D C motor drive with tropizilla excited induced e m f. .