Advanced Electric Drives
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Lecture - 15

Hello and welcome to this lecture on advanced electric drives. In the last lecture, we have seen the space vector modulating technique of an in water, fitting a 3 phase motor. And we have also seen that a voltage source inverter will have 6 possible switching states, and it will be able to generate 6 non-zero vectors and 2 zero vectors, in total we have got 8 possible states. And out of 8 possible states we have 6 non-zero states and 2 zero states.

So, in this lecture we will be discussing about the director control of induction motor. And we will see how an induction motor can be controlled from the first principle, where torque and the flux can be controlled independently. Of course we have all ready seen that in case of a vector control drive the torque and flux are controlled independently. But a vector control drive is a sophisticated drive where we need lot of signal processing. In fact, what we need in a vector control drive is a coordinate transfer machine from d q reference frame, rotating synchronously to a b c frame which is stationary in the space.

So, this transformation in a vector control drive takes lot of computational power. And in a in a director control drive the transformation is not available there, we do not have transformation in a director control drive, which is very simple to implement. So, in this lecture we will be discussing the director and the flux control of induction motor.

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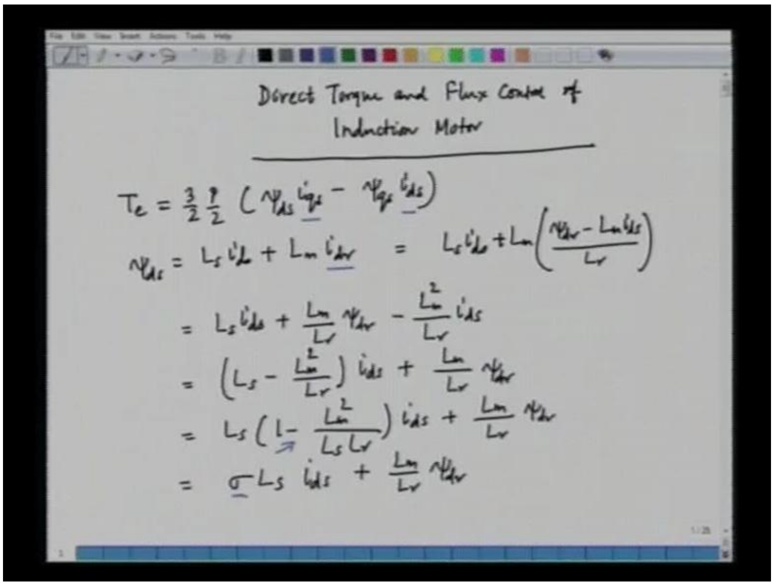

So, we know the equation for the torque of an induction machine which is straight forward. So, we can ride the torque equation of an induction machine in stationary reference frame using d q variable; T e is equal to 3 by 2 into p by 2 into psi d s i q s minus psi q s i d s; we are talking about the stationary frame here. And psi d s psi q s, i d s and i q s are variable in the stationary reference frame.

Now, what we have do here; we will try to express this torque equation in terms of 2 fluxes. And the 2 fluxes are one is the stator flux; other is the rotor flux. So, this the present torque equation like psi d s, i q s minus psi q s i d s as got 2 types of variable; one is the flux, another is the current. So, we will be converting this equation into one variable time that is only flux. So, what we will do here; we will try to eliminate this current from this equation.

So, to do that we will write down the expression for psi d s; psi d s is equal to L s i d s plus L m i d r that is equal to L s i d s plus L m; we can also express this psi d r in terms of i d s. So, what we will do here desire it is psi d r minus L m i d s by L r; we will further simplify this. So, that is equal to L s i d s plus L m by L r into psi d r minus L m square by L r into i d s. If we simplify this we can take this i d s common here; L m square by L r into i d s plus L m by L r into psi d r. So, this is the expression for psi d s.

Now, we can write this as L s into 1 minus L m square by L s L r into i d s plus L m by L r into psi d r; that is equal to sigma into L s into i d s plus L m by L r into psi d r; sigma here is call the leakage factor. So, we know that this sigma in this case is coming from this expression L s into 1 minus L m square by L s L r.

Now, if in an induction machine say for example the leakage inductances are 0; the stator leakage inductance is equal to the rotor leakage inductance equal to 0. It means the coupling is the 100 percent; the coupling between the stator and the rotor which is through the air gap. If suppose it is 100 percent we can say that L m square by L s L r equal to 1.

So, if leakage inductances are 0 this leakage factor sigma will be will be equal to 0. So, this sigma indicates the amount of leakage and in an ideal situation sigma which is hypothetical situation. So, sigma is a small number which is an indication or which is indicative of the leakage inductance of an inductance machine. So, from in this expression we can find out what is i d s.

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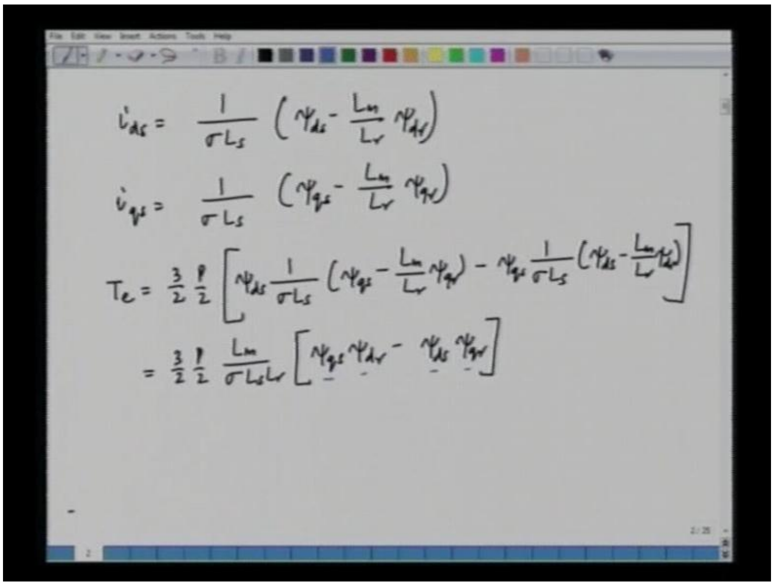

So, we can say that i d s is equal to 1 by sigma L s into psi d s minus L m by L r into psi d r. So, this is the expression for i d s; which is the current of the stator in the d-axis. similarly, we can have the expression for i q s. So, we can say that i q s is equal to 1 by in a similar fashion 1 by sigma L s into psi q s minus L m by L r into psi q r.

So, these 2 are the stationary reference frame currents into axis d and q respectively. Now, what you will do? You will take these expressions and we will substitute for i d s and i q s in the torque equation; and the torque equation is this. So, we will be substituting in this torque equation for i d s and i q s and simplify this. So, we will rewrite the expression for the torque T e is equal to 3 by 2 into p by 2 into psi d s 1 by sigma L s psi q s minus L m by L r into psi q r minus psi q s 1 by sigma L s into psi d s minus L m by L r into psi d r.

So, this is what we have here we can further simplify this. If we simplify this expression further what we are obtain is the following 3 by 2 into p by 2. And we will have here L m by sigma L s L r common. So, we will have in this case psi q s psi d r minus psi d s psi q r. So, this is the expression for the torque in terms of the stator flux and the rotor flux in the stationary reference frame. So, what we will do here; we have the expressions in this case which are start psi q s psi d s and psi q r and psi d r. And we will try to find what are the meanings of this fourth ((Refer Time: 09:21)) ok. So, suppose we are talking about stationary reference frame.

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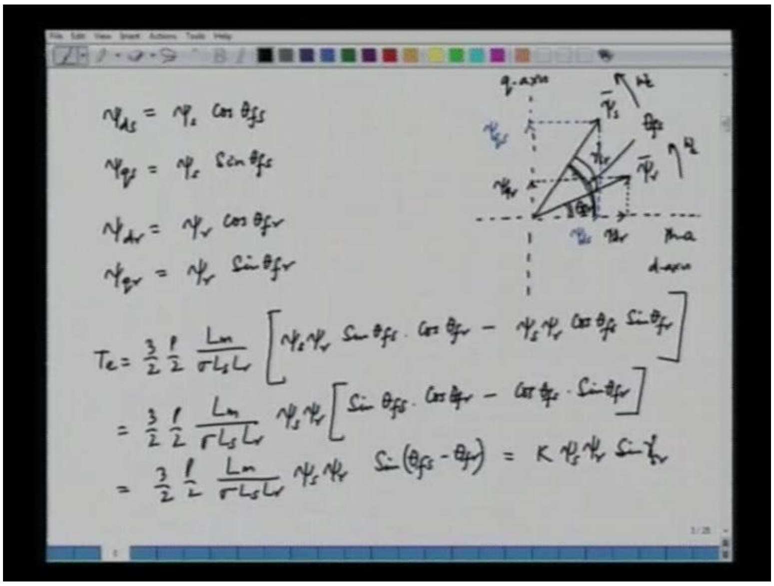

And, we have the rotor flux that is psi r which is a vector. And then we have the stator flux which is psi s which is also a vector; and both the fluxes are rotating in the space as synchronous speed. So, in the steady state condition one can imagine that the stator flux and the rotor flux both are rotating in an induction machine at synchronous speed. But both are stationary with respect to each other; and that is how there is a torque production. So, we can think of a situation suppose I have 2 permanent bar magnets; if I hold this bar magnet at an angle. If I have a south pole and if I have a north pole they will attract each other. And if one is do not permanent magnet; they are electro magnets generated by the currents in the induction machine; and both are rotating at synchronous speed. So, this is rotating at synchronous speed and this also rotating at synchronous speed maybe we can call this is omega e and omega e respectively.

And, the related velocity between them will be equal to 0; however they will have a angle between these 2. So, there is an angle which is which you can call here is gamma s r; the angle between the stator and the rotor flux. And if we take a stationary axis I can call this is my phase reactor; this is also my d-axis; I can call this to be my d-axis. And this axis which written to this is a q-axis and I can find out the component of these fluxes on these 2 axis.

So, for example if I talk about the rotor flux; I can take the projection of the rotor along d-axis and q-axis respectively. So, if I project this along this axis; this is psi d r. And if I project this along the q-axis this will be psi q r; and the angle of the rotor flux with stationary space a-axis; I can call this angle to be theta f r. And similarly this is the angle theta f r and similarly the stator flux will also have some angle with a phase a-axis; and I can call this angle as theta f s. So, if I am write down the expression for psi d s; psi d s is psi s into cos of theta f s.

You can see that if I want to find out the projection of the stator flux along the d-axis; this will be psi d s. And the projection of the stator flux along the q-axis will be psi q s. So, if I find out what is psi d s; psi d s will be given by psi s into cos of theta f s; that is what I have written here. Similarly, psi q s is equal to psi s into sin of theta f s; sin of this angle theta f s angle theta this is the angle theta f s.

And, in the similar fashion we can find out what is psi d r? Psi d r is psi r into cos of theta f r the projection of this the rotor flux along the d-axis is psi d r; psi r cos of theta f r and psi q r is equal to psi r sin of theta f r. So, these are the 4 fluxes that I can write down in terms of a magnitude of the flux and angle of the flux with respect to stationary phase reactor.

Now, the purpose of the writing this is that we can substitute this fluxes in the original torque equation; what you have here is that the torque equation has got the expression psi q s psi d r minus psi d s psi q r. So, what we can do here is that we can take this equation for the torque T e is equal to 3 by 2 p by 2 into L m by sigma L s L r. And we can write down this torque expression as psi s psi r into sine of theta f s into cos of theta f r minus psi s psi r into cos of theta f s into sine of theta f r.

And, we will take here psi s psi r common. So, if you take this psi s psi r is common here; that is equal to 3 by 2 p by 2 L m by sigma L s L r we can take here psi s and psi r common. So, we have sine theta f s into cos theta f r minus cos theta f s into sine theta f r. And that is the expression for the torque can be further simplified as psi s psi r; this quantity is sine theta f s minus theta f r or we can say that is equal to sometimes k some constant k psi s psi r into sine of gamma s r.

So, what it shows is that the expression for the torque is given by the product of the 2 flux magnitude psi s and psi r into sine of the angle between them. So, if we want to control the torque or if we want to change the torque; what we have to do? We have to change psi s psi r or we can change gamma s r; gamma s r is this angle. What is this gamma s r? This is the gamma s r; gamma s r is the angle between psi s this is my psi s and psi r; this is the psi r.

So, if we take this angle between the rotor and stator flux that angle is gamma s r; that is something similar to the torque angle. So, if I can change the angle of the angle between the 2 fluxes; I will be able to control the torque. Now, with this background we can say that torque can be controlled in 2 different ways.

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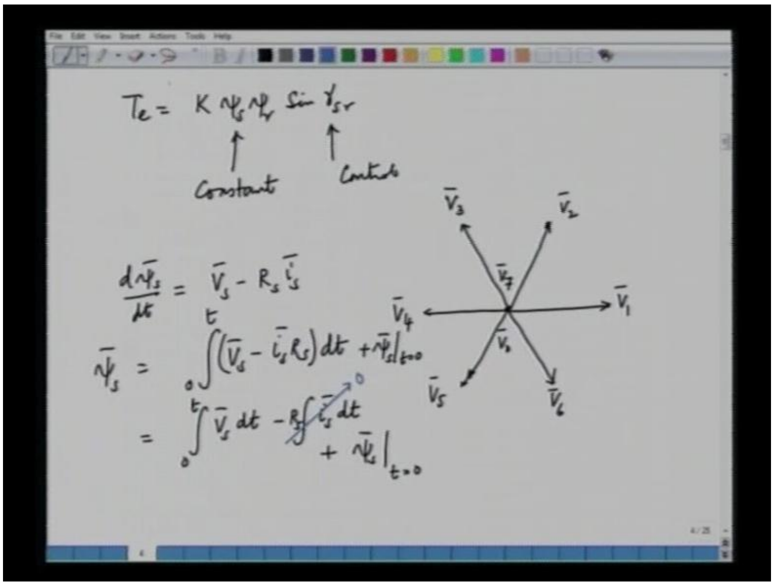

So, we can say here T e is equal to K into psi s psi r into sine of gamma s r. So, we can either control the flux or we can control the angle. So, if we control the flux it will be flux control; if we control the angle we call that to be the torque control. Now, usually you know that when we talk about the control of an induction motor; we keep the flux constant. Because the flux of the machines should be kept constant at the rated value. If we do not keep the flux constant the machine may going to saturation or the machine may operate in a operating appoint with reduced flux; it means the machine cannot deliver the rated power.

So, we should be able to or we should operate the machinery rated flux. So, psi s should be kept constant. In fact, what we are talking here we should be keeping the flux constant psi s constant; and here we can control gamma s r to control the torque. So, that is call the direct torque and flux control of induction motor. So, we will see how it is done.

And, we have already seen that in case of V S I; we have got 8 different voltage vectors. What are the voltage vectors? We can have v 1, v 2, v 3, v 4, v 5, v 6 these are the voltage vectors. So, we have 6 non-zero voltage vectors and we have 2 zero vectors; we have got v 7 and v 0 so we have 8 possible choices. And when we apply this voltage vector to the induction machine this vector is created in the space. And as a result the stator flux is affected. So, we know that d psi by d t this is the stator flux that is equal to V s minus R s i s. So, d psi by d t is the differentiation of the or the derivative of the flux linkage in the stator; psi is the flux linkage in the stator. So, if we differentiate that as per the faradays law it will be the induced e m f.

And, the induced e m f is V s minus i s R s; i s R s is the resistance drop. So, this is the induced e m f. So, if you want to find out the flux linkage psi s we can integrate this; V s minus i s R s into d t. So, if you integrate this we can integrate the entire expression. So, this is V s into d t minus integration of R s I can take common in this case i s d t. And of course when we take a definite integral I have to also consider the initial value of flux. So, we can say that this will be the initial value of flux is psi s if it is from 0 to t integration 0 to t. So, I have to take psi s a t equal to 0. Similarly, always zero flux; there may be some flux a t equal to 0.

So, when we when we integrate this expression; we also have take into account the initial condition. And initial condition is the stator flux linkage at t equal to 0. Now, this expression will tell us how we can control the torque of a induction machine. Now, we know that we can apply this V s and V s we can have 8 possible V s; s v 1 to v 6; v 0 and v 7. Now, first simplicity what we will do we will ignore the resistance drop; we know that the resistance drop is the fraction of the total voltage. So, what we can do is that we can approximately say this equal to 0.

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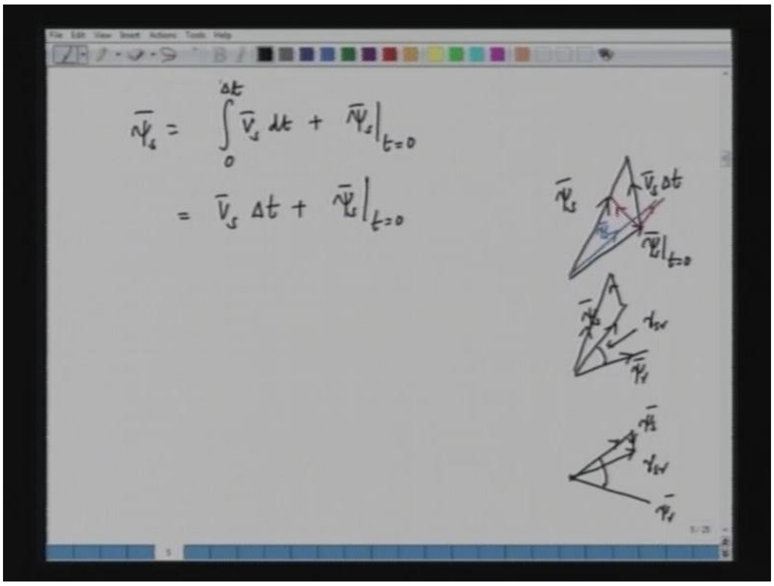

So, if we ignore the resistance drop; we can write down the expression in the following fashion; psi s equal to integral 0 to t V s d t plus psi s at t equal to 0. Now, this we have vector addition; what do you try to find out is the resultant flux that is psi s. And that is basically the vector sum of V s d t integral from 0 to t plus psi s a t equal to 0. And if we assume that the voltage vector remains constant for a small time and the small time is delta t.

So, what we will take here we will take the integration to delta t here; and we will assume that this voltage V s remains constant. So, we can say that that is equal to V s into delta t plus psi s a t equal to 0. So, it means psi s is the resultant of V s into delta t plus psi s t equal to 0. So, if suppose this is the initial flux psi s a t equal to 0 and we are applied some voltage vector that is V s into delta t; remember the time is the scalar quantity time is not a vector time is a scalar quantity. So, V s into delta t will have the direction of original V s and V s is one of the 8 voltage vectors.

And, if we complete this vector triangle we will get the resultant here; this resultant is psi s. So, this is our vector triangle and in one side we have got psi at equal to 0 and other side is V s into delta t. So, we have this is V s into delta t and the third side is the flux the stator flux that is psi s. So, it means if you want to control the stator flux vector you have to apply a suitable voltage vector V s. So, you know that this V s can be in various direction; it can be something like that, it can be something like that depending upon which voltage vector we are choosing it can one of the 8 voltage vector and 6 are non-zero voltage vector.

And, accordingly suppose this is my V s into delta t. So, the resultant this would be now may here. So, instead of this flux I will have this flux. So, it means we have control over the flux. And if we control over the stator flux this side what we are try to do; we are able to control the stator flux. So, if we are controlling the stator flux we are able to control the angle between the rotor flux and the stator flux for that movement; at that particular instant. Because rotor flux has got no option but to follow the stator flux. So, rotor flux in a induction machine lags behind the stator flux because stator flux creates the rotor flux.

So, if we have the stator flux in this direction, rotor flux is in this direction psi r. And we are able to control the stator flux instantaneously by applying a suitable voltage vector. So, we can increase or decrease this angle gamma s r. So, this gamma s r in this case can be increase or decrease depending upon how we control the stator flux; this angle is gamma s r. So, if you want to increase this gamma s r you have to apply a voltage vector.

So, that the angle is increase this angle is increase further. If you want to decrease this angle you can take another situation where the angle is reduce; this is the rotor flux psi r this is the stator flux psi s. And if you want to reduce this angle gamma s r what you do instead of moving away what we can do here; we can move towards the rotor flux vector. So, this is the resultant of the tube and hence the angle is reduced. So, we have a freedom; we have freedom to choose any one of the 8 voltage vectors and thus we can control the stator flux accordingly.

If we can control the stator flux accordingly we can control gamma s r; we can increase or decrease gamma s r. And if we increase or decrease gamma s r we basically we increase or decrease the torque. And hence torque of the machine is control directly;

hence the name is director control. But to achieve this to obtain this we have to use a lookup table. So, that we will see subsequently. Now, let us see that how is the torque control. So, to be able to understand that little in detail we will go back to a original 8 voltage vector.

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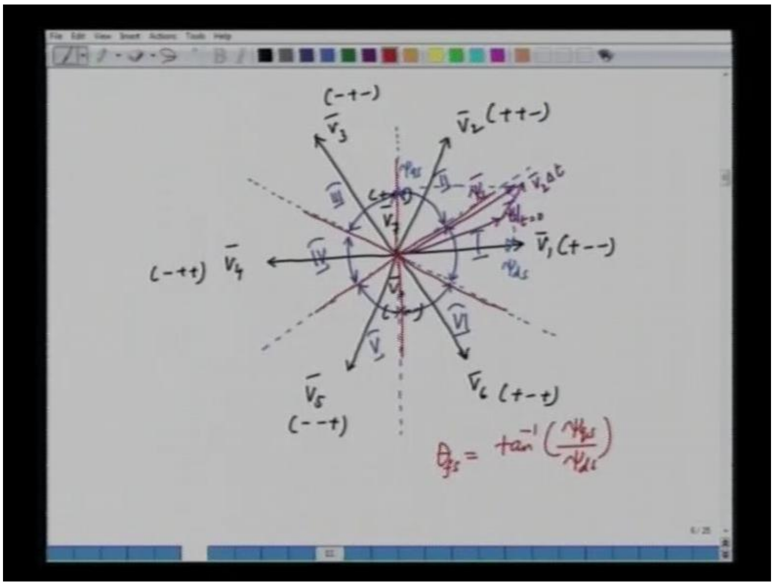

So, we have v 1, v 2, v 3, v 4, v 5 and v 6 and this is our v 7 the zero voltage vector v 0 also 0 voltage vector. And if you remember that each voltage vector by the associated with some switch condition. So, for example v 1 associated with plus minus minus; which means the phase a upper switch was turn on phase b and c the lower switches were turned on.

Similarly, v 2 us plus plus minus phase a and phase b upper switches at turned on; phase c the lower switch is turned on. Similarly, v 3 is minus plus minus v 4 is minus plus plus, v 5 in this case is minus minus plus. And v 6 is plus minus plus and v 7 is plus plus plus; it means the machine is sorted through the upper switches phase a, phase b and phase c plus plus plus means all the upper switches of 3 phases are sorted. Similarly, v 0 is minus minus minus it means the lower switches of 3 phases are on and the 3 phases of machine are sorted in the lower switches.

And, this is basically in the space we can have 8 possible voltage vector. And we can divide the whole space into 6 different sectors. Sector 1 we can call this to be we can have 30 degree angle. So, what will try to do here we are dividing the entire space into 6 different sectors. And what are the sectors? This our sector 1; we can call this to be sector 1, this to be sector 2, this to be sector 3, this sector 4, sector 5 and here sector 6. So, we have 6 sectors in the space and in the 6 sectors the stator flux which is rotating against synchronous speed can remain in any one of the 6 sectors ok.

So, for example the stator flux can be somewhere in sector 1 this is psi s; and suppose if I apply v 2; v 2 is along the directions. So, I will have this is my v 2 into delta t. So, v 2 into delta t will be parallel to the original v 2; and the resultant of this could be this; this is psi s. So, this psi s a t equal to 0 and if I apply v 2 for a time delta t; it will be v 2 into delta t the resultant of these 2 will be v s which is shown in the figure.

And, hence what I am trying to do I am able to control the stator flux. And if I am able to control the stator flux the angle between the rotor flux and the stator flux is automatically being control. And hence torque is control. The objective in this case is that the flux should be maintain constant. So, what we do we control the torque and flux within 2 hysteresis back. So, accordingly we have a flux controller; we also have a torque controller and that is realize in the following fashion.

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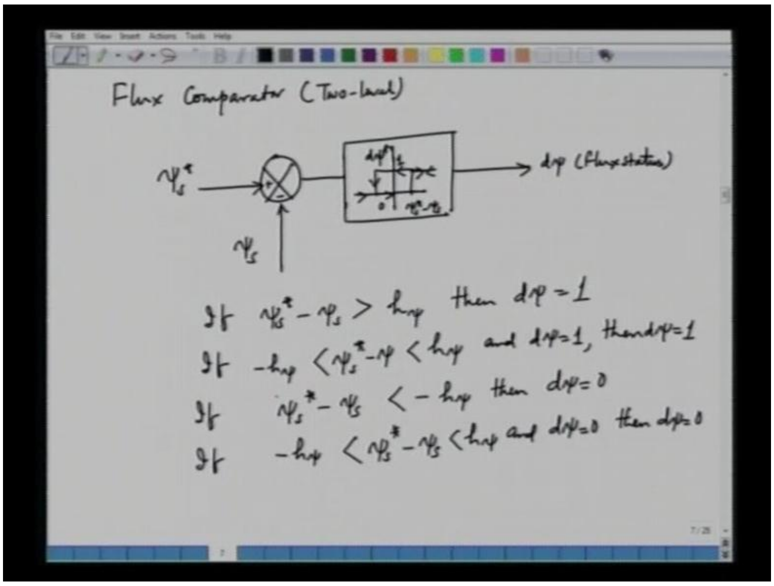

So, we have a flux comparator; what we do here is the following that we have reference flux psi s the stator flux psi s amplitude. And we compare that with the actual flux; we have a actual flux feedback psi is the actual flux. And we feed these to the error we feed to a hysteresis comparative. So, what we have here is the hysteresis comparator.

So, the hysteresis comparator looks like this. So, in the x-axis what we have here psi s star minus psi s the error. And in the y-axis we have the flux stator that is d psi; the output of this the d psi. So, this d psi is called the flux stator; this is called the flux stator and the flux stator can have 2 values it can either 0 or it can be 1. So, we can have here it is 0 and this 1. So, in the y-axis we have the flux stator is the x-axis we have the flux error that is psi s star minus psi s. So, this is call a 2 level flux comparator. So, we can say here this is basically a 2 level flux comparator; it means when the flux error goes beyond certain band the flux status is high. And when it goes below certain band flux status is low.

So, we can write this in the form of a logic. So, we can say that if psi s star minus psi s is higher than h psi; h psi is the flux band; then we can say that d psi is equal to 1 all right. And then we can also say that if psi s star minus psi s is greater than minus s psi and less than h psi it mean if is the flux error is within the band. And d psi is equal to 1 then d psi is equal to 1. So, it means if it is within the band the previous status is maintain; if earlier d psi is the flux status was 1; right now the error is within the band the flux status is maintain that is d psi it was previously equal to 1 right now also it will be equal to 1.

And, we can say if psi s star minus psi s is less than minus h psi; then d psi is equal to 0 the flux status become equal to 0. And we can say here that if psi s star minus psi s is greater than minus h psi and less than h psi and d psi is equal to 0 then d psi is equal to 0. If the flux error is within the band and previously the flux status was equal to 0; the status score is maintain it means the flux status within the band will also be equal to 0.

So, this is basically the expression in terms of the logic statement for 2 level flux comparison. So, what we are trying to do here we are trying to see the behavior of 2 level flux comparator. And we have seen that this is the these are the logic statement which will enable us implement 2 level flux comparator. Now, what we are trying do here we are trying to control the flux within the hysteresis band.

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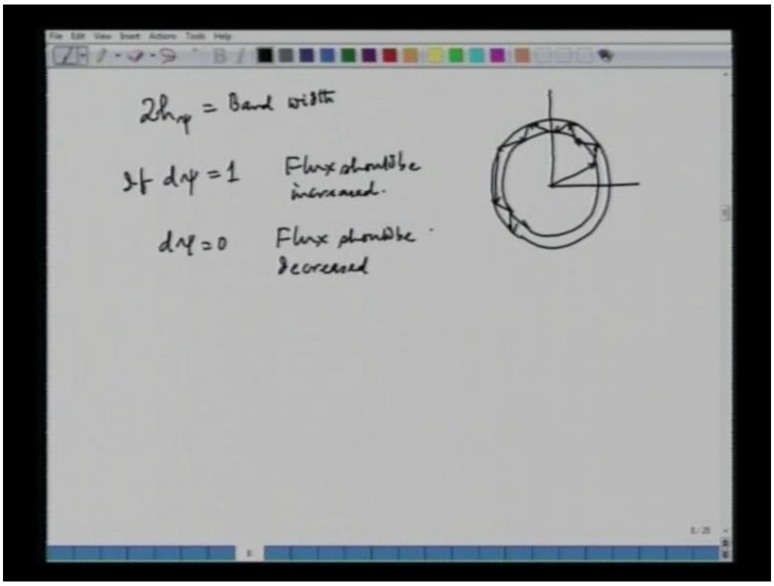

So, if you see that the flux should rotate in the circular fashion in the air gap; we are having a band for the control of the flux. So, if this is the flux the flux will be contain within this band this will go on changing no doubt. But this cannot come out of the band. So, we have to apply suitable voltage vector so that this goes on rotating. And it is confined to 2 bands and we have this h psi; h psi is the positive half of the band and minus h psi is negative half of the band. So, the total band is of the length that is 2 of h psi is the band width the width of the band.

And, what about the flux status? If we see actually the hysteresis comparator here is the 2 level hysteresis comparator. So, we can add here it is a 2 level hysteresis comparator; the output has got 2 level that hence it is call a 2 level hysteresis comparator it could be either 0 or a 1. Now, if d psi equal to 1 it means the flux should be increased; we have 2 status in this case; if d psi is the flux stator is 1 flux should be increase flux.

So, the flux status can have 2 different values; the flux status is d psi if it is 1 the flux should be increased; if it is 0 the stator flux should be decreased; and this can be increase or decrease by applying the suitable voltage vector from the voltage source inverter V S I. And we know that we have 6 non-zero voltage vectors and 2 zero voltage vectors. So, we have to apply such a voltage vector; so that star state in the flux status is fulfill. So, this is about the flux status and what about the torque comparator?

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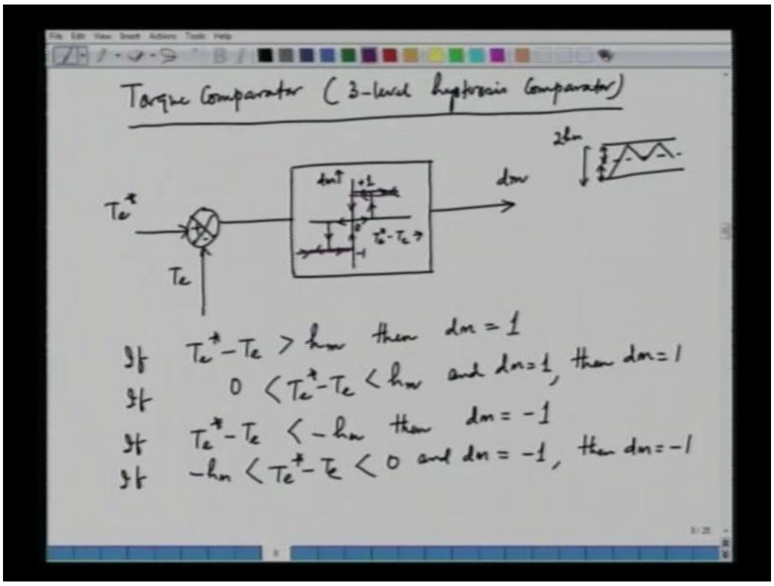

So, we can we can also have a torque comparator and here we have a 3 level hysteresis comparator. Now, why we have a 3 level hysteresis comparator is the following that in case of torque; torque can be positive, torque can be negative torque can also be 0. So, we can sometimes have positive torque say for example if we have a forward rotation the torque will be positive.

In case of a reverse rotation or in case of breaking torque could be negative. And sometimes you would like to keep the torque unchanged it means the torque should be neither increase not decrease. So, we can we can have also 0 status. So, therefore you know that you have we have a torque comparator here and the torque comparator is a 3 level hysteresis comparator.

So, this torque comparator is realize in the following fashion; we have the reference torque here and we have the actual torque. And this is say to a 3 level hysteresis comparator; why discuss 3 level because output can have 3 possible values. So, this is output here we have the torque status that is d m; this is the y-axis we have plus 1 0 x-axis we have T e star minus. So, this goes like this we have the various travelling path can go in the following fashion.

So, we can have plus 1, 0 or minus 1 depending upon now the operation, depending upon the error and how the error is increase or decrease. So, we can also write a logic statement state of a logic statement to implement a 3 level torque comparator. And the logic statements are as follows if T e star minus T e is greater than h n; h n is the half of the hysteresis band for the torque again the torque will be control within the hysteresis band. So, we have the torque in this case and what we are trying to do in this case is that the toque will also be control within hysteresis band. So, we have in this case the band width is 2 of h m; we have upper band here it is h m and the lower band is also h m in this case. So, the total band width of the torque is 2 into h m.

So, if T is star minus T e is higher than h m then the torque status d m is equal to 1. It means the reference torque is becoming more than the actual torque or in other words the actual torque is coming below the reference torque larger than an amount of h m. And hence the torque has to be increase is the torque has to be increase the torque status has to be 1; d m equal to 1.

And, if the torque error T e star minus T e is greater than 0 is less than h m. If it is within the upper band and previously the torque status was 1; then keep the status go unchanged then d m equal to 1. So, it means if we are travelling along this path like this; if earlier the torque status was 1 if an entering the upper band; the status has be maintain it means d m should also be equal to 1. And then we can also write down in the following fashion for the lower band; if T e star minus T e is less than minus of h m then d m is equal to minus 1.

It means if the actual torque is more than the reference torque; the torque has to be reduced or has to be decreased. And torque reduce means the status is minus 1; d m is equal to minus 1. And similarly if T e star minus T e is greater than minus of h m and if less than 0 and d m is minus 1. Then, the status co is maintain d m is minus 1 it means in the lower band if the torque status is minus 1 and if it comes to the lower band the torque status has to be maintain as minus 1. So, we are basically travelling along this line this is basically here it is minus 1; and if it goes into this particular region this is also be minus 1. And then we can have other statement for this implementation.

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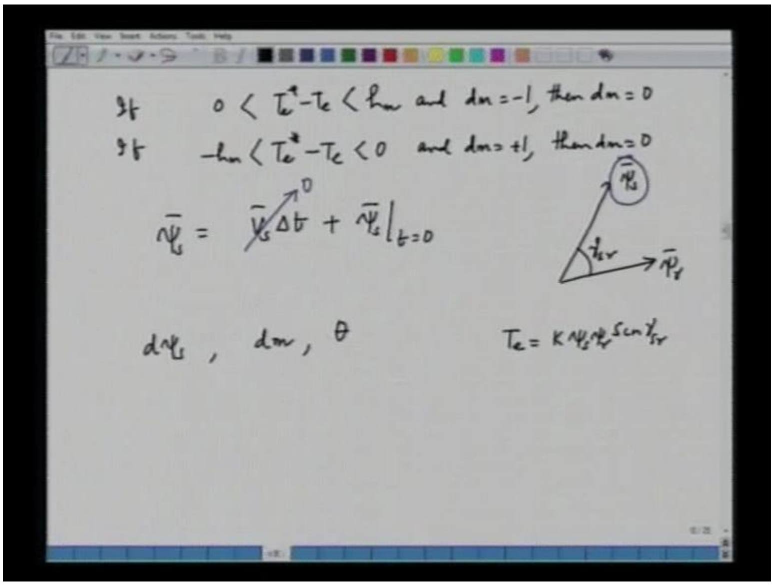

If T e star minus T e is greater than 0 is less than h m; and d m is equal to minus 1 then d m equal to 0. So, if we enter this part say for example we are travelling from minus 1 to 0; how does it happen? If we are entering in to this region if earlier it was minus 1 and we are entering in to this region then it will be 0 the status will be equal to 0; it means the torque neither be increase nor be decrease; we are safely within the band.

And, there is known into increase the torque or decrease the torque only where it goes beyond the band; then the torque will be control. If it is within the band then the torque will be safe. So, we can we may not increase or decrease the torque. So, this is a d m equal to 0. And in a similar fashion we can say that if T e star minus T e is greater than minus of h m less than 0 and d m equal to plus 1 then d m is equal to 0. If we are coming from the upper side from this side and we are going into this region. Then, the torque status will again be equal to 0 it means the torque did not be increased nor be decreased. So, if it falls within the band here and earlier it was plus 1 and then the torque status will be equal to 0.

So, this 3 level torque comparator helps us decide whether the torque will be increase or decrease or should be remain unchanged. Now, how to increase the torque? Now, the torque is increase by decreasing the angle gamma s r; we know that gamma s r is the angle between the rotor flux and the stator flux. And if we increase gamma s r the torque can be increase. And if we do not want to increase gamma s r we can freeze the flux; we know that we have this equation that psi s is equal to V s into delta t plus psi s a t equal to 0.

Now, suppose we do not want to increase the angle. And which angle the angle is the angle between the stator flux and the rotor flux psi r and this angle is gamma s r. If you want to increase the torque increase gamma s r; if you want to decrease the torque decrease gamma s r. Because we know that the torque expression is given as K psi s psi r into sine of the angle between psi s and psi r. So, if you want to increase the torque you can increase sine of this angle or if increase this angle the sine will change. And if you want to decrease the torque you can decrease gamma s r.

And, if we do not want to increase or decrease the torque gamma s r should be remain unchanged. So, the this flux is goes in this flux is neither accelerator nor decelerator. So, what we do here? We can do that by applying a zero voltage vector. So, if you suppose you apply V s equal to 0 if V s equal to 0 the flux is neither increase nor decrease; we know that psi s equal to psi s a t equal to 0 because we applied the zero voltage vector. So, by applying a zero voltage vector we are freezing the flux; it means the torque is neither increase nor decrease.

So, that is how we can maintain the status scope of the torque unchanged. So, this is about the various status of the flux and the torque. Now, what we have here we have we have the following; we know what is the flux status, we know what is the torque status. And in addition to the flux status and the torque status we should know the sector information; it means we should know in which sector the flux is remaining. Because we know that there are 8 possible sectors here; I mean 6 possible sectors sector 1, sector 2, 3, 4, 5 and 6.

So, this is the first sector, second sector and third sector is within this; the fourth sector, the fifth sector and the sixth sector. So, the flux can remain in any one of the 6 sectors and accordingly the voltage vector will be decided. So, we obtain the flux status in the torque status from the flux comparator and the torque comparator. And then we also find out the information about the sector in which sector the flux is remaining. And if we how to find out that information? That information of theta can be find out by taking the tan inverse of psi q s by psi d r; we know that we can always have 2 components of the fluxes. If we have the flux in here say for example we can find out is x component; and x component is psi d s and the y component here is psi q s. And if we find out tan inverse of psi q s by psi d s; what we obtain here is theta f s.

And, if we know this theta f s we can find out in which sector the flux remaining; depending upon the value of theta f s. And if we know the sector of the flux vector we can appropriately select the voltage vector to fulfill the torque status and the flux status. So, we draw a lookup table or we form a lookup table based on the torque status and flux status and also the sector information that is theta f s. And we will see how we form this lookup table.

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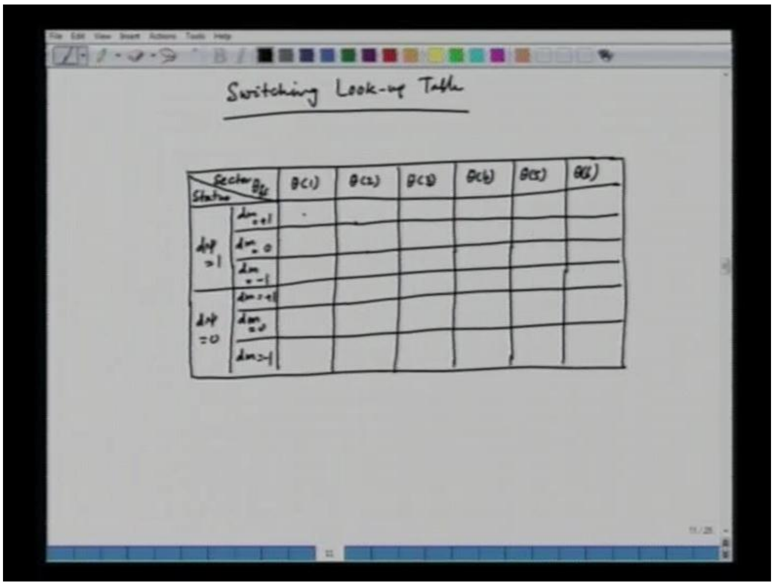

So, what we have here is the following; so we have 6 different sectors. So, we can so the various sectors here; this is the sector information that is theta f s. So, we have got theta 1 sector 1, theta 2 sector 2, sector 3, sector 4, sector 5 and sector 6.

And, here we have the status about the flux and torque. So, what we have here is this; this is the flux status d psi is equal to 1; this is the flux status d psi equal to 0. And similarly we can have the torque status. And as we know that the torque status can be up to a 3 values it can be plus 1 0 1 minus 1 because we have 3 level torque comparator. So, d m is equal to plus 1, d m is equal to 0 and d m equal to minus 1. Similarly, here also we can have 3 different torque status. So, we have d m equal to 0, d m equal to 0 here and this is d m equal to plus 1, d m equal to 0 and d m equal to minus 1.

So, we have to select a suitable voltage vector. So, was to fulfill the torque status and the flux status simultaneously. So, for example if we concentrate on the first element of this lookup table we have d psi equal to 0 and d m equal to plus 1; it means both we have to increase the flux and the torque. So, we apply here a voltage vector that is v 2. Now, if we have to increase the flux but keep the status scope the torque unchanged we apply a 0 voltage vector. Similarly, if we have d psi equal to 1 and d m equal to minus 1 we apply v 6. So, this is how we fill up the entire lookup table here. So, in the next class we will see how we will fill up this entire lookup table. And how we can have a close loop speed control of director controlled induction ((Refer Time: 54:50)).