Advanced Electric Drives
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Lecture - 19

Hello, and welcome to this lecture and advance electrical drive. In the last lecture, we discussing about the dynamics of torque production in a synchronous motor, when it was apprising under vector control. By vector control we mean gamma is equal to 0 and I d s is equal to 0. So, just we recap what we done in the last lecture we can just go back to our phaser diagram.

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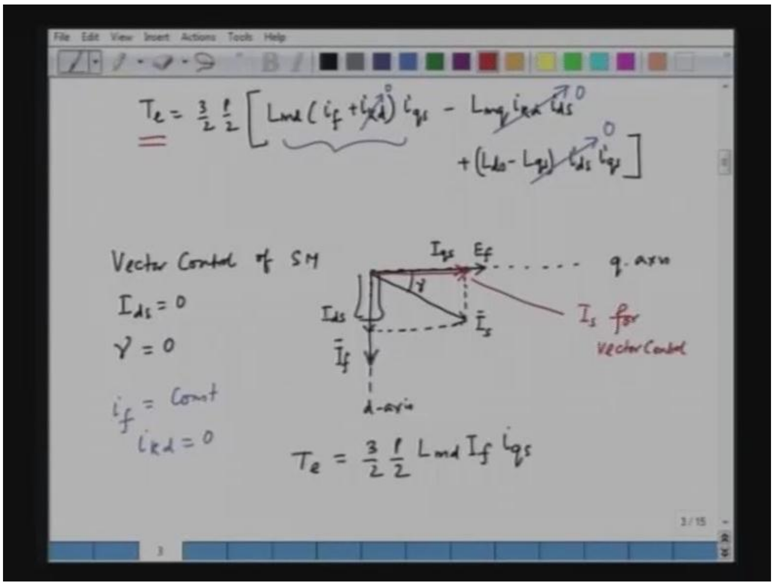

So, we have the d axis here, and this are q axis and the field current is naturally along the d axis. So, we can say that this is the field current and this is the, i f and due to the filed current, we will also have a field induce e m f, and the field induced e m f is in the q axis. So, this should be our field induce e m f that we can call as E f. And armature current phaser can be any orbiter direction.

So, what we do here, we have this is the current phaser I s the current of the stator this is also phaser, this is also a phaser, all this things are phaser quantity and this angle is gamma. And this I d s this I s can have 2 component; 1 along the d axis and other along the q axis. So, we can say that this is the d axis component. So, we can call this to be I d s and if you project this along the q axis this would be the q axis component we can call this to I q s. So, we are talk me about the vector control and the vector control we mean I d s is equal to 0.

So, for vector control of synchronous motor; we have I d s equals to 0 which also means gamma is equal to 0. And if gamma is equal to 0, the torque equation becomes very simple. So, what we have here this is the equation for the torque we can see that this is the equation for torque; T e is equal to 3 by 2 into p by 2 and the expression within the bracket. And here if we put I d s equal to 0, this quantity will vanish this is 0 is a product of I d s into I k d, this term is also equal to 0, because; this is the product of I d s and I q s. So, what we obtain here is this term which is L m d into i f plus i k d into i q s and further more if we keep i f constant.

So, for example, if we keep in this case i f constant we do not change i f, if we keep i f constant and I d s is also equal to 0 there is no flux change in the d axis. I d s is not existing and the field current is kept constant. So, in the d axis there is no flux change and since we do not have any flux change in the d axis the dumper winding currents in the d axis will be 0. So, we can say here that i k d is equal to 0.

So, if i k d is equal to 0 now, see the torque expression if we put i k d here equal to 0. The expression for the torque finally, will be 3 by 2 into p by 2 into L m d in to i f into i q s. So, it is something like a d c machine. We can keep i f constant here, what we can do here is that i f is constant. So, we can represent by capital I f, it is a constant quantity and we can change the flux with good dynamic by changing i q s. So, this is this is the principle of vector control of synchronous motor, we keep I d s equal to 0 or in other words the angle gamma is equal to 0. So, the hole current is align along the q axis.

So, this is a general diagram and for the vector control I s will be along the q axis. So, we can say that this is our new I s for vector control. So, the stator current for the armature current is the aligned along the q axis there is no component of current along the d axis and the torque can be control with good tangent response by controlling the stator current that is I s which is same as I q s. Now, what we do here is that we make 1 relaxation, we assumed that i f is constant. Now, if we say i f is variable; what happens? If i f is variable that is what that is what we discussing in the last lecture, but; if I f is variable. What is the situation? If i f is variable or it is not constant if it is not constant the dumper currents in the d axis will not be constant. So, due to the change of the field current in the d axis will have a dumper current in the d axis and the dumper current can be evaluated in the following way.

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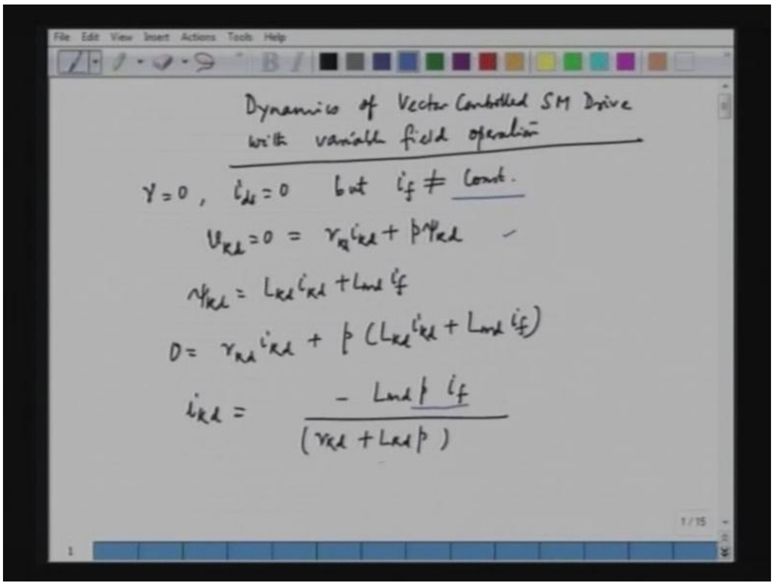

We have the dumper equation here; v k d equal to 0, r k d into i k d plus rho psi k d. And psi k d is the total flux linkage in the d axis dumper winding which given us L k d i k d plus L n d into i f. And then when we substitute this in the previous voltage equation and we simplify this i k d we do get an i k d. Because i f is not constant and hence the derivative of the field current this 1 is non-zero. So, due to the change in i f, we get change in i k d and i k d will be negative of this. So, if we increase the field current it means we are trying to increase the flux. And by the property, the flux linkage will be kept constant. And the flux linkage will be kept constant by the dumper winding current which will induce a negative current plus to maintain the flux constant for a time b.

In the steady state condition dumper currents will die down, because; it is a dissipative circuit we have the dumper inductance and the dumper resistance. So, the dumper current will die down and a time constant which equal o the dumper inductance by the dumper resistance. So, this is the time content L k d y r k d. So, with this time constant dumper current will gradually die down, in the study state condition the flux will reach the final value and the torque will also adjust to the final value.

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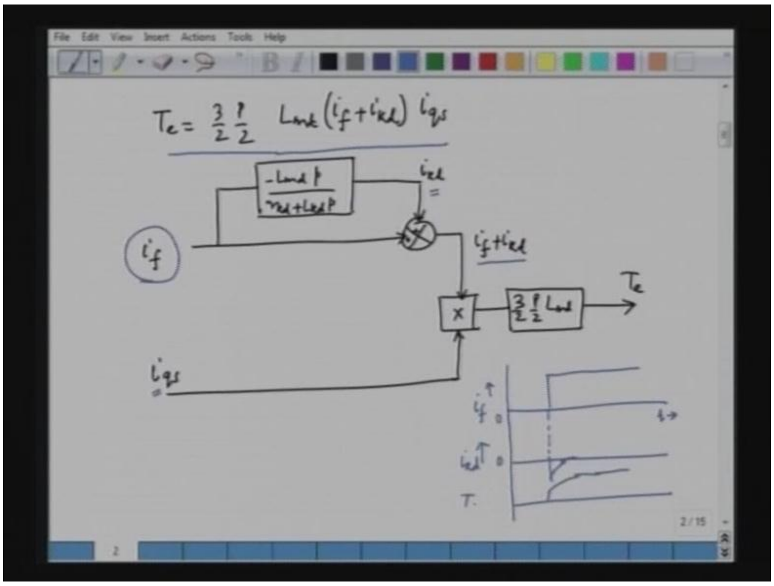

So, we will see that if this is the situation; the torque response is not instantaneous this is our expression for torque that we discuss in the last lecture. For the vector control drive we have T e is equal to 3 by 2 into p by 2 L m d in to i f plus i k d in to i q s and here i k d is non-zero, because; the field current is variable. So, this is non variable, when we change the field current will have a dumper current. And the dumper current will be negative of L m d p into i f by r k d plus L k d p and this dumper current will be added with the filed current and that will be responsible for the torque production with the interaction of i q s.

So, here what we trying to do; we trying to change the torque not by changing i q s by changing i f. So, we will see the response here, the response will look like this. What we trying to do here is this; that we are trying to change i f where, giving a step change in i f. In this case; this are t axis this origin. So, due to the change of the field current, dumper current will spring up, will appear and the dumper current will be such a direction. So, we has to keep the flux constant for the time b. Dumper current infect will be negative of the of p f p is the derivative operator. So, if we increase the field current, dumper current will be negative. If we decrease the field current dumper current will be positive. So, here we are increasing the field current and hence the dumper current here will be negative and it will d k down to 0, as per the dumper time constant.

So, due to this negative dumper current the torque which is the product of i f plus i k d and i q s will be delete. Because dumper current is gradually decaying down and the torque will gradually increase to the study value. So, this is the torque response initially it is 0 then, it will take some time to release the study value this is study state respond. So, there is a delay in the torque production. So, this is T e. So, we see that when we change the field current to change the torque the torque is delayed. And hence it is advisable to keep the field current constant. The field current change will induce a dumper current and will further delay the torque response. Now, this is about the vector control synchronous motor drive.

Now, we have already said that there are 2 conditions; 1 is gamma equal to 0. And gamma equal to 0 is called vector control as we are discussing right now. And if gamma is non-zero it is called angle control. Angle control is sometimes preferred, because; you know that in case of vector control drive as we have seen in the last lecture, although the tangent response is good, the torque response is very fast, the motor power factor becomes lacking. And that is a disadvantage especially, for high power application where, the power converter has to supply both the active power and reactive power if we implement vector control. It means i d s equal to 0. So, if i d s equal to 0 the motor power factor will be lacking and the converter has to supply both real power and the reactive power.

And, some situation it is prefer to only supply the active power. So, if we are interested to only supply active power; we operate the machine under unity power factor condition. So, for u p f operation or unity power factor operation, we have to us e angle control. This is the one of the example where, angle control can be used. So, in angle control gamma is not equal to 0. So, we will now discuss the response of the synchronous motor drive with angle control.

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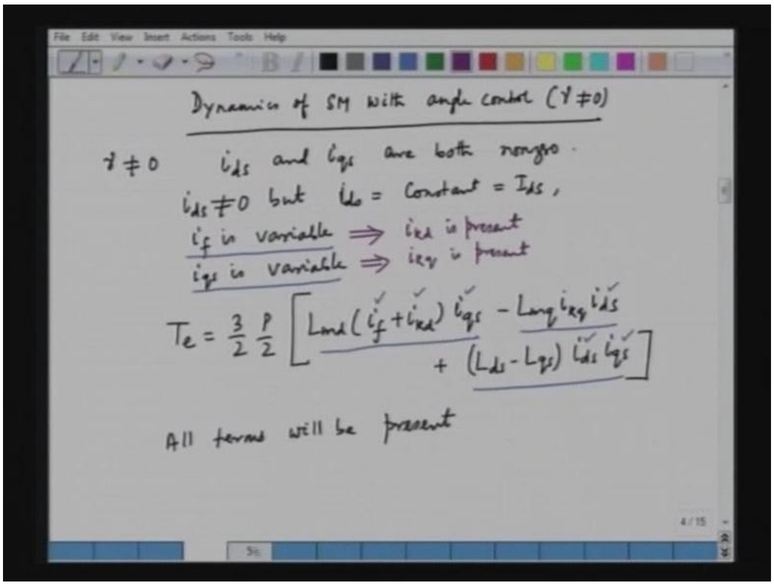

So, we will be discussing here; dynamics of synchronous motor with angle control which means gamma is non-zero. So, if gamma is non-zero; what happens? If gamma is non-zero the currents will have 2 components i d s and i q s. So, we can say that gamma here is non-zero which means i d s and i q s are both non-zero. So, we can say that i d s and i q s are both present. And here we can assume that i d s is non zero, but; i d s is constant. i d s is non-zero, but; I d s is kept constant and that is equal to capital I d s, but; i f is variable and i q s is also variable.

So, if we have this situation; if we see the expression for the torque, we can appreciate which all terms will be present. Now, let see the expression for the torque once again. The toque expression is given us 3 by 2 into p by 2 then we have L m d i f plus i k d into i q s minus L m q into i k q i d s plus L d s minus L q s in to i d s into i q s. So, if this is the torque expression what are the terms that would be present in the torque expression i d s is non- zero.

So, we cannot neglect this term, this term will be present, because; i d s is present here, i d s is also present so this term will be present this term this i q s is also present here. So, L d s minus L q s is the reluctant star that torque will also present. What about the field torque? i f is also present so this term will be there, and since; i f is variable i k d will also be present and i q s is non-zero. So, all this 3 term will be present. So, we can say that all terms will be present and this becomes little complex, because; equation of the torque for synchronous machine is not a simple one because it is a doubly exited system.

So, we have interaction of field winding with the stator currents, we have the interaction of the stator currents with the dumper currents. And hence when all the terms are present equation becomes complex. So, we can understand this interaction by drawing a block diagram. Now, please understand that here damper winding current will be present whenever there is a flux change. Dumper winding is basically a short circuited winding and whenever we have a rater change of flux linkage that winding will be circulating a current, may be in the d axis, and may be the q axis. In the d axis here we have assumed i f is variable here, i f is variable. So, if i f is variable, defiantly i k d will be present. So, we can say that this list to the result that i k d is present.

And, what about the q axis; in the q axis again, dumper winding was circulate a current whenever, there is rate of change of flux linkage in the q axis rotor and that is true here, because; i q s is also variable. So, i q s is variable here, and that leads to the fact that i k q is present. And we can of cores find out the expression for i k d and i k q by respectively solving the equation of the dumpers in the d axis and q axis. Now, let us draw the block diagram for the torque production. We can draw the block diagram for the torque production in the following way.

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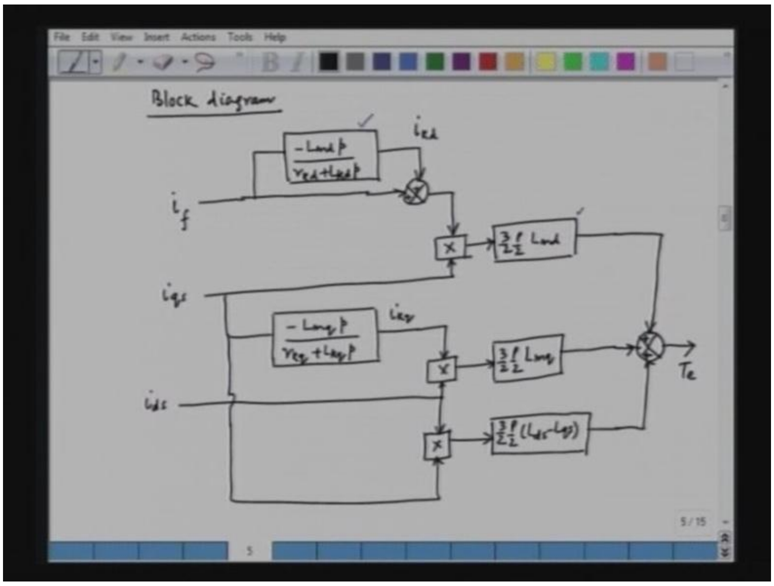

So, we have let us say the field current and the field current is changing and due to the change of the field current will have dumper current. And the dumper current is given by minus L m d p by r k d plus L k d p. So, this is a field winding current i f and this is the dumper winding current i k d which is appearing, because; of the change of the field winding current. And this will be leading to the first step. So, what we have here, this can be vector multiplier and the other variable in the multiplier is i q s. And this is again multiplied with some constant term 3 by 2 p by 2 into L m d. So, this is the first component of the first term of the torque.

We can say that the torque will have 3 distinct terms; this is the first term, second term and the third term. So, the first term has been shown in this particular figure this is the first term. What about the second term? We also find out the second term here, what is the second term, second term is minus of L m q i k q in to i d s. i k q will be appearing because of the change in i q s. So, i q s change will initiate a dumper winding current in the q axis. So, that we can shown here, that we have this i q s and i q s when we change this i q s dumper winding current in the q axis will appear and this equation can be similarly, derive similar to the equation in the d axis. We have similar equation in the q axis.

So, we can show that as minus of L m q p divided by r k q plus L k q p and this is i k q. And this i k q has to multiplied with i d s to produce a torque. So, this is multiplied with i d s so we again have multiplied here. So, we can multiplied this with i d s and then there is some constant, this constant is 3 by 2 p by 2 into L m q this is the second term. And we have the third term; and the third term is basically the reluctance term which is L d s minus L q s is the constant term into i d s into i q s. So, it is a product of the 2 currents in the 2 axis i d s in to i q s. So, this term is called the reluctance torque, it is coming up because of the saliency in the rotor when L d s is not equal to L q s this torque appears. So, we can write down the third term here, we have i d s here. So, we can we can multiplied that with i q s and the i q s can be obtained from this.

And then what we do here is that we have the constant term constant term is 3 by 2 p by 2 into L d s minus L q s. So, the summation of this 3 term will give us the final term. So, when we find out the final torque the final torque will have the following expression, this is negative here. So, we are discussing about the torque production in the angle control situation, when i f is variable. So, i f is variable, but; i d s which is non-zero plus constant. So, we have seen actually there are 3 different terms in the torque and all the 3 terms are present. So, the torque equation is little complex and we can show the torque production by means of a block diagram.

So, this is the block diagram that we are talking about. So, this is the first term that we have here, which is the interaction of i f plus i k d with i q s. The second term is a interaction of i k q because i q s is changing. So, we have change in i k q the dumper winding q axis current with i d s. And the third is the interaction of i q s with i d s this is our i d s and i q s they are multiplied. Then, we have a constant term which is 3 by 2 into p by 2 L d s minus L q s. So, the final torque expression is T e which has the 3 term the first term is here, the second term will have a negative sign in this case. And the third term is the reluctance torque which is L d s minus L q s 3 by 2 p by 2 into I d s in to I q s.

So, in angle control case; we have seen that the torque expression is not very simple, it is quit interactive and hence the torque does not build up is simultaneous. It takes some time to build up, because; interaction of the dumper winding currents. And the damper winding currents spring up in the tangent condition in the study state they again go down to 0. So, due to the existence, presence of dumper winding current the torque is delete. So, we will take another situation where, all currents are variable i f is variable i d s is variable and i q s is variable. So, that is the most general situation.

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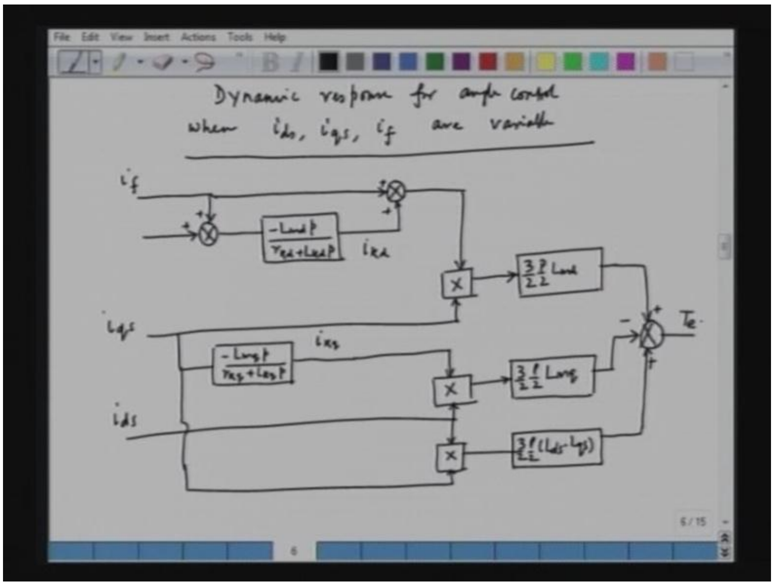

So, dynamic response for angle control; when i d s, i q s, i f are variable, all are variable i d s, i q s, i f all currents vary. Under that situation the torque expression all the 3 terms will be present as you already seen, but; it will be little more complicated, because; i d s is not constant. So, the dumper winding d axis current is contributed not only because of change in i f, but; also because of change in i d s. So, we will see by block diagram how this torque is produced. Now, if we see by means of a block diagram we will see the following.

We have the field current here i f and then we have the d axis stator current plus and plus then, due to the change of this 2 current we will have i k d. So, i k d will come up because this currents change L m d p by r k d plus L k d p and this is i k d. And this i k d is added with i f and then what we have here is i q s. This is the first term; we have the torque constants here 3 by 2 p by 2 L m d. So, we have first term of the torque equation. Similarly, we has the second as we have seen in the previous case; the second term is the interaction of i k q with i d s. Now, how i k q is coming to picture, because; i k q is the q axis dumper current that comes in to picture because of the change of i q s the q axis stator current.

So, we have i q s and then from because of the change of i q s will have i k q minus L m q p by r k q plus L k q p and this will be i k q. And this i k q is again multiply with i d s these are i d s and this is multiplied with a constant 3 by 2 p by 2 L m q, this is a second term. Now, what about the third term; third term is the reluctance torque which is the product of i q s with i d s in to L d s minus L q s. So, we have the product of i q s and i d s. So, i q s is i d s is here and will have again another multiplier and i q s obtained here. And then we have the constant, and the constant is 3 by 2 p by 2 in to L d s minus L q s. So, these are the 3 terms of the torque; the first term which is the interaction of i f and i k d with i q s, second term the interaction of i k q with i d s, the third term the interaction of i d s with i q s.

And, then we have the final expression for the torque; we have a summer here, this is plus and then we have this is minus, the third term which is coming from this side this is the reluctance torque and the final torque is T e. Now, we have already seen that how complicated is the equation for the torque. Now, here this is the general situation that everything is variable gamma is not equal to 0 which is which is under control. And the all possible torques are present here, the filed torque, the dumper winding torque, and the reluctance torque.

So, this is a general situation; as I was talking little earlier that we have vector control which means gamma equal to 0, the torque response is very good. And when gamma is not equal to 0, we call to be angle control. Vector control leads to a lagging power factor we have already seen that. Angle control by means of angle control we can achieve unity power factor, which is expedient for high power drive. So, we can think of high power application of synchronous motor where, we want to operate the motor under you will deep power factor of the condition. So, we will not discuss the operation of synchronous motor drive under unity power factor condition for very high power application.

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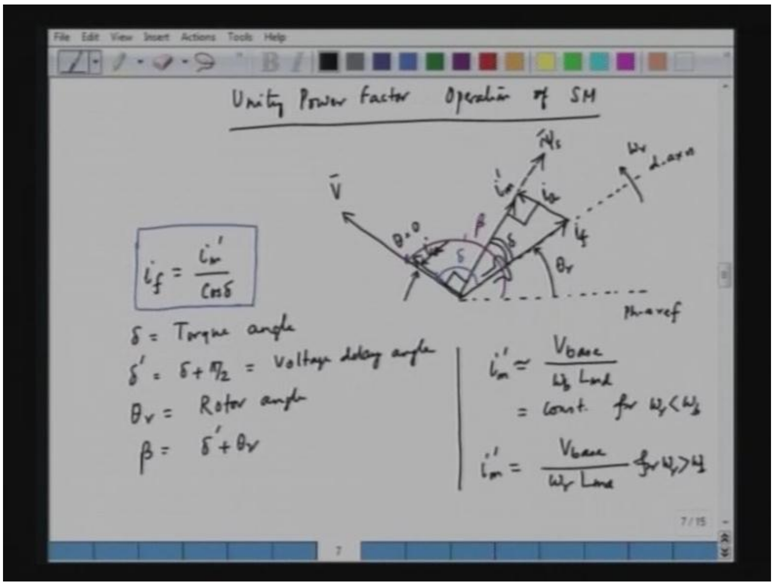

So, unity power factor operation of synchronous motor; now, before we understand this is unity power factor of operation, we make some simplification. For simplicity we would not consider saliency, we assume that the motor is a cylindrical motor. So, what we have here, we have the phase a reference. So, we can draw the phase a diagram this is our phase a reference, the stationary phase a, and the rotor is rotating at a speed of omega r. So, we have the d a axis of the rotor, this is the d axis of the rotor and the rotor is rotating at a speed of omega r and this angle which the rotor suspend with phase a reference is angle that is theta r is the rotor angle.

And, naturally we can say that the field current in the along the d axis. So, the field current phaser this should be i f. And we also have a armature current and armature current will be in this direction, this is armature current we get call these to be i a. And the result at of the field and the armature in the machine, we have 2 excitations. The field excitation and the armature excitation and the resulted of the field in the armature is the resultant current which we call to with the magnetization current. So, this is the resultant m m f or the magnetizing current is I m prime which is the resultant of i f vector and i a vector.

Each is one is a vector, because; of m m f is a vector. So, we can represent each current as a vector. So, this i m is a vector which is along this direction as per the triangle, the law of triangle we have 2 sides of a triangle and third one is i m. And this armature current is so control that this angle is 90 degree. The angle between i a and i m prime is 90 degree ((Refer Time: 33:50)) this i m prime is the magnetization current which will be producing the status flux linkage.

So, we can assume that the stator flux is along the same direction. So, we can assume that the psi s is along the same direction we can call these to be psi s. and the vector for the armature voltage is right angle to psi s, because; psi s will induce the armature voltage or the armature back e m f. If we neglect the resistance drop the back e m f or the induce e m f and the voltage are at the same. So, the induce e m f will be leading the flux by phi by 2. So, if this is our flux vector the induce e m f vector will be phi by 2 leading the flux vector. So, this is the induce e m f vector. We can call these to be E or V and we call these to be V, because; we assume that the resistance drop is negligible. So, if this is V this angle is also 90.

So, under this situation we have a right angle triangle here, and we can write down the following expression. Now, this angle between d axis and the stator flux psi s this also vector, this is called the angle that is delta the torque angle. So, we can from this right angle triangle, we can say that i f is equal to i m prime by cos delta. So, if we maintain this relationship, we can achieve u p f operation or unity power factor operation. So, this i a will also be along the voltage vector, we can say this is also i a, this vector is i a, this vector is also i a. So, we see that if we have this right angle triangle condition the voltage and the currents are in phase and hence we can say that the power factor is unity.

The angle between the V and I theta is equal to 0. Here, theta is the power factor angle and cos of theta is 1. So, we can say that the motor is operating under unity power factor condition. We can define few other angle here. So, this angle is called voltage delay angle, this is delta prime. So, we can find the various angles here, the first angle in this case is delta. Delta is called the torque angle. This is the angle between the d axis and the stator flux. And then we have this delta prime which is equal o delta plus phi by 2, we can call this to be the voltage delay angle. This is delta plus some constant that is phi by 2 and this is the angle by which the voltage is delayed or leading some the d axis of the rotor. And then we have theta r; theta r is a rotor angle, this is our theta r is angle between the phase a reference on the d axis and the motor is rotating at a speed of omega r. So, angle that d axis obtains with phase a is called the rotor angle.

And, then we also define another angle called beta. Beta is equal to delta prime plus theta r. So, this angle is beta, we can say that this angle is the beta. So we have all this angle defined in the phaser diagram here, and to achieve this unity power factor operation we have to have certain condition. The first condition is that the field has to be control as per this equation. So, this is what we have to implement. We have to insure that the field current is control in occurrence with this equation. This i m prime is the magnetization current. So, what we usually do, we keep the air gap flux constant. So, if you want to keep the flux constant, we keep the magnetization current constant. So, i m prime is kept constant up to the base speed.

And, what is the value of i m prime? Now, i m prime is approximately given in the following way. So, this I m prime is equal to the base voltage V base by omega base the base frequency into L m d. So, we assume that delta angle is very small. So, i m prime can be approximately the current through the d axis magnetization inductance. So, this is L m d is the d axis magnetization inductance. So, omega b is the base frequency in radiant per second. So, the base voltage per phase is equal to i m prime in to omega b in to L m d. So, i m prime can be approximately equal to b base by omega b in to L m d which is kept constant.

For omega r less than omega b; omega r is electrical speed when the electrical speed is then the base frequency in radiant per second. We can assume that this i m prime is kept constant. Now, beyond the base frequency beyond the base speed i m prime is changed. And how it is changed? It is changed in the following fashion. i m prime is equal to V base by omega r into L m d, for omega r higher than omega base. So, when the speed increases beyond the base speed the maintaining current is reduced, b base is a constant quantity base the voltage is constant that does not vary. So, if the speed increases beyond the base speed we decrease i m prime this called field weakening and what about the voltage here.

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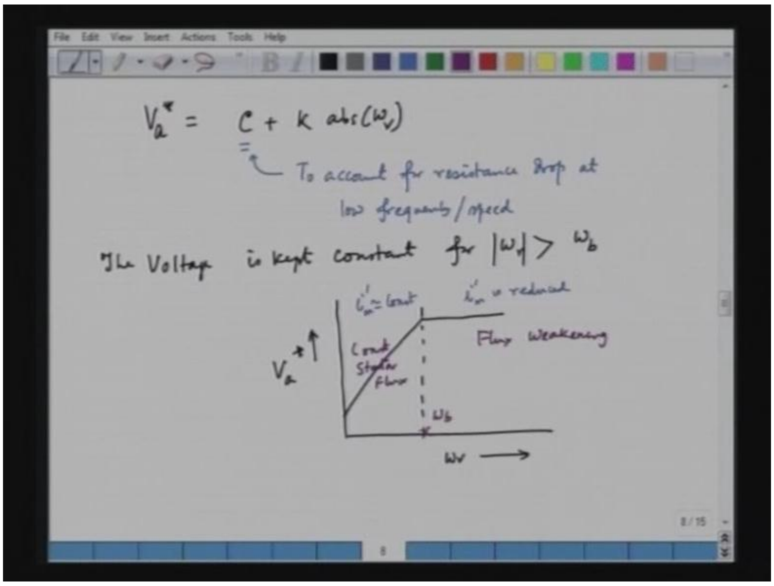

So, we can define the armature voltage in the following fashion; that is equal to a constant plus k into absolute value of omega r. We know that we have to keep the volt per hertz constant. To keep volt per hertz constant; we change this armature voltage as a function of the frequency, when the speed increases voltage also increase proper straightly. And the C here, this constant quantity C here is added to account for the resistance drop at low frequency or low speed. So, we know that we have to increase this voltage with the increase of speed and after the base speed. We know that we have to keep the voltage constant, because; when omega r is equal to omega b the voltage reaches the rated value.

So, after the base frequency we keep the voltage constant. So, we can say that the voltage is kept constant for omega r higher than omega b. So, we can say omega r modulus it can also be a negative speed, for omega r higher than omega b the voltage is kept constant. So, this is actually the structure here. So, if we see the function of the voltage this is V a and this is our omega r. So, initially we have offset in this case that is C and as the frequency as the rotor speed changes here, the voltage is increased and then after the base speed is raised the voltage is kept constant.

So, this is the function of V a against omega r as a function of omega r. and this is basically done to keep the maintaining current constant below the base speed. Here, we can assume that i m is approximately constant, here i m is reduced. So, we can call this to be field weakening or flux weakening and here we operate under constant stator flux. So, up to the base speed this is basically our base speed. So, below base speed we operate under constant stator for condition and beyond base speed we go for flux weakening. So, this is basically the voltage profile and the voltage is a function of the speed as a speed increases voltage also changes beyond the base speed the voltage maintain constant which leads to flux weakening.

So, this is basically the way we control a synchronous motor under u p f operation under unity power factor operation. Now, what is the application of this kind of drive, this scanned up drive is applied in high power application. For example, we can have a cyclo converter feeding a synchronous motor. Now, when we have a cyclo converter the stator is feds of cyclo converter. So, we have phase a phase b phase c which are fed from cyclo converter. The field is also controlled from a rectifier.

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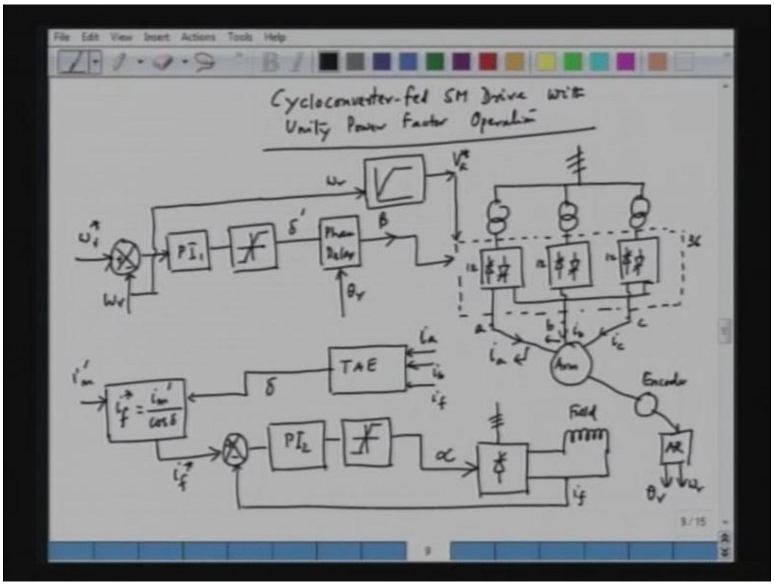

So, we can see how we can have a cyclo converter fed synchronous motor drive with unity power factor operation. So, we can show in terms of a block diagram and see how we can implement this block diagram in practice. So, we have cyclo converters. So, these are the cyclo converter blocks and the cyclo converter, each one is having 2 anti parallel bridge. And we have a isolation transformers here, and then we feed the armature of the synchronous machine. So, and we to have a encoder for the position feedback. So, this is our encoder.

So, this has to variable speed drive. So, we have to our speed control, we have to have speed feedback. So, here is our reference speed omega r star and then we compare that with actual speed and we feed the error to a P I controller. It is the simple P I controller then, we have a limiter, to limit the output of the P I controller. P I controller usually consist of a proportional gain and integral gain. So, output sometimes can feed infinity if not properly limited. So, we have to use a limiter following a P I controller to limit the output.

And, then this has to be something to do with the torque. So, the output of the limiter is the voltage delay angle delta prime, as we have already discussed. So, this voltage delay angle is this angle, delta prime, angle between d the axis and the voltage vector V or V a. And here this we add with the rotor angle, we have a phase delay block it is simple, it is addition of delta prime with theta r and what we obtain is beta. And this is the cyclo converter; this is the cyclo converter module that we have. And the cyclo converter has 3 phases. So, we have phase a phase b and phase c and in every phase we have 2 anti parallel bridges.

This is our phase a, this is phase b and this is phase c. Similarly, we have the currents here i a here we have the currents i b and here we have the currents i c to the armature of the synchronous machine. And this current is by directional, it means the phase a current is a a c current. So, if a c current we mean it can be positive, it can also be negative. So, to facilitate it the by directional current flow we have to 2 bridges connected in anti parallel, 2 S C R as thyristor bridges connected in anti parallel. So, this is shown schematically by 2 thyristors in anti parallel. So, each 1 is a bridge. So, per phase we have 2, 6 pulse bridges. So, per phase we have 12 thyristors. So, 12 here, 12 here and 12 here, we have 6 plus 6 12, 6plus 6 for phase b, and 6 plus 6 for phase c.

So, in total we have 36 thyristors in the cyclo converter feeding the armature of the synchronous machine. And controlling the cyclo converter; to control the cyclo converter we need a reference voltage. As a reference voltage means; we need amplitude and a phase angle. And the phase angle is beta, what about the amplitude? The amplitude is obtained from the speed. So, we have already seen that we can have this voltage generated by means a function generator. So, this is our V a star and the V a star is obtained by means of function generator from the speed signal. So, we can feed here the speed signal and we can generate V a prime. And this V a prime and beta will solve by the reference of the cyclo converter.

So, we have 3 phases and we can generate the any 1 phase. So, for example, if we generate phase a, we can generate phase b, and phase c. Phase b nearly lags behind phase a by 120 and face c lags behind phase b by 120. So, in fact, if we have the amplitude angle of phase a we can generate all 3 phase reference for the cyclo converter. And then this cyclo converter will be feeding 3 voltages to phase a, phase b, phase c of the armature. What about the field winding? If we see the field winding; the field winding is exited by means of separate converter. So, this is our field winding and we use a converter for energizing the field winding.

So, we have again a 3 phase converter and this is the field winding which is fare from the 6 pulse 3 phase converter. And we control the field winding in occurrence with the equation that we have already derived. What is the equation i f prime equal to i m prime by cos delta. So, what we have here is the following, we can generate the reference current of the field winding i f star that is equal to the magnetization current i m prime by cos delta. And this becomes the reference current for the field winding. So, we have positive and negative here, this is i f star. And we can have a current sensor to sense the field winding current, we have the i f as a feed back here, and then this field winding current error is fed to a second P I controller P I 2. And we can have a limiter also here.

And, then we can generate the triggering pulses alpha to the converter bridge. So, this is how we can control the field winding current. The field winding current is control by means of a independent 3 phase 6 pulse converter as shown in the figure. Now, how do you obtain delta? Delta is a torque angle. So, we can obtain this delta by means of a block called torque angle estimator. So, this is basically estimation block. So, what we do here is this we take the feedback of the currents here, we take i a here, we take i b we can have the current sensors, we can we can sends i a, we can also sends i b and user the feedback to this torque angle estimation block.

And, we also have the feedback of the field current i f. So, from i a i b and i f we can calculate the torque angle. And this torque angle delta will be input to this field current referring generator block. So, i f star equal to i m prime b cos delta and delta is obtain from the torque angle estimator. So, we keep this I m constant here, we can have the i m fed here as a reference. And we can generate delta in this case, we can calculate cos delta and we can find i f star. And this theta can be obtained from the encoder, we can have another block called angle resolver from the encoder we can calculate theta r and omega r. So, this is an example how we can use a synchronous motor drive with unity power factor condition.

And this is a cyclo converter phase synchronous motor drive and the cyclo converter are very robust, they can be designed for very high power application and this kind of drive that we are discussing can be use for very high power and low speed application. For example, in cement keel, mind winder, and applications for high power and low speed as we have already mention. So, in the next lecture we will try to understand how we can calculate the torque by using a torque angle estimator, and what is an angle resolver, and how can we find out the speed, and the rotor angle theta r by means of an angle resolver.