Advanced Electric Drives
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Lecture - 18

Hello and welcome to this lecture on advance electric drives. In the last lecture, we are discussing about the steady state operation of a synchronous motor, the motor is operating on the steady state condition, and what do we mean by steady state condition; the steady state condition we mean the speed is constant and the currents and the voltages which are applied to the machine are having constant amplitude and phase angle. So, we will start from that steady state operation of synchronous motor in today lecture.

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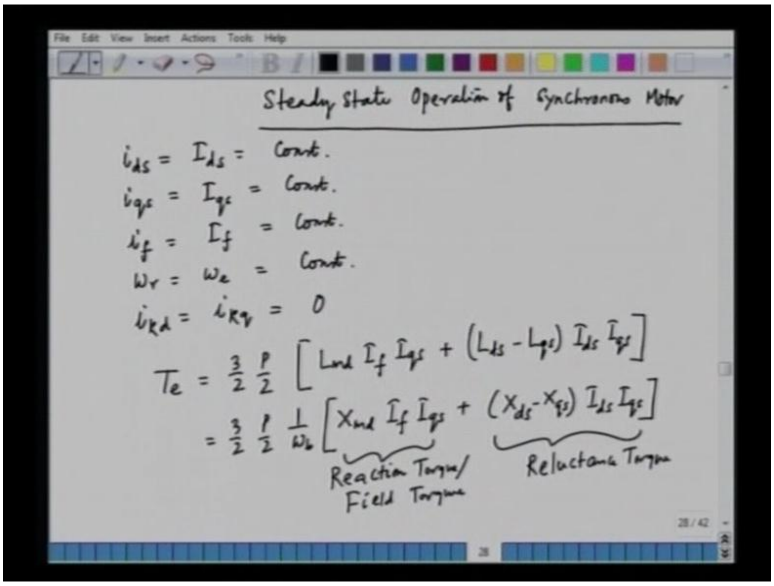

Now, in this case by steady state we mean the following things the currents are constant in amplitude and phase angle the phase angle is also constant. So, we can say here that we are of course we are talking in rotor reference frame; the currents are evaluated in the reference frame attached to the rotor which is rotating as synchronous speed. So, we can say that i d s equal to I d s is constant. And similarly we can also say that i q s is equal to I q s that is also constant. So, the currents are constant is phase angle and also in amplitude these are the stator currents.

Now, what about the rotor current the field current is also constant. So, we can say here that i f is equal to I f here this is also constant; the field current is also constant and the speed is constant. So, we can say that omega r is equal to omega e; the motor is rotating at synchronous speed in the steady state condition and that is constant; we know that in synchronous motor we also have the dumper windings. And the dumper windings are present in the d axis and q axis respectively; what about the damper winding currents? Here, we also assume at the flux linkages in the rotor are constant it means psi k d and psi k q are constant there is no transient disturbance. And hence naturally the damper winding currents will be equal to 0.

So, we can assume here that i k d is equal to i k q these are 0. And under this condition we had evaluated the torque in the last lecture and the torque is the steady state torque of a synchronous machine. And we can expense this steady state torque in a following way Te was given by 3 by 2 into p by 2 into [L m d, I f, I q s plus (L d s minus L q s) into I d s into I q s]. So, this is the torque inductor inductions; we can also replace the torque in terms of react chances. Because we know that the inductions can be obtained by dividing the reactions by the base speed. So, we can also say that is equal to 3 by 2, p by 2, 1 by omega b; omega b is the base frequency in radian per second into [X n d, I f into I q s plus (X d s minus X q s) into I d and I q s.

Now, this torque expression does not have any damper winding currents because the damper winding currents are equal to 0. And this expression has got 2 distinct parts; the first part this part is called the reaction torque this is because of the reaction between the field and the stator current or the armature current; this also called the field torque it is produced because of the field current. So, we can call this to be the reaction torque or field torque what about the second term; second term if we see this basically an expression which has got x d f minus x q f and this is called the reluctant torque. Because the torque is a functional X d s minus X q s it means; if we have a silent pole machine in a silent pole machine we have X d s different from X q s. In fact, it X d s is higher than X q s in a silent pole vowed phase in synchronous machine.

So, we have a torque production and that torque is given by X d s minus X q s into I d s into I q s. So, this is called the reluctant torque which only appears in a silent pole machine. In a cylindrical machine X d s is equal to X q s; since, X d s is same as s q s the torque is equal to 0. So, these are the 2 torques which appear in the steady state in a synchronous machine.

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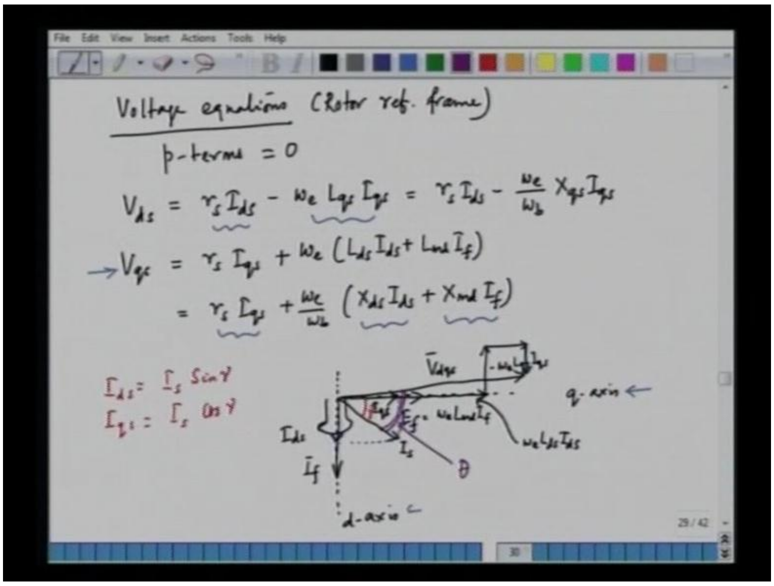

Now, fobbing near the torque equation we would also like to see the equation for the voltage; the voltage equations are as follows. So, we can write down the voltage equations and these are in the rotor reference frame. And since we are talking about the steady state situation the p terms are equal to 0; the p means the small p means d by d t. So, we can say that the p terms are equal to 0. Because we are talking about the steady state operation; in the steady state condition, in the rotor reference frame the variables are all d c variables. Because if we observe the currents of the stator from the rotor reference frames the currents and the voltages in the steady state condition would appear to be d c variables. And since we are talking about the steady state operation the p terms are equal to 0. So, the equations are further simplified.

So, we can write down the equation in the d axis; V d s we are writing capital because these are d c variables that is equal to r s into I d s is a resistance drop minus the speed is omega r; as omega r as same as omega e. So, we can say this omega e into the stator flux linkage in the q axis that is psi q s. And what is psi q s that is L q s into I q s; we can also rewrite this in terms of reactance here r s into I d s minus omega e by omega b into X q s into I q s the equation is very simple and this is a d c equation it is a algebraic equation, because we are talking about the steady state condition.

Similarly, in a q axis if we write the voltage equation in a q axis; we can say here what is V q s? V q s is equal to r s into I q s plus the rotor speed into the q axis flux, d axis flux. So, here omega e is a rotor speed and the d axis flux linkage is given by L d s into I d s plus L m d into I f; dumper currents are 0 they are not existing. So, we have the d axis flux linkage is given by L d s into I d s plus L m d into I f because I k d is equal to 0; because we are talking about the steady state condition. Now, this can be written in terms of reactant also. So, we can that is equal to r s, I q s plus omega e by omega b into X d s, I d s plus X m d into I f.

Now, from this 2 voltage equation we can draw the phasor diagram. So, we can draw the phasor diagram with an intention to find out the relationships between the phasor relationships, between the voltage and the current. So, we can draw a phasor diagram. So, to draw the phasor diagram we have to represent all the variables in terms of phasor. So, let us say this is our d axis. So, this is our d axis because we are talking about the silent pole synchronous machine; we have distinct d axis and q axis. So, this is our d axis and this is our q axis and the d axis would have the field winding. So, we can; so that in terms of the field pole and the field current is along the d axis. So, we can say this to be i f. So, we can see there we have 2 components in this case a d axis component of voltage and q axis component of voltage V d s and V q s.

And, we can write this 2 equation in the d axis and q axis respectively. So, in the q axis we can; so this term, so for example, if you so this term here this is basically the q axis equation and we are representing all the variables in the q axis. So, this X m d into I f or L m d into I f into omega e represents the field induced p m f. So, we can say that is equal to E f. And what is E f; E f is same as omega e into L m d into I f. So, this is this term and then we also have a term which is omega e into L d s into I d s that is also in the q axis. So, we can; so that the term s that is this term is omega e into L d s into I d s. And what about this currents I d s and I q s; the stator current will be allow in obituary direction this is the armature current I s and this I s can be resolved into 2 components along the 2 axis d and q respectively.

So, if we resolved this along d axis this would be I d s and if we resolved the same current along the q axis we get I q s. So, we can resolve this along the q axis here and we get I q s. And this omega e into L d s into I d s is basically the component of this current along the d axis that is I d s. Similarly, apart from the resistance part; we have already accounted for this part and this part this resistance part we can add little later. So, let us come to the q axis. So, in the q axis, d axis we have this term; in the d axis what we have here is minus of omega e L q s into I q s. Now, the d axis here is vertically down wards this is our d axis minus of omega e into L q s, I q s is opposite to d axis. So, we can show that this is our d axis that is minus omega e, L q s into I q s. So, this is again an induced area which is shown as a phasor, then we can add the resistance drops.

Now, the resistance drops are r s into I q s which will be in the in the q axis. And then r s into I d s which will be in the d axis and a result on voltage would be some as here. So, this is V d q s this also phasor. So, we have been able to write the equation in the d axis and the q axis we have 2 algebraic equations and we separated these 2 equations and we added the phasor in the q axis, in the d axis. And we could draw the final space vector for the phasor of the voltage V d q s; the V d s q s is the phasor of voltage applied to the stator synchronous motor.

Now, here we can also define a value called gamma; gamma is angle between the current phasor and q axis. So, this is our angle gamma; this angle is gamma. So, we can very well say here that what is I d s; I d s is equal to I s into sine gamma and I q s is equal to I s into cos gamma. So, we can write down component of the stator torque I d s and I q s in terms I s and gamma; gamma is angle between the stator current phasor and I s and the q axis which we have shown here.

Now, the purpose of this analysis is that we can find out the power factor is here; the power factor is angle between applied voltage here and the current phasor. So, this is the power factor angle; so we can say that this angle between the V d s and I s and this is equal to theta; theta is the power factor angle. So, this is the phasor diagram of the signal motor under the steady state condition. And we have deliberately taken a silent pole synchronous machine to show the stator phasor to get the reserve tank voltage phasor applied to the synchronous motor.

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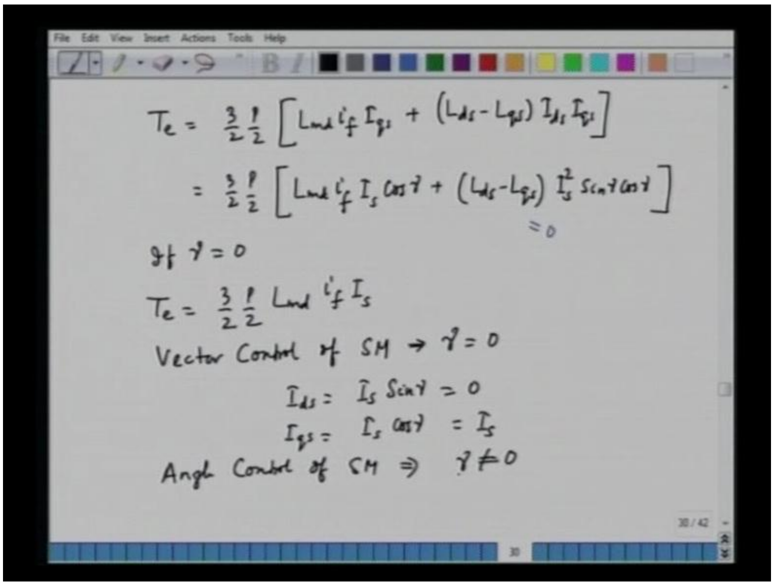

Now, from this we can also find out to the torque. So, we have already seen the expression for the torque. Now, if we just rewrite the torque expression. So, we will obtain here T e is equal to 3 by 2 into p by 2 into [L m d i f, I q s plus (L d s minus L q s) into I d s into I q s]. And we have already seen that the first part is called the reaction torque or the filter and second part this called the reaction torque. Now, if we express in this term of let say I s only we can also say that is equal to 3 by 2 into p by 2 (L m d i f what is I q s; I q s is given as I s into cos gamma that is we have already seen what is gamma here I q s is I s into cos gamma; gamma is angle between I s and q axis. So that we have already seen there and that is why we have taken [L m d into i f into I s into cos gamma plus L d s minus L q s] and if we replace this I d s and I q s derived by I s sine gamma and I s cos gamma respectively. So, we get here I s square sine gamma and cos gamma.

So, this is the equation that we have this equation is a equation of torque equation of synchronous machine under steady state condition for also this is determine complex because this involves I s square is a non linear equation. So, if you have a simplified the torque expression from the point of view of each of control; we would like to take some condition here on the condition is gamma equal to 0. And if you put gamma equal to 0; gamma angle between I s and I q of the q axis is equal to 0; we will see that cos gamma is equal to 1 and sin gamma equal to 0. So, we can see that T e is equal to 3 by 2 into p by 2 into L m d into i f into I s and the second term vanishes this term becomes equal to 0; the second term does not exist and we have only the first term.

And, in the first term what we can do here is that we can keep i f constant and we can change I s; I s is the stator current. So, we can keep the field current constant and varies the stator current and control the synchronous machine just like a d c machine and this condition is called the vector control of the synchronous machine. So, we can say that this is called the vector control of synchronous machine. So, if gamma equal 0 what are the 2 components of currents we know that I d s is equal to I s into sine gamma that is become to 0. So, if gamma equal 0; I d s that is what about I q s? I q s is equal to I s into cos gamma that is equal to I s same as to the stator current.

So, in case of a vector control synchronous motor I d s does not exist; I d s equal to 0 and on the torque is controlled that is controlling I q s. And if we want to have any higher dynamic response we can keep the stator current constant and control the torque by controlling the stator current or the armature current. So, this is what we have here and what about if gamma is not equal to 0; that is not vector control and we call that be the angle control.

So, we can say that angle control gamma is not equal to 0; if you operate motor on any other condition for which gamma is non 0 that is called angle control of synchronous motor. Because for that the dynamic is not for in case we have vector control time. Now, we will see that how the dynamic improves in vector control drive when you have gamma equal to 0. Now, before that we will take some implementation resource. Now, if gamma equal to 0; how we can implement vector control synchronous motor drive system?

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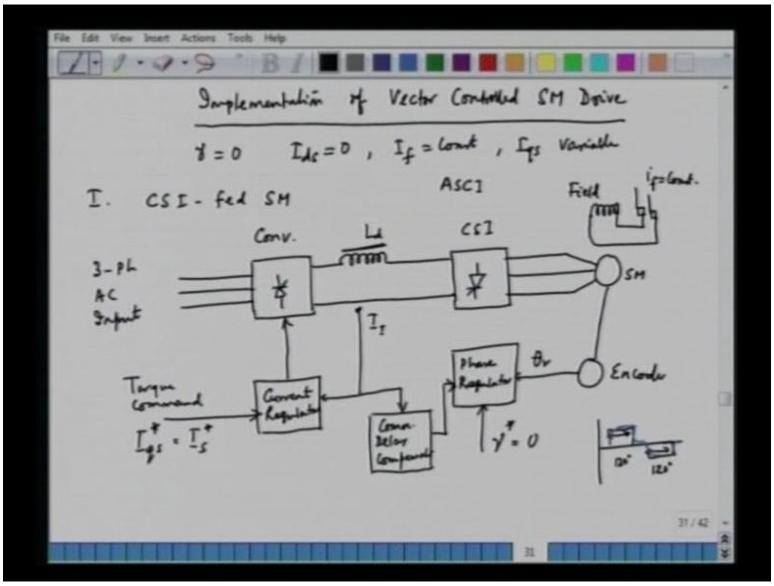

Now, we will see that how implement of implementation of vector control synchronous motor drive. Now, here gamma is equal to 0. So, we are saying that gamma equal to 0 which means I d s is equal to 0. And we can keep I f constant and I q s is variable we can have 2 approach; one approach is that implement the drive using a current source inverter. So, if you use current source inverter you can inject the current in such a way that I d s become to 0 and I q s can be controlled by changing the cell in current. So, the first implementation is C S I fed synchronous motor.

So, here what we have in this case is the following that we have a force committed C S I this is the simulate block diagram these are C S I. And we have dissolving here and we have a large inductor in the dissolving in the keep current constant. And the C S I feds the synchronous motor and we have the field winding here and the field winding is the slip link; and we can keep i f constant these the field wind. And we have to also control we have the 3 phase A C condition and this is the converter or the 3 phase converter; we have 3 phases A C input and here we have a phase regulated; to control the synchronous motor we have to use a position center that is very much associated. Because the motor is having with self control mode on that we have position feedback we cannot have control. So, we have to have measurement of theta r.

So, this is achieve by using an encoder here we obtain the position information that is theta r. And here as you already discussed that we can make gamma reference, gamma start is equal to 0; we are talking about vector control drive. So, we can make gamma this angle between I q s and I s phasor is equal to 0. And then what we have we can have a current frequency we have a current regulated. And we will give a torque command and the torque command is same as I q s gamma because here gamma is variable. So, we can give a reference I q s; if we change the I q s the torque automatically change. So, this I q s same as I s.

So, we can give the command for stator current to the current regulator and the current regulator we have the feedback of the dissolving current. So, we can have a current sensor here and this I I; let us say that this inverter input current is being same here by means of a current sensor. So, we have a current sensor here and then the triggering signal; the signal generated and the converter is controlled so as to achieve the current regulation. So, in the steady state condition I I; so the inverter current will be match that the required current might is to be injected to be stator of the synchronous machine.

Now, when we go for this current regulation we know that in case of this C S I is a auto sequence commutated C S I. So, we call this to be auto sequence commutated C S I. So, here what we have in the case is that that is a phenomenal called overlap when we have more and more current the output current is not exactly what we have go; in ideal condition what we have here is this that output currents will be a quasi squirrel by this and this duration is 120 and we have symmetrical condition in the positive half and in the negative half. But however when the current increases there is a progressive delay in the overlap so we call that it to be a overlap delay. And because of that the current actually lags little bit by this angle.

So, the actual current becomes something like this it take some time derives take some time fall here similarly, it take some time arise in the opposite direction falls like this. So, effectively the current is delayed. So, to compare this for overlap delay we have to give some compensation here. So, here what we have is that; we have the commutation delay here commutation delay compensation. So, this is obtain this basically function of I I and this is given to the state regulator. So, this delay is because of the commutation; the commutation progresses and there is a delay of the current as we increase the current magnitude the commutation delay also increases; and to compare for that we have to have a compensator.

So, that we advance this angle in such a way that delay is canceled. So, this is actually overall symmetric diagram of vector control synchronous motor drive we just made the C S I fed. Now, there is other way of implementing the same vector control drive that is by using a current regulated falls is modulated C S R.

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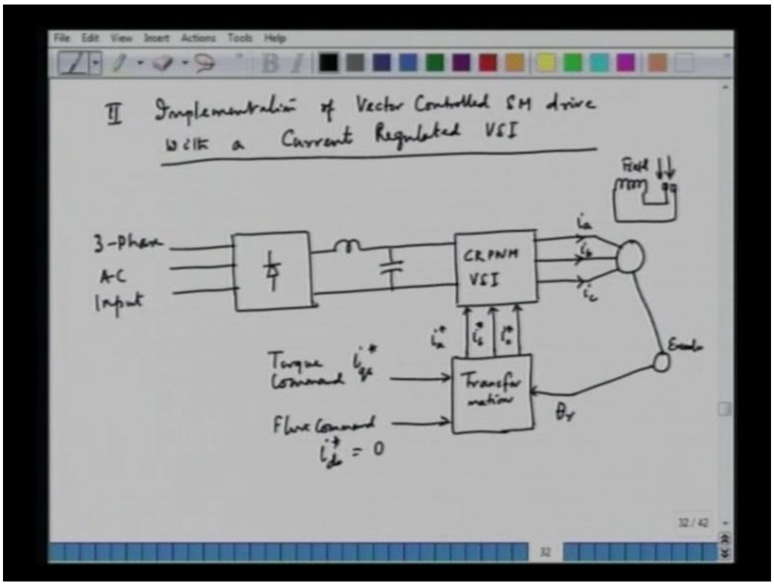

So, we will see how we can implement vector control synchronous motor drive using c r p double wave inverter tank. So, we will see that implementation of vector control synchronous motor drive with a current regulated voltage source inverter. Now, this drive is popular for medium for application not for very higher application; this involves a P W M voltage source inverter. And here the P W M frequency is a expected to be in the range of you kilo hertz to achieve good current regulation. So, this drive is suitable for low to medium application for approvals up to 100 kilo volt not in the mega volt rate.

So, what we have here; we have C R P W M and C S I. So, this is the V S I we have and the feds the stator of the synchronous motor. And similarly we have the field in this case and field is separately exacted we have the stripling in this case. So, we can have the still current here we have a separately exacted field winding here and then we will have the encoder for the position feedback. And this V S I is supplied form a rectify and uncontrolled rectify bridge it could be a 3 specify bridge. So, we have 3 phase A C input and then we have small filter here small inductor and capacity filter out to the refues in the rectify output.

And, what we have fed to the current regulated P W V S I at the 3 reference current; I s star, I d star, and I q star. And these are the basically actual current here and i a, i b and i c the inverter this injects this i a, i b and i c in such a way that they are close to i a star, i b star, and i c star. So, this adopts the hysteresis current control to control the 3 currents of the 3 phase a, b, c in such a way that the current follow their reference value very closely. So, this i a star are i b star and i c star are obtain by means of a transformation and the transformation is basically by the rotor angle. So, what we have here is the root angle which is obtain from the encoder; we can call with the theta and the rotor angle transform this V d s and V q s into i a, i b and i c.

So, what we have here; we have 2 commons in this case and the commons are torque common and this is i q s star and we have the flux common i d s star; for this i d s star made equal to 0. So, what we give here we have i d s and i q s are we make deliberately I equal to 0. So, as a vector control because gamma equal to 0 same as i d s equal to 0 and we apply here and i q s and this block is the transformation block. So, we will transform this i d s and i q s from rooter reference frame to the actual stationary reference frame. And the i a, i b and i c are the current in the stationary reference frame which become the reference current for the P W M and V S I. And the V S I inject this current to the stator phases of the synchronous motor.

So, as you already seen that we can also implement the vector control of synchronous motor drive from a current regulated P W M voltage sources inverter and this is suitable for low and medium application up to few 100 kilo of volts not in the mega volt range. Because of this involves a P W M and V S I which we shall call the power limitation. And what we have here is that we are able to transform; in this case we have a transformation here and we transform i d s and i q s into i a, i b and i c .And, this i a, i b and i c are the reference current for the C R P W M for the C S I.

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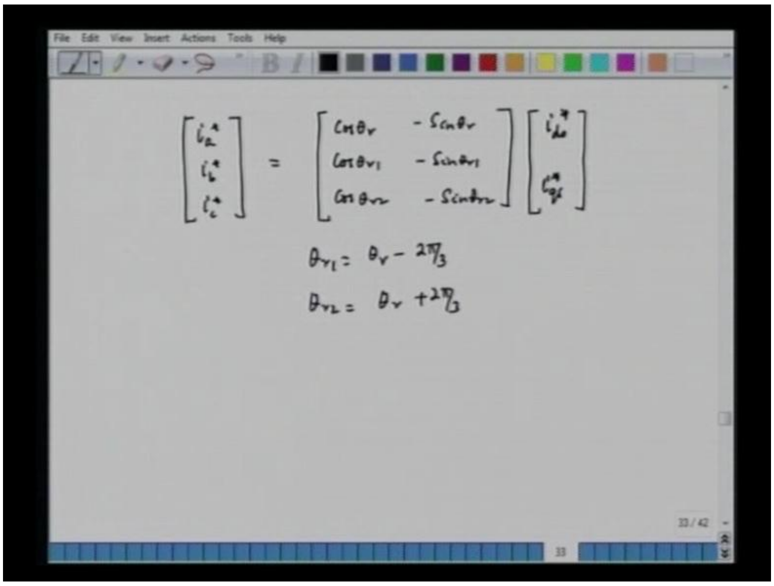

Now, what is this transformation; this transformation we have already discuss in the previous lecture just to recaps late that once more we can write down that transformation once again here. So, we obtain what we have to obtain this i a star, i b star and i c star. And we obtain that by a transformation involving theta r and we have cos theta r, cos theta r 1 and cos theta r 2, minus of sine theta r, minus sine theta r 1, minus sine theta r 2. And here we have i d s star the reference value of i d s current and we have i q s star is the reference value of q axis stator current. And theta r 1 is equal to theta r minus of 2 by a 3 and theta r 2 is equal to theta r plus 2 by 3.

So, this transformation transforms i d s and i q s into i a, i b, i c with which are used for the reference for the C R P W M and C S I. Now, this actually is the as for the implementation. So, we can ask it earlier that how are we guarantee that in vector control synchronous motor drive the response is quite fast. Now, to be able understand that we have to derived the equation for the torque of synchronous motor.

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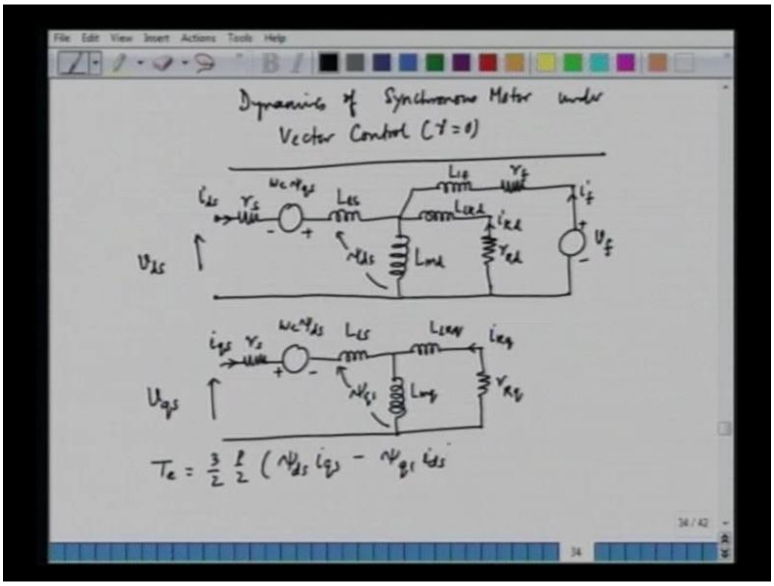

Now, this also we have already torque in the fast; we will just recaps late the torque equation that we are derived in the earlier pre lecture of this particular course response of the dynamic of synchronous motor under vector control which means gamma equal to 0. Now, we are always talking about of always trying to model in this synchronous machine in the rotor reference frame; it means our reference frame d and q axes are housed on the rotor. So, we can write down the equivalent circuit in the d axis and q axis respectively. So, in the d axis what we have; we have the resistance, we have the back e m f we have the leakage inductions of the stator, we have magnate induction of the stator then we have the leakage of the dapper winding, the resistance in the dapper winding. And then we have leakage of the field winding, the resistance of the field winding and then we have the voltage of the fill winding.

So, this is v d s and similarly, we can also write down the q axis equivalent circuit, the resistance to back e m f, the leakage induction in the q axis stator, the magnetizing induction in the q axis and then we have the leakage of the dapper winding then we have the resistance of dapper winding. So, this is the q axis voltage v q s in the d axis equivalent circuit; we can define the various of parameters and also the variables. So, we have the stator resistance here r s, the leakage of the stator is L l s, the field leakage inductor is L l f, the field resistance is r f, dumper leakage inductor L l k d and the dumper resistance is r k d; all the variables are referred from the timer speed.

And, then we have the magnetizing inductor L m d here and this is the speed voltage v f this is the field current is i f, this is the dumper current is the i k d, the stator current here is i d s and this is the damp e m f and what you have here is polarity and this is omega e into psi q s. Similarly, here in the q axis we have the stator resistance r s this is i q s in the stator q axis current, L l s is the stator leakage inductions then we have L m q is the magnetizing inductions of q axis, L l k d is L l k q the leakage inductions of the dumper of q axis and this is the our q axis dumper current i k q and this is r k q the resistance of the dumper all the parameter are respectively primary side.

Now, here we can be derive the expression for the torque expression this is our psi d s the flux linkage in the stator d axis and this back e m f in the q axis would be this flux and this minus this is omega in to psi d s. And this flux linkage psi q; the flux linkage in the q axis stator which is the flux linkage associated with the magnetizing inductions of q axis and the linkage inductions of the q axis. So, we can write down the expression for T e is equal to 3 by 2, 3 by 2 into psi d s, i q s minus psi q s into i d s.

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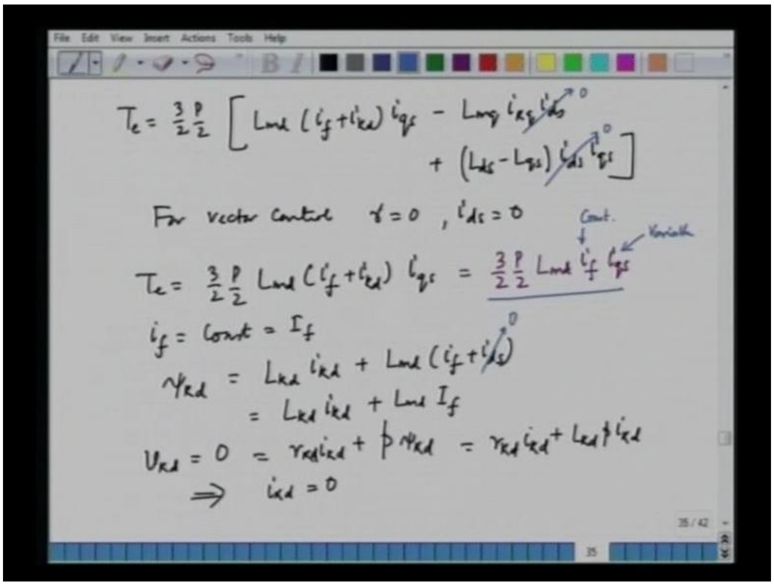

And, if we simply this will get the following expression T e is equal to 3 by 2 into 3 by 2 into [L m d (I f plus i k d) into i q s minus L m q, i k q into i d s plus L d s minus L q s into i d s in i q s. So, this is the expression of torque involving all variable this is the exact expression for the torque both the under steady state condition and the tangent condition; here we the try to understand the dynamic of the vector control synchronous motor drive. So, we have to take into account the tangent condition as well we are not only talking about the steady state condition, we are talking about the steady state condition as well as tangent condition. So, here all currents will be existing; we have the current of the field winding, current of the damper winding in the d axis, damper winding in the q axis, we have i d s and i q s.

Now, in vector control drive we put gamma is equal to 0. So, we can say that vector control gamma is equal to 0 and it also means i d s is equal to 0. So, if you put i d s is equal to 0 in this equation what happens so this quantity will vanish we have an i d s here and this i d s will be 0. And similarly here also this quantity will be also be 0. So, we can write down the expression for the torque T e is equal to 3 by 2 into p by 2 in L m d, i f plus i k d in to the i q; this expression is simpler then the complete torque equation but yet involves i k d; i k d is a. So, i k d is damper d axis current. So, what is the value of i k d? Now, to be able to find out the value of i k d; we have to write down the equation of the d axis damper current. Now, if you see here that i f is constant, i f is not changing that is equal to capital I f.

And, what about psi k d psi k d is equal to L k d into i k d plus L m d into i f plus i d s. But here under the condition that we are operating with vector control i d s is 0. So, this quantity does not exist is equal to 0. So, what we have here is follow and i f is constant. So, we can represent that i f by capital I f should be constant quantity and we can write down the equation for the damper; the damper is v k d and the damper winding is half circuited winding there is no voltage applied in the damper winding. So, v k d is equal to 0 it is a starter winding that is equal to r k d, i k d plus p psi k d.

And, what is psi k d and what is i k d is L k d plus L m d in to i f; i f is constant. So, the derivative of a constant quantity is equal to 0. So, the p the small p here small p signifies d by d t the derivative operator. So, that is equal to r k d into i k d plus L k d into p i k d. Now, since have any applied voltage this current i k d will be 0 for steady state condition even the tangent condition if we do not change i f this current will be equal to 0; it means which implies i k d is equal to 0. So, we have the equation for the torque T e is equal to 3 by 2 p by 2 L m d, i f ,i k d into i q s. So, we can write here that this is equal to 3 by 2 into p by 2 into L m d into i f into i q s. So, i k d is equal to 0; i k d does not exists because of field current is constant.

So, since we are keeping the field current is constant i k d is equal to 0. So, this is actually the equation of the torque and the say if we keep i f constant of the torque is proportional to i q s. So, this equation is simple equation in the sense that i f is kept constant. So, we can keep i f constant and we can change i f we can change i q s to change the torque. And if we change the i q s torque will be change proper straightly.

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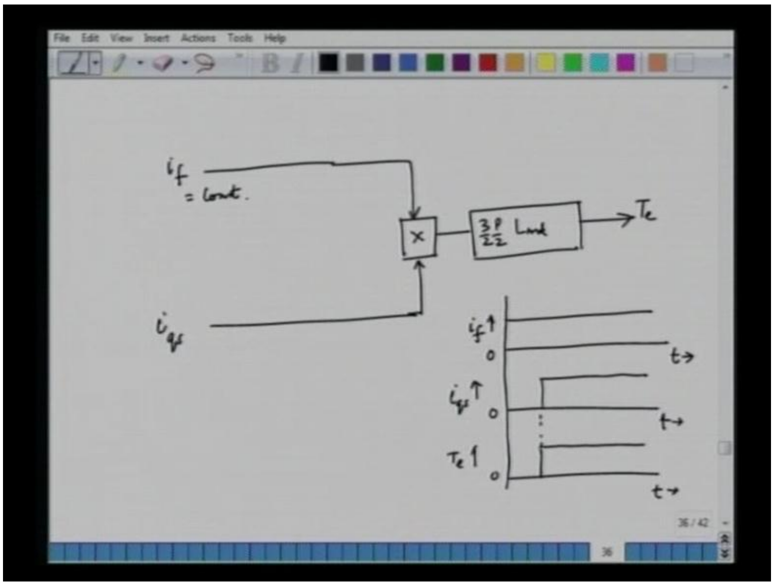

So, we can in terms of a block diagram so we can; we will have you will have in this case the field current i f and we have i q s and this is multiplied with 3 by 2 p by 2 into L m d and what we obtain is the torque. So, there is no dynamic involved here we can keep i f constant and we can change i q s to control the torque. So, if we so in terms of a response so this is our control response. So, we can change here we can keep i f constant i f is kept constant; t is in the X axis. And if we change i q s the stake, the torque also change unceremoniously; this is i q s and this is the torque.

And, that is why the vector control has got very good dynamic response; one of the advantages of this vector controls drive is that the dynamic response is very fast; the torque changes immediately when we change i q s because the field current is kept constant just like a drilling machine. However, just to have a remark here in vector controls drive although we have very good torque response there is a little bit of difficulty; the difficultly is that it leads to lagging power factor. The vector control drive is synchronous motor in which keep i d s equal 0. And control the torque by controlling i q s results in a lagging power factor that we can see in the correspond phasor diagram.

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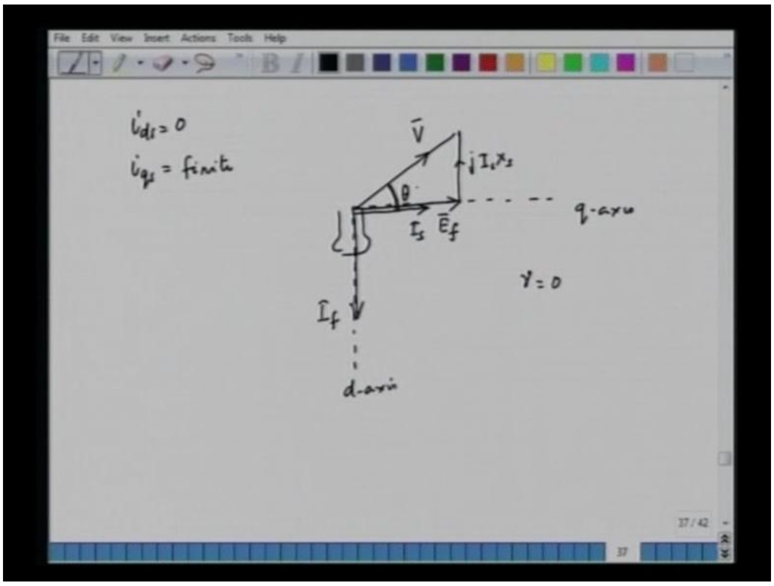

So, what we have here is that I d s equal to 0. So, when we have I d s equal to 0; this is the d axis and this is the q axis and we have a field current which is the constant. So, we can show these the field current i f and this is the field induce current c m f we can say that is e f and i d s equal to 0. But i q s is finite, i q s exist. So, if we for simplicity if we ignore the resistance torque; the reactants can be added here and what about the current the current is along the q axis so this is our I f; gamma equal to 0 here. So, the current is along the q axis.

So, we do not have any compound i f along the d axis. And if we are this reactions here j i f into X s and we can assume that there is no resistance job. So, if you ignore the resistance job j I f X s, I f is along the q axis and j example of we are simplicity we are talking about cylindrical synchronous machine where the simpler reaction is constant X f is constant here this is our phasor diagram and this is the voltage in this case. So, this voltage E f and I f and this is our current in this case. So, this is the power factor angle for the theta; the current lag behind the applied voltage. And hence in a vector control synchronous motor drive the power factor is lag in; however, the torque response is quite fast; if you want to have torque change we can change i q s in the torque change in resistance.

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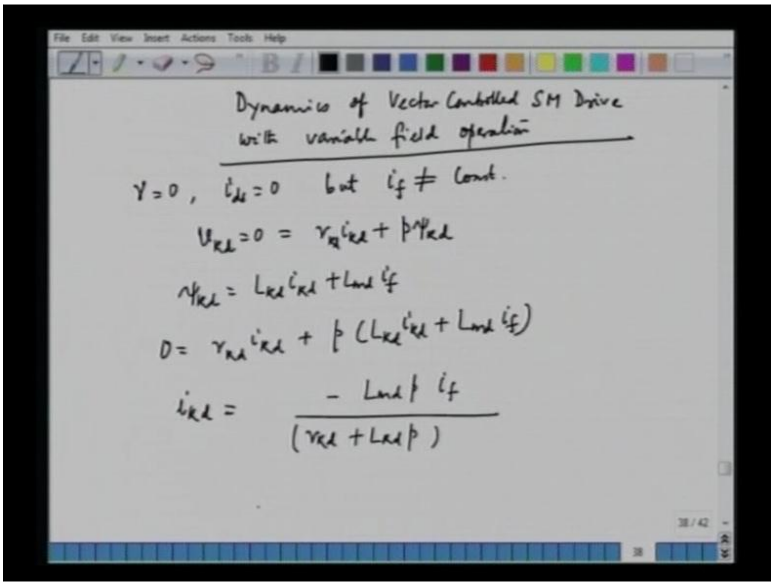

Now, we can have illustration i f is not constant. So, if we have same vector control drive with i f variable; let us see what term dynamics of vector controlled synchronous motor drive here i f is not constant with variable field operation. So, what we have here is that gamma is equal to 0 and i d s also is equal to 0 but i f is not constant. So, if i f is not constant we cannot ignore i k d; you understand that v k d is equal to 0 is equal to r k d, i k d plus p psi k d what is psi k d; psi k d is equal to L k d, i k d plus L m d into i f, i f is not constant.

So, we can rewrite this equation following passion 0 is equal into r k d, i k d plus p L k d, i k d plus L m d into i f. Now, this will little final value of i k d; i k d will not be equal to 0 here. Now, if we find out the expression for i k d what is i k d here; i k d is equal to minus L m d p i f divided by r k d plus L k d p. So, this is what we have this in this case. So, i k d is finite; i k d is not equal to 0. So, if i k d is not equal to 0; the torque will not unsteadily variable where we vary i q s.

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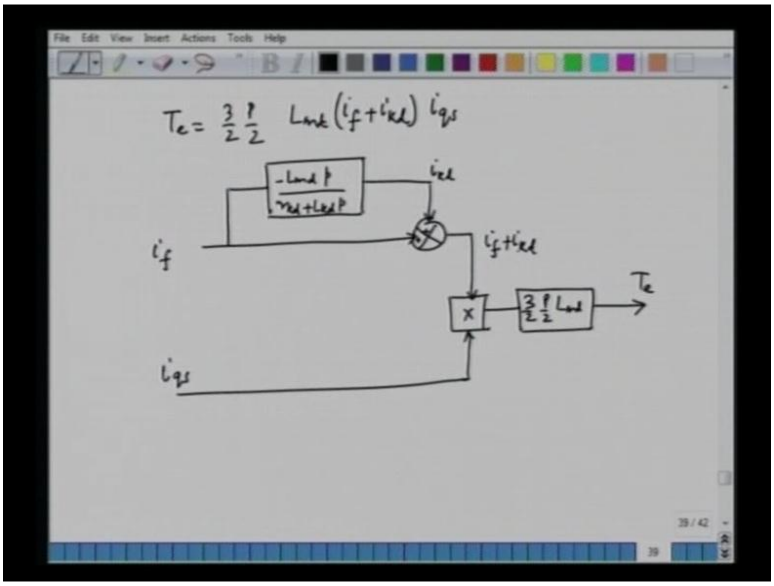

Now, let us see the expression for the torque. Now, if we see the expression for torque the torque expression was vector control drive T e is equal to 3 by 2 into p by 2 into L m t into i f plus i k d into i q s. Now, i k d is not 0; because we are changing also i f. So, when we are changing i f, i k d not exist. And because of that the torque equation becomes that more complicated compared to the situation; where i f is constant; the field current was constant. Now, here we can draw a block diagram to illustrate how the torque changes with change of field current.

So, what we have here is the following we will have the field current here. Now, the field current was not constant and that changes with this transfer function L m d p by r k d plus L k k d p and this is i k d and i k d is added with i f and then we have a multiplayer and this is multiplied with i q s and we have 3 by 2 p by 2 into L m d and this is the torque of the equivalent. So, we see that when we change i f the rooter find i k d and the i k d will try to delay the torque response; it will try to delay it. Because we have a negative torque here; the effective current that is produce i f plus i k d this will be less then i f.

And, finally in the steady state condition i k d will be the 0; what is the tangent condition will be changing i f; to change the torque of synchronous motor the effective current here i f and i q d will be less then i f. Because i k d is negative to keep the flux constant and hence the torque will be derived. So, in the next lecture we will see how the torque response changes will be go for angle control it means gamma not equal to 0; gamma is not equal to 0 means we have both i d s and i q s in the torque equation become more complex in that will be see in the next lecture.