Advanced Electric Drives
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Lecture - 16

Hello and welcome to this lecture on advanced electric drives. In the last lecture, we were discussing about the direct torque control of induction motor. And we have see that in the direct torque control, the torque and flux are compared into hysteresis comparator, and the torque and flux stators are generated. And this torque and flux stators are used to switch the voltage source inventor which ultimately speeds the induction motor. Now we also know that whenever you have a VSI, we have eight possible switching states and out of the eight possible switching states, six are nonzero switching vectors and two are zero switching vectors.

And in director control we have to select one of this eight switching vectors, so that we can full fill the torque and the flux stators. Now we will just discuss how to find out the switching vector from the torque and flux stators. So, we will draw a lookup table, and we will fill up the lookup table based on the various voltage vectors that we have for a 3 phase 2 label voltage source inverter.

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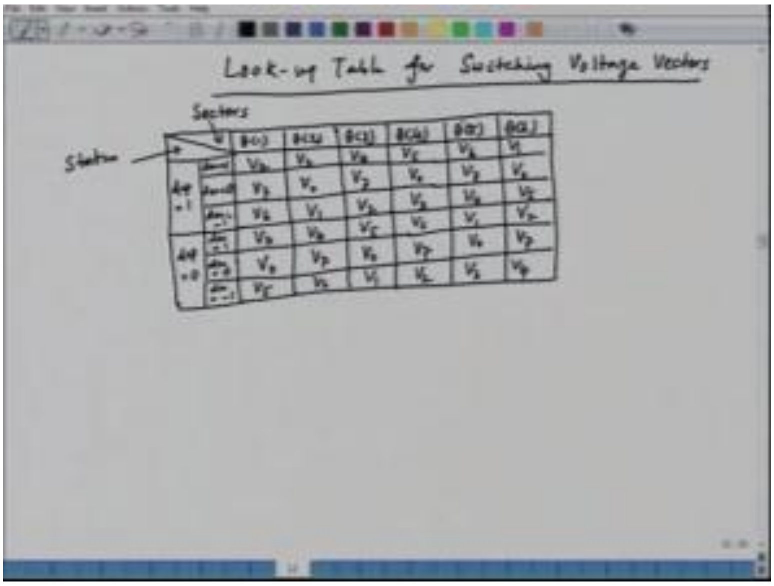

Look-up Table for Switching Voltage Vectors

So, we are trying now the lookup table for switching voltage vectors. Now we have six different sectors. So, this is the look up table we have, and in this case we have six different sectors. So, this is our sector 1, this is sector 2, sector 3, sector 4, sector 5, and sector 6. These are the sectors. And then we also have the torque and flux stators. So, this is the stators, and what are the stators? Here we have d psi equal to 1 and d psi equal to 0; d psi equal to 1 means the flux will be increased and d psi equal to 0 means the flux will be reduced or deceased. And corresponding to 1 flux stators we can have three possible torque stators because we know that the torque hysteresis comparator is a 3 label hysteresis comparator.

So, we will have three different stators. The torque will be increased, torque will not be changed, and torque will be decreased. So, we have d m equal to plus 1, d m equal to 0, and d m equal to minus 1. So, we have three different torque stators d m equal to 1, d m equal to 0, and d m equal to minus 1. And similarly, here also we can have three possible torque stators d m equal to 1, d m equal to 0, and d m equal to minus 1. Now we have to find out the voltage vector which is fulfill a 3 phase VSI and we have eight possible voltage vectors. And the voltage vectors are V 1 to V 6 are the nonzero voltage vectors, V 0 and V 7 are the zero voltage vectors. So, we can draw them once again.

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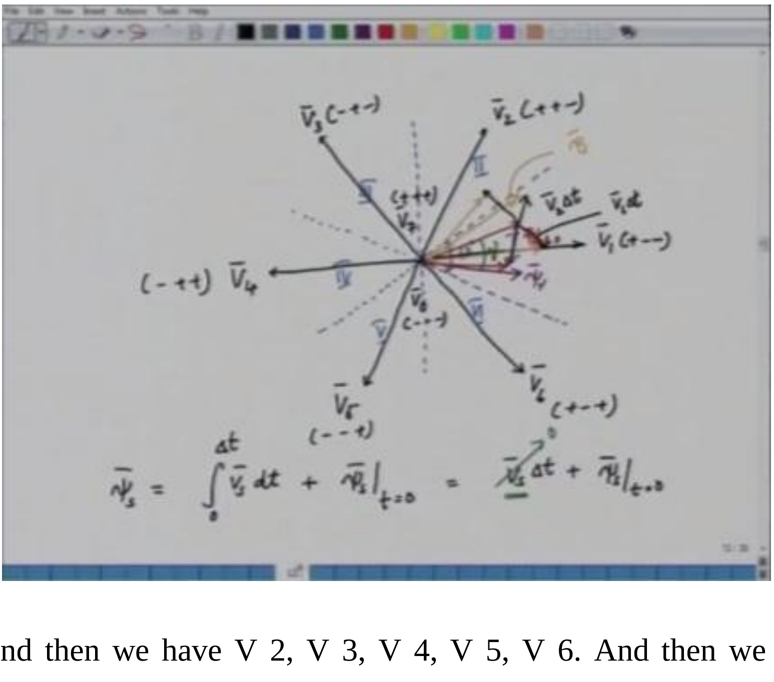

$$\bar{\psi}_s = \int_0^{\Delta t} \bar{V}_s \, dt + \bar{\psi}_s \big|_{t=0} = \bar{V}_s \Delta t + \bar{\psi}_s \big|_{t=0}$$

This is V 1, and then we have V 2, V 3, V 4, V 5, V 6. And then we have the zero voltage vector V 7 and V 0 is also a zero voltage vector. And if we also show the switching stators we can show which switches are on for V 1. We can show V 1 as plus minus minus. Similarly, V 2 as plus plus minus; plus minus minus means phase a upper switch is on, phase b lower switch and phase c lower switches are on. Similarly, the plus signify the upper switch being on and minus signify the corresponding phase the lower switch is on.

And similarly, we can write for V 3, V 3 is minus plus minus, and V 4 is opposite of V 1; that is minus plus plus and V 5 is opposite of V 2; that is minus minus plus. V 6 is opposite of V 3; that is plus minus plus. And and V 7 is plus plus plus, V 0 is minus minus and minus. So, we have eight voltage vectors, and we can divide the whole space into six sectors, and each sector will be having an angle of 60 degree; each sector is equal. So, we can divide this whole space in to six different sectors in the following fashion. So, we can call this as sector 1 and this as sector 2, and this angle is 60 degree. Similarly, all this sector angles will be 60 degree.

This will be sector 3; this is sector 4, sector 5, sector 6. And the objective here is that we have to find out the suitable voltage sector which will fulfill the torque stators and the flux stators simultaneously. So, let us say that our original flux vector is in sector 1. So, we can say that, say, for example, our flux vector is here. This is psi s at E equal to 0, and we know that we have equation that we have already seen in the last lecture that psi s the resultant flux vector is given as integral of v s d t o to delta t; let us say plus psi s at t equal to 0 So, it means if we want to find out the resultant flux vector, we have to apply a particular voltage vector that is V s. Now if V s is kept constant for a time that is delta t, so we can write this equation as V s in to delta t plus psi s at t equal to 0.

So, this is a vector equation and the resultant vector is psi s and the psi s is the vector sum of V s into delta t and psi s at t equal to 0. So, a here lets us say that our flux vector at t equal to 0 is in sector 1. And what we have to do here is that we have to increase the torque and increase the flux, d m equal to 1 and d psi equal to 1. So, if we take these situations that d m equal to 1 and d psi equal to 1, it means both the torque has to be increased and flux has to be increased.

So, if we see this diagram here, now which vector shall we apply? Shall we apply V 1? Now if we apply V 1, then thee vector will be moving in this direction; that is not correct, because we know if you apply V 1 the torque will be reduced up to some extent will not be increased, but we have to increase the both torque and flux. So, what we will do here is the following; may be this is not the right choice. We will apply V 2. Now if we apply V 2 in this case, this is our V 2 in to delta t. We will apply V 2 for a small time delta t and as a result our resultant flux vector will be along this direction. So, this is psi s.

So, we that see psi s have moved. When the psi s has moved, gamma has changed. Gamma is the angle between psi r and psi s, gamma psi r the rooter flux may be somewhere here. Say, for example, this could be the position of the rotor flux vector. So, the gamma has changed instantaneously, and when gamma has changed instantaneously, gamma has increased sign of gamma has also increased; the torque has also increased. So, we have fulfilled the torque stators; torque has to be increased. Now what about the flux stators? Now we can see that here when we are applying this voltage vector, psi s seems to be greater than psi s at t equal to 0. So, in this case the flux has also increased.

So, we have satisfied both the torque stators and the flux stators. So, here what we will do in this case is that we will say that here we apply V 2, okay. And then if you come to the next condition under this sector 1 theta 1 that d psi equal to 1 and d m equal to 0. The flux has to be increased, but the torque should be maintained as it is. Now if you see this equation, if we want to maintain the torque, gamma should not be changed. So, gamma is the angle. What is gamma here? Gamma is the angle between the rotor flux and the stator flux.

This is our gamma, and if we do not want to increase gamma we have to freeze the stator flux vector. The flux vector should not be accelerated, neither it should be decelerated. Angle at that instant should be as it is; it will be held constant. And if you want to hold that angle constant, you have to apply a zero voltage vector. It means in this equation, if suppose V s equal to 0 then psi s equal to psi s at t equal to 0 So, the flux does not change; the position of the flux vector also does not change. So, if you put V s equal to 0 or if you apply a zero voltage vector, the flux vector is frozen, and hence, torque neither increases nor decreases.

What about the flux then? Now when we have two stators, flux stators and toque stators the torque stators will have higher parity compared to the flux stators, because ultimately when we drive what we want is that the torque should be controlled. Flux should also be controlled, but if you see the priority the torque at a given time should be given more parity than the flux. And we know the flux cannot change instantaneously; flux will take some time to change. So, we can we can give a lower priority to the flux, and we can fulfill the torque requirement. So, in this case we know that if you apply a voltage vector that equal to 0. So, what we can say is that this component vanishes.

So, if that vanishes you know that psi s equal to psi s at t equal to 0. So, if psi s is kept as it is, it means the torque does not increase nor it decrease. What about the flux? Flux also does not change, because we are not increasing the flux nor we are decreasing the flux. So, the flux is the minted at that particularly value. So, we will apply in this case a zero voltage vector. So, if you see that the voltage vector here will be V 7. We have the choice to apply either V 0 or V 7. We are the two zero voltage vector, V 7 and V 0. And we have applied V 2 little earlier, because we wanted to increase the torque and increase the flux.

Now we want to keep the torque as it is. So, from V 2 it is easier to switch to V 7 than V 0, because V 2 is plus plus minus, and if we switch to V 7 it is plus plus plus. So, there is a change of only the switches of one leg; that is the c phase, the upper switch is turned on and the lower switch is turned off. So, what we say here to avoid the minimum number of switching, we will have V 7 here. And then the third row here the flux d psi equal to 1 and d m equal to minus 1 means flux should be increased; torque should be decreased.

Now if we see here we have the flux vector which is in the sector 1, and we have to increase the flux but decrease the torque. So, gamma has to be reduced. It means the flux vector should be decelerated, but the magnitude should be increased. So, we will apply such a voltage vector which will make gamma small. So, in this case you know that we have the choice to apply V 6. Now if we apply V 6, suppose we apply V 6. So, V 6 will be in this direction, and this is V 6 into delta t. We are only applying for a small time delta t, because the whole interval has been broken down into small sampling time, and sampling time is delta t.

So, in this case if you apply this V 6 for delta t, the vector will be moving in this direction. This is the vector that is V 6 into delta t, and the resultant of the two would be. And here what we see here that results in the reduction of gamma, but the flux has increased. The magnitude of the flux has increased, but the gamma has reduced. So, the flux has increased, but the torque is reduced. So, we can say in this case that here we will apply V 6. Now similarly when the flux stators is 0 d psi is equal to 0, we want to increase the torque d m equal to 1; it means the flux should be reduced, but the torque should be increased. So, we will play in this case I mean we have the vector which is in sector 1, and we want to reduce the flux but increased the torque.

So, we will apply in this case V 3. So, if we apply V 3 we have the flux changing like this. So, when it is changing like this, the resultant of this two will have a reduced flux, but since gamma has increased, the flux vector has moved in the anticlockwise direction; gamma has increased. And hence, instantaneously we will experience an increased in the torque; however, application of V 3 will reduce the flux up to some extent. So, we are able to satisfy increase of torque but decrease of flux. Of course, the reduction in the flux is not significant, because we are not applying a voltage vector to fully demagnetize the flux; we are applying a voltage vector in such a way that some component of the voltage vector will be opposing the stator flux.

So, flux reduction will not be by significant amount, but however, that will be enough to satisfy the flux stators. The flux is reduced, but the torque is instantaneously increased because gamma angle; the angle between the rotor flux and the stator flux is momentarily increased, and hence we experience an increase in the torque. So, we will apply in this case v 3. So, this is what is V 3 here; we are applying V 3. So, to increase the torque and decrease the flux we will apply V 3. And then to decrease the flux and keeping the torque unchanged, we will apply V 0 similarly, because from V 3 it is easier to come to V 0, because if you see this V 3 is minus plus minus.

So, from minus plus minus it is easier to come back to minus minus minus; only b phase, the upper switch will be switched off and the lower switch will be switched on. So, it is easier to move from V 3 to V 0 than from V 3 to V 7. So, in this case in the lookup table we will have V 0 here, and then the last row the torque should be decreased; d m equal to minus 1 and the flux is 0, the flux should also be reduced. So, if the flux is reduced and torque is reduced, we will see which one is most appropriate; both are to be reduced.

So, if both are to be reduced which vector shall we apply? We can apply in this case V 5. Now if we apply V 5, the vector will be moving in this direction. So, we have a reduction in gamma, also reduction in the magnitude of the flux. The resultant in this case will be from here, and this will lead to a reduction in the flux magnitude as well as reduction in the angle gamma which is the angle between the stator flux and the rotor flux. So, we satisfy both the flux and the torque stators. So, we will have here this is V 5. Similarly, we can find out by the same logic, the switching vectors in sector 2 in sector 3 up to sector 6.

And since they are symmetrical, we can just write down out of symmetry this is V 3, V 2 V 3 this is V 4, V 5, V 6 and V 1. And this will be V 0, then V 7, V 0, V 7 and V 0, and out of symmetry this is V 6, V 1, V 2, V 3, V 4, and V 5, and here this is V 3. And out of symmetry, this will be V 4, and this will be V 5, V 6, V 1, and this is V 2. So, since the sectors are identical we can write down out of symmetry, because we have V 1, V 2, V 3, in the anticlockwise direction.

So, the sequence is given to be V 6 and this zero vectors will alternate, because it is easier to switch to V 7 from one sector, and it will be easier to switch to V 0 from the other sector. So, we can similarly do here V 7. It is easier to switch from V 4 to V 7. What is V 4? If you see that V 4 is minus plus plus; so, we can easily move to V 7 that is plus plus plus form minus plus plus. So, from V 4 we can go to V 7. Similarly, from V 5 we can go to V 0. Then from V 6 it is easier to move to V 7. From V 1 it is easier to move to V 0. From V 2 it is easier to move to V 7. So, this is how the vectors are changed.

And similarly the last row we can have V 5, then V 6, then V 1, V 2, V 3 and V 4. This is out of symmetry we can write down all the voltage vectors. So, this is basically our switching lookup table. It means if we know the sector information of the flux and if we know the torque stators and flux stators, we can uniquely find out one voltage vector that simultaneously fulfills the torque stators and flux stators for the direct torque control of induction motor. Now it is every easy to implement in the sense that we have do not have to have much computation here; at best what we have to do is to find out the flux sector information theta. And once the theta is available and by means of a comparator, we can compare the reference flux and the actual flux and have flux stators.

Similarly, we can compare the reference torque with the actual torque and have torque stators. And from the lookup table we can select which vector is the most appropriate vector. If we apply that particular vector, the torque and the flux stators for the induction motor will be fulfilled. Now this we can show this in form of a block diagram. Our objective here is that we should be having a variable speed drive where the speed is controlled. We have to control the speed very smoothly, and for a variable speed drive we can draw a block diagram using the director control principle.

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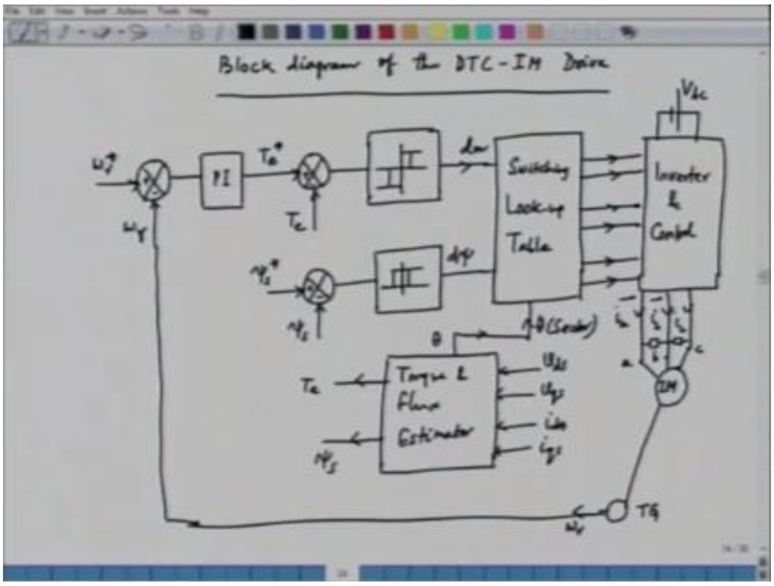

So, this is our block diagram. Now here we are actually employing a voltage source inverter; our machine is fed from a voltage source inverter. So, that I will show here and, we will have actually the reference speed, and we can compare this with the actual speed. And then we can feed it to a p I controller, and usually the speed error is fed to a p I controller, and the p I controller gives us the reference torque. It means if the error is more I mean we should be leading more torque for the acceleration. If the error is positive, the actual speed is less than the reference speed. So, we should be having more and more torque.

So, the p I controller output is basically the torque reference. So, this is T e star, and this is what we compare with the actual torque. And then as we have already discussed this is fed to a 3 label hysteresis comparator. And out of this what we obtain is the torque stators. Similarly, in case of the flux we can give the reference flux. And we compare this with the actual flux, of then what we do here? We fill to again a 2 label hysteresis flux comparator and the output of that is the flux stators; that is d psi.

Then we have the switching lookup table, and we have the VSI inventor and control. And this feeds the induction motor, and we have let us say a speed sensor or a tachogenerator. Out of this we obtain the speed feedback. So, speed is fed here; we have omega r in this case and this is our omega r which is the obtained here. And we can feed this omega r to have closed loop speed control. Now the switching lookup table also requires the information about theta. Theta is sector information, whether the flux vector is in sector 1 or sector 2 or in sector 3 up to 6. Unless we have that information we cannot uniquely find out the voltage vector which has to be applied on the machine.

So, we have to find out the sector information, and how do we find out the sector information? We can find out the sector information from a calculator plug; that is torque and flux estimator. And here in the estimator we feed in this case V d s, V q s, i d s and i q s. And this is our induction motor, and these are the various currents here, I a, I b, I c, and the switching lookup table will be giving the signal for six switches; the inverter will have six switches. So, these are the two switches for phase a, two switches for phase b, and two switches for phase c, and the inverter will be fed from a DC source. This is our V d c; it is a voltage source inverter.

So, we have to have a DC supply which can be obtained by means of a rectifier as well. So, this DC supply will be the input to the inverter, and the inverter will be controlled by this signals that has been obtained from the switching lookup table depending upon which vector is to be applied. So, we have six driving signal, the gear driving signal for the switches of the inverter which are fed to the inverter for turning on and turning off of the six switches. And then the output is fed to the induction motor, and of course, what we need to do here is that we have to have a sensor.

We have to have some sensor to sense the currents and the voltages, because in this case we need V d s; how do you operate V d s? Now V d s is the stationary reference current. That can be obtained from the output V a, V b, Vc; of course, in this case what we have here is phase a, phase b and phase c. We can have all sensors here to measure the line voltages, and from that we can calculate what is V d s and V q s. And similarly we can have the current sensors here, and this current sensors will give us I a and I b, and from I a and I b we can find out what is I d s and I q s in the stationary frame. We do not have to have any rotating transformation, because these variables are being calculated in the stationary frame.

And this are the input to this torque and flux estimator, and this output of the torque and flux estimator will be T e the torque and the stator flux psi s respectively. The T e will be fed to the torque comparator, and the flux will be fed to the flux comparator and out of all this also we can obtain the information about theta, and the theta information can be used to find out the sector. Now we can have a mathematical expression for this torque and flux estimator. We can write down a few equations which will tell us how do we estimate the flux and the torque of an induction machine.

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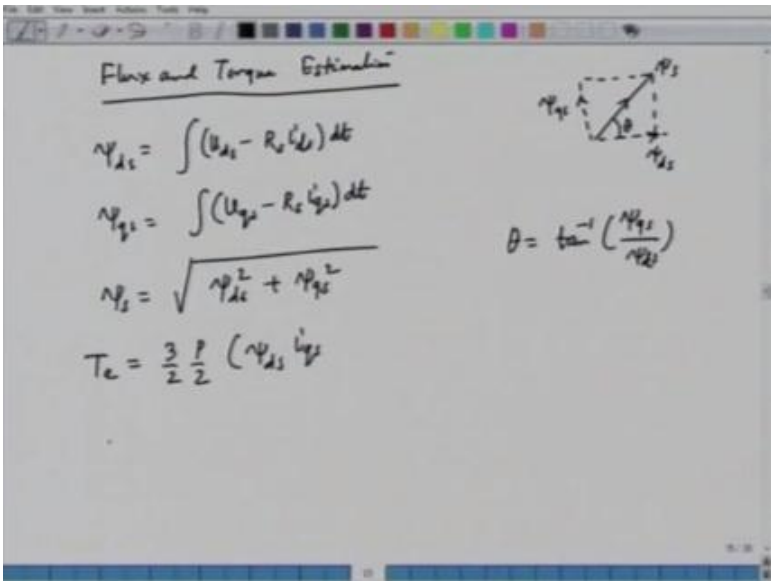

Flux and Torque Estimation

$$\psi_{ds} = \int (v_{ds} - R_s i_{ds})\, dt$$

$$\psi_{qs} = \int (v_{qs} - R_s i_{qs})\, dt$$

$$\psi_s = \sqrt{\psi_{ds}^2 + \psi_{qs}^2}$$

$$T_e = \frac{3}{2}\frac{P}{2}(\psi_{ds} i_{qs}$$

$$\theta = \tan^{-1}\left(\frac{\psi_{qs}}{\psi_{ds}}\right)$$

So, we can write down the expressions for flux and torque estimation. So, we have a simple integrator here for finding out psi d s; that is equal to V d s minus R s i d s d t. Simple integrator will tell us what is psi d s, and similarly we can calculate what is psi q s integration of V q s minus R s i q s. And then what is psi s? Psi s is the square root of psi d s square plus I q s square. So, we have been able to find out the amplitude of psi s; it should be used for the feedback. What about the sector information? The sector information can be calculated theta is equal to tan inverse of psi q s by psi d s, because we know in this case this is our psi s. And this component is psi d s, the stationary reference frame components, and then this will be psi q s, and this angle is theta.

So, we can take simple tan inverse of psi q s by psi d s and that should will be our angle theta, and then what about the torque? The torque can be estimated T e is equal to 3 by 2 into p by 2. We have psi d s; we have been able to calculate psi d s in to i q s. I q s we can always measure using a hull sensor minus psi q s into i d s. So, this is the expression for the torque, and this expression for the torque can be obtained from the flux and the current. The flux is calculated, and the currents are measured; I d s and I q s are measured. So, this torque can be used for the feedback here, because we have a torque feedback.

And then similarly the flux which is calculated is also fed back here, and the angle theta is used for the computation of the sector. And when we know the torque stators and the flux stators and the sector information, we can find out which vector has to be applied. And once we apply that particular vector, the flux and the torque stators are fulfilled, and the motor is controlled using the direct torque control. So, this concludes our discussion on direct torque control of induction motor.

We have already discussed the control of induction motor drives, and the induction motors are very widely used in the industry, about 70 to 80 percent of the motors used in the industries are induction motors. We will also be discussing about the control of synchronous motors. Synchronous motors are used for high power applications; they are not used for lower and medium power applications. They are used for very high power applications ranging from a few megawatts to tens of megawatts, may be up to 100 megawatt, also in certain application were very huge drive. But usually these motors the synchronous motors are used for rating higher than 1 megawatt.

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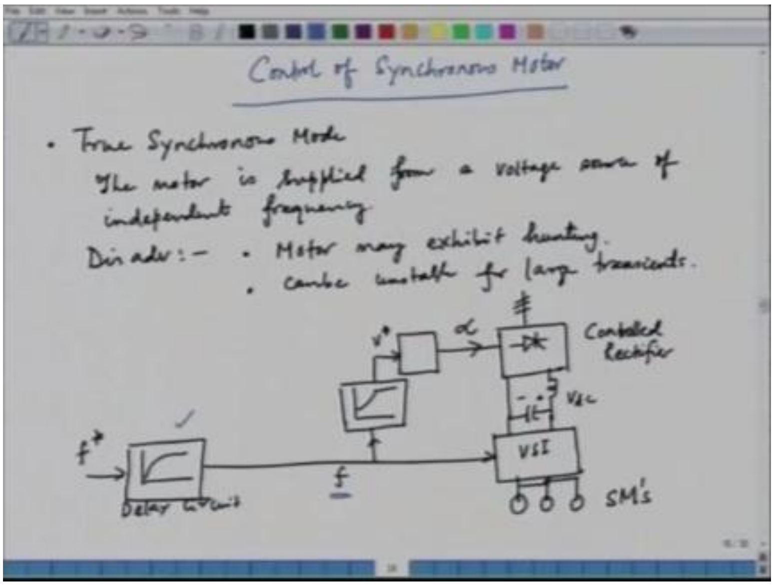

Control of Synchronous Motor

- True Synchronous Mode
  The motor is supplied from a voltage source of independent frequency
  Dis adv :- • Motor may exhibit hunting.
  • Can be unstable for large transients.

So, we will be discussing about the control of synchronous motors. Synchronous motors can be controlled in two different ways. The first one is called the control with two synchronous mode, and second one is called a self control mode. Now we will be discussing this one by one. Let us first concentrate on true synchronous mode of control. Now in true synchronous mode what happens is that the motor is fed from a voltage supply of independent frequency. Say for example, a synchronous machine connected to an infinite box; that is an example of a synchronous machine operated in true synchronous mode.

And you know in many applications like fixed feed application where the speed is not variable, true synchronous mode is sufficient. We do not have to control the speed; the frequency is constant, and the frequency is independent of the speed and the motor speed remains constant; however, the true synchronous mode is not very suitable for variable speed application. So, in true synchronous mode the motor is supplied from a voltage source of independent frequency. Now what is the drawback? The drawback is that whenever we are connecting a synchronous motor to a voltage source of independent frequency, there is a question of stability. And you know that in the transient condition there could be hunting.

Synchronous motor should be running as synchronous speed. If the synchronous speed does not match with the rooter speed that is a transient oscillations. And sometimes if we have a large transient, the machine may also fall out of step; that may also become unstable. So, the difficulty in the case is that the motor may be unstable, motor may exhibit hunting. So, the disadvantage here motor may exhibit hunting, can be unstable for large transients. Large transients means suppose we apply a very high load which is applied, and the motor may fall out of step. Furthermore, suppose we want to increase the frequency of the supply and we increase from let us say 25 hertz to 50 hertz immediately, the motor may not be able to respond such a large change of frequency.

So, it may fall out of step. So, these are the inherent problems of motors operating with true synchronous motor; however, if we are taking about a fixed speed application, this is one of the ways we can feed a synchronous machine. In some situations where the speed response is not a big constraint but is drawn actually; the frequency of the supply has not changed in step, it is changed slowly, and the machine the rotor being a mechanical entity that can respond to a slow change of frequency. So, instead of applying a step change of the frequency one can apply very slow change of frequency, and the motor may respond to the slow change of frequency, and the speed may gradually vary.

So, we will see an example of how we can control a synchronous machine with true synchronous speed. So, let us say we have a rectifier here, and the rectifier may be a 3 phase rectifier. And then we may have a small filter, and then we get half of VSI. And we can connect one or multiple motors. These are synchronous machines, and then we need to control the frequency of the voltage source inverter, and that is basically controlled slowly. So, we have a frequency command here f star, and this is connected to a delay lock. So, there is a delay here; we can have delay circuit. And then this delay circuit will be giving a frequency with respect to the VSI.

The VSI can be a sine wave VSI; it can be a sine PWM VSI, and it will be applying a 3 phase voltage to the stator of the synchronous motors. And the fundamental frequency being f and f is changed slowly. And then as f is changed, this could be a control rectifier; we can use here a control rectifier. I mean instead of a dielectric rectifier if we want to change the voltage here, it can be a control rectifier. And then we know that as we change the frequency, we also have to change the voltage. So, here we change the voltage to keep approximately the V by f forms.

So, here we have function generator which will be generating the amplitude of the voltage that is V star, and then we have a triggering circuit which will be generating alpha. So, this alpha is the triggering angle of the rectifier, and if you want to increase the voltage, we reduce alpha. And the descending voltage goes up, and then this descending voltage is V d c. It could be a semi controlled rectifier to keep this descending voltage in the same polarity, and then we have a VSI which is a synchronous motor. So, this frequency change here f is not very abrupt because of the delay circuit here, the frequency changes gradual

But this cannot be used for very high performance drive system, because we cannot change the speed immediately. So, we have to have a mechanism of changing the speed starting from zero to the full speed with good anomic response. So, we go for what is called a self controlled mode.

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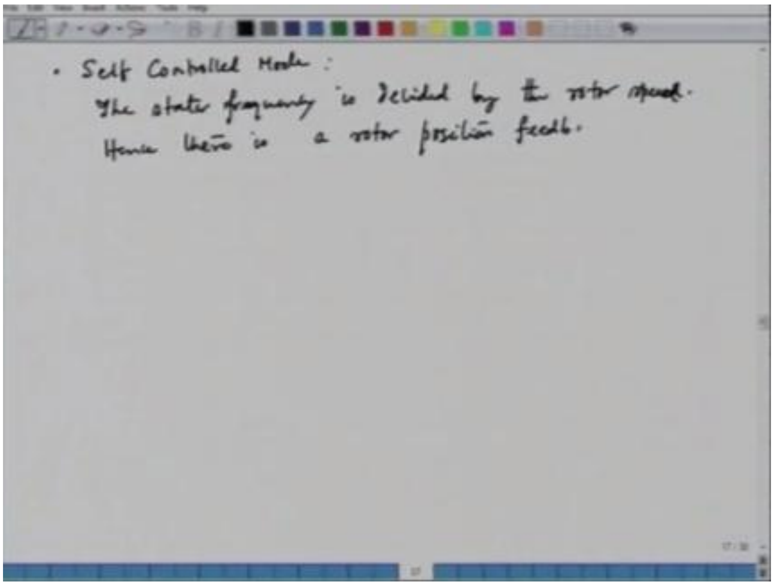

- Self Controlled Mode :

The stator frequency is decided by the rotor speed.
Hence there is a rotor position feedb.

So, we will see actually what is a self controlled mode. In this case, the stator frequency is not independent of the rotor frequency as the rotor speed. The stator frequency is decided by the rooter speed. It means the motor is controlling itself; synchronous motor is always synchronized with the rotor. So, it means the rotor is controlling the stator frequency, and hence it is called self controlled mode. So, we can say here that the stator frequency is decided by the rotor speed. Hence, that is a rotor position feedback. So, in case of a self controlled drive synchronous motor drive, there has to be a rotor position feedback.

On this we have a position feedback; the stator cannot be synchronized with the rotor, and hence all self controlled drive should have a rotor position feedback. And the advantage here is that we do not have any hunting. We do not have any instability; a self control derive cannot be in stable. In a sense that it cannot fall out of step, because the stator frequency has been decided by the rotor, so it cannot fall out of step with respect to the rotor. And similarly, there is no question of hunting here, because the rotor frequency and the stator frequency are logged together. So, the hunting is also prevented here.

So, the advantage in this case is this that hunting is prevented; it does not fall out of step. And also one big advantage is that this kind of drive can be employed for variable speed application, because the frequency can be varied. There is a no fear of losing the synchronous, and hence we can operate starting from zero speed to the full speed. It can be applied for variable speed application. So, we will take an example of a synchronous motor derive which is self controlled, and we will see how we can control this, and how we can control this with variable speed application.

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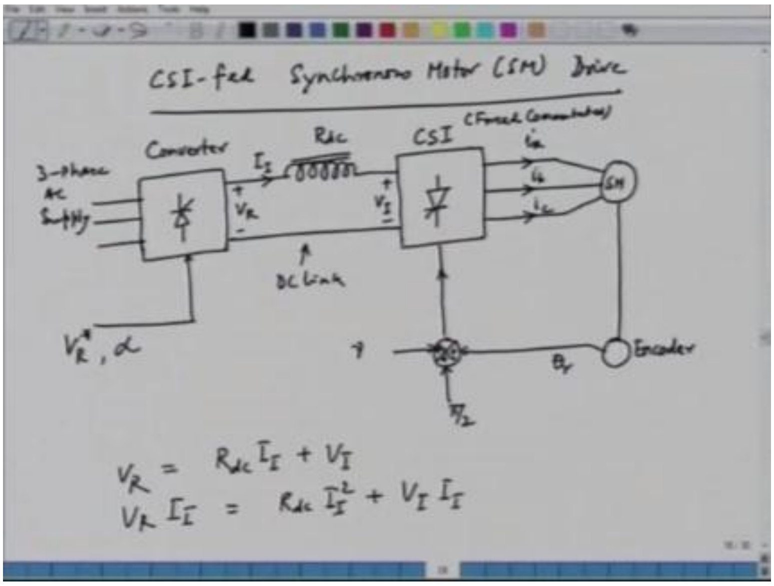

CSI-fed Synchronous Motor (SM) Drive

$$V_R = R_{dc} I_I + V_I$$

$$V_R I_I = R_{dc} I_I^2 + V_I I_I$$

So, let us take an example of a CSI-fed synchronous motor drive. Now CSIs are basically used for high power application, and this drive is suitable for high power application. So, what we have? We have a CSI which is being fed from a control rectifier, and in the DC link we have a large inductor to keep the current constant. So, we have here a control rectifier, and these are 3 phase supply. Then in the DC link we have a large inductor to keep the current constant. And then we have a CSI, and the CSI is feeding synchronous motor. Now synchronous motor of course will be having a position sensor. So, we can use here an encoder or a resolver which will be giving of the information about theta r. Theta r is the rotor position, the position of the rotor.

And then the CSI is this is our CSI, and this is the converter or the control rectifier. And this is V R, and this is V R, and this is the DC link. We have a large choke here, and this choke is having a resistance of R d c. And this is I i, the current which is being supplied from the converter to the inventor. So, we can call this to be the inverter input current I R, and here in the synchronous machine we have three different phase. So, we have a I a, I b and I c, and this CSI are the current source inverter is basically a forced commuted one. It means we can switch on and switch off each phase irrespective of the load power factor. So, this is the forced commutated CSI. So, we say here it is forced commutated.

So, the nature of this I a, I b, I c will be quasi rectangular; ideally, this should be quasi rectangular having a block of 120 degree. And we can define an angle gamma here, and we can add this three; we have a pi by 2 here theta r, and we can decide the phase of the current which is injected into the stator of the synchronous machine. And similarly, in the convertor side what we have here is this is the following that we can apply a reference V R, and alpha is automatically controlled to give us the reference V R. We can apply it; say for example, we can say that V R, V 1 to be 200 volts or 300 volt, and depending upon the V R, alpha is generated to satisfy the reference V R.

So, this is the power circuit diagram of CSI fed synchronous motor drive. Now we will do some analysis here. The question is this; it is a self controlled drive and the performance of this derive will be similar to that of a DC drive, because ultimately what we are doing here. We are feeding a DC voltage, although we have a 3 phase AC supply the output of the converter is a DC voltage. And the DC voltage is the input of the CSI. So, it is something like we can control the synchronous motor just like DC machine.

So, what we will do here we will just write down a few equations in this case. Now in this DC link, this have DC link. So, we can say here that V R the applied voltage is equal to R d c in to I i plus V I. This is the equation Kirchhoff's voltage equation, and we can multiply this equation by I i. And so if we multiply with I i, we can say that V R into I i that is equal to R d c into I i square plus V I in to I i. So, this is the interesting equation and CSI input power is V I in to I i.

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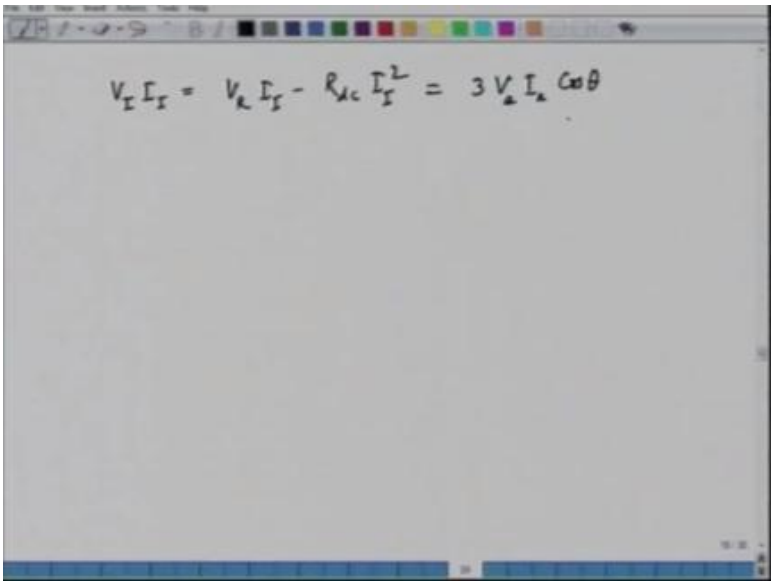

$V_I I_I = V_R I_I - R_{dc} I_I^2 = 3 V_a I_a \cos\theta$

So, if we simplify this we can do some mathematical rearrangement here; V I into I i that is equal to V R into I i minus R d c into I i square. Now we assume that the synchronous machine I mean the CSI the current source inverter is lossless. It does not have any loss. So, what we can assume here is that that the CSI does not have any loss. So, whatever is the input power here is going to the machine directly; there is no loss inside the CSI. So, if we assume this we can say that that is equal to this is the input power of the current sources inverter, and that is equal to the power which is given to the machine. The machine is having a power factor of cos theta.

So, we can say that is equal to 3 into V a is the per phase voltage of the machine into I a is the per phase current into cos of the angle between V a and I a; that is theta. So, this actually is the power balance equation of the CSI fed drive. And from this equation we can derive an equivalent circuit which will show that the behavior of this machine is similar to that of a DC machine. So, this equivalent circuit derivation we will be discussing in the next lecture.