Advanced Electric Drives
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Lecture - 10

Hello. Welcome to this lecture on advanced electric drives. In the last lecture we have seen that in a vector control drive, the torque response is quite similar to that of a separately excited dc motor. The torque is proportional to the torque component of current that is i q s. So, in this lecture we will see the variation of the flux on the effect of vector control drive, but before that let us try to see the response of the vector control drive under torque control.

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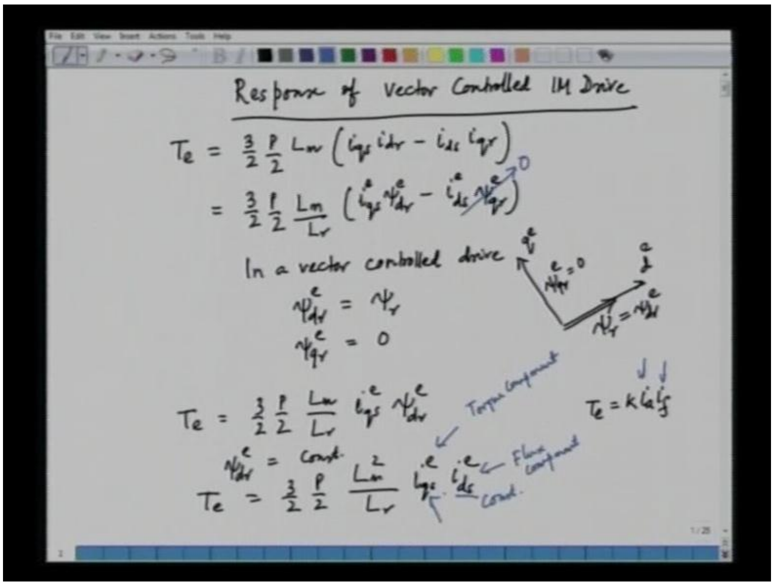

So, we will be discussing on the response of the vector control induction motor drive when you want to change the torque. Now we have seen that the torque response of a normal induction motor is given by the following equation. T e is equal to 3 by 2 into p by 2 into L m into i q s i d r minus i d s i q r. And we can also simplify this equation 3 by 2 into p by 2 into l m by l r i q s psi d r minus i d s psi q r, and this equation is a general equation which is also true for a drive or for a motor in a synchronous rotating reference frame. So, we can we can take this d q axis rotating synchronously with the rotor flux vector. So, we can have a superscript here.

So, we can say this is also true for i q s e psi d r e i d s c and psi q r e. And in a vector control drive we have seen that the d q axes are rotating with rotor flux vector and the d axis is aligned with the rotor flux vector. So, we see that in a vector control drive psi d r e is equal to psi r, and psi q r e is equal to 0, because the d axis of the reference frame is aligned along the rotor flux vector. If this is the d axis and this is the q axis we can call this to be d e and q e. The d axis is aligned along the rotor flux vector. This is psi r, and hens we can say that psi r equal to psi d r e and psi q r e equal to 0 which is the condition for a vector control, right. Now if we apply this particular condition to this equation we can see that this part will vanish. This will be equal to 0 because psi q r e equal to zero. So, if psi q r e equal to 0, the torque equation becomes a very simple equation.

So, we can say that the equation for the torque is equal to 3 by 2 into p by 2 into l m by l r. This i q s e into psi d r e and which is quite similar to that of a dc machine. In the dc machine we have seen T e is equal to k into i a into i f. The torque is proportional to the armature current, and torque is also proportional to the field current; here we are ignoring saturation. Similarly, if we can say that psi r d is constant, the torque equation is given by 3 by 2 into p by 2 and l m square by l r into i q s e into i d s e. This equation is quite similar to that have a dc machine equation, and we say that i q s e is called the torque component of current, and i d s e is called the flux component of current similar to the armature current of a dc machine and the field current of a dc machine respectively.

So, this is the equation for a vector control drive, and we understand that in a vector control drive the torque can be controlled similar to that of a separately excited dc motor. In this case of course, we have two options, either to vary i q s or to vary i d s and normally i d s is comparable to the field current. So, we want to keep the flux constant at the rated value. So, we keep i d s constant, and what we do keeping i d s constant we change i q s e. We keep this constant. Usually what we do we keep this constant, and we change this one to control the torque. And if we change i q s to control the torque, torque will be controlled instantaneously. So, we can see that by a control block diagram.

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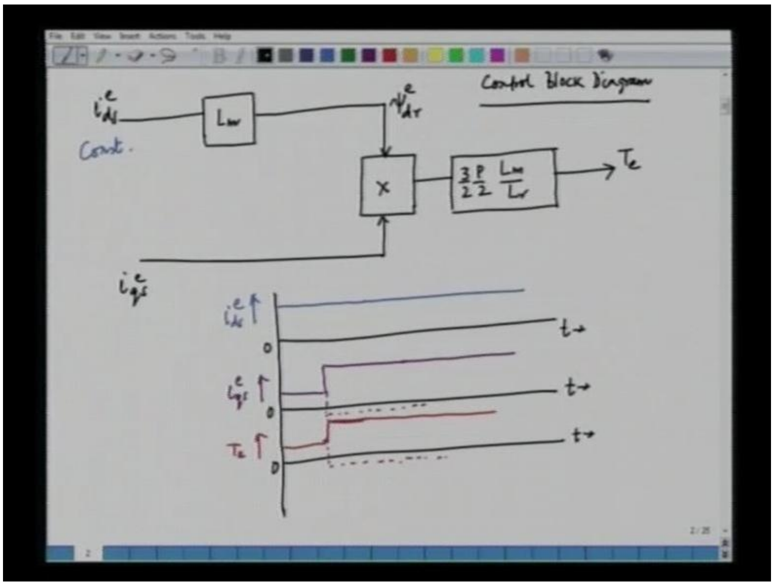

So, if we see that by a control block diagram it will look like this. Say for example, i have two variables in this case. One is i q s e and I have i d s e; I will multiply that by l m. What I will obtain here is psi d r and here I have again a gain block. In this case I can multiply by 3 by 2 p by 2 into l m by l r and output this is my T e, and this is my control block diagram. So, in this control block diagram what I can do here is that I can keep i d s e constant. So, it means this component I will keep constant. I do not want to vary this, because if I vary this the flux is going to vary. And if I vary the flux the response will be sluggish, because any change of i d s e will not be accompanied by an instantaneous change in the flux. Flux will be delayed by sometime, and that will be resulting into the delay in the torque.

So, we can change i q s. If we see the response I can plot against time, all the variables I can plot against time; in this case let me keep i d s e constant. So, this is my i d s e, and then what I will do here? I will change i q s e; i q s e was initially something here, and then here I will apply step change. This is i q s e, then what about the torque? The torque will vary proportionately. So, if I show the torque the torque was initially like this, and as soon as I change i q s e torque will change proportionately. So, this is torque response. So, it means if I want to have very good torque response I would definitely keep i d s e constant and change the change torque component of current. I q s e is called the torque component of current to have an instantaneous change in the torque.

The torque can also be decreased. Torque can be increased; in the same way torque can be decreased. Torque can also be made negative, because i q s e can also be made negative. So, if I want to have lets say breaking operation I would like to have a negative torque. So, instead of giving response like this, what I will do here? I can also make this i q s negative. So, if the i q s is made negative the torque will also follow i q s that will also be negative. So, it means an induction machine which is a fairly complex machine having multiple variables, and it is also a non-linear machine. I can control it just like a separately excited dc machine by keeping the flux constant.

However in some situation, especially when the machine goes beyond the base speed the flux has to be decreased. There is some genuine need for the decrease of the flux. Now we would like to evaluate the response of the machine when the torque is varied the flux is varied; I mean the torque is controlled by controlling the flux. If we change the flux how does the torque response look like?

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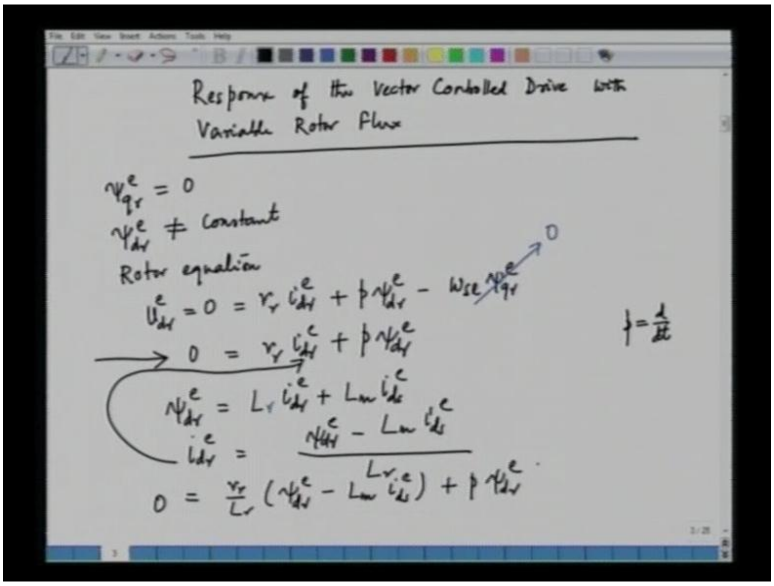

So, we can now speak the response of the vector control drive with variable rotor flux. So, we will first derive a few equations, and the equations can be explained by means of a block diagram, and we will see if we try to vary flux whether the torque response is instantaneous or it is delayed. So, let us first write down the equations for flux variations. So, what we will see here is the following that as usual we know that psi q r is equal to 0 but psi d r is not constant, and we can write down the rotor equations.

We can say that v d r, the rotor d s equation equal to 0; that is equal to r r i d r e plus p psi d r minus of omega s l psi q r, but we know that in case of a vector control drive there is no q axis rotor flux. So, we can make this equal to 0. This component does not exist, and if this component does not exist we can further simplify this equation. 0 is equal to r r i d r e. Psi d r is not constant. So, if psi d r is not constant unlike the previous case when psi d r is constant we cannot make this psi d r equal to 0. We must know that p is equal to the derivative operator d by d t. So, p psi d r is not equal to 0, what we would like to do here we would like to eliminate i d r. I d r is not easily measureable; i d r is the rotor current in the d axis.

The rotors are inaccessible so we cannot measure the rotor current. So, what we will do we will try to replace i d r by the stator currents and the flux linkage. So, we can say here that the expression for psi d r is equal to l r i d r plus l m i d s, and we can say here that i d r equal to psi d r minus of l m i d s by l r. So, what we will do here we will replace this i d r in this equation and simplify what is the expression for this equation is giving us i d r. So, what we will do in this case is the following that we will be replacing the expression for i d r in this equation and simplify and get the expression for the flux linkage that is psi d r. So, if we do that we will get the following equation. This equation of the rotor can be rewritten in the following way, 0 is equal to r r by l r into psi d r e minus l m into i d s e plus p psi d r e.

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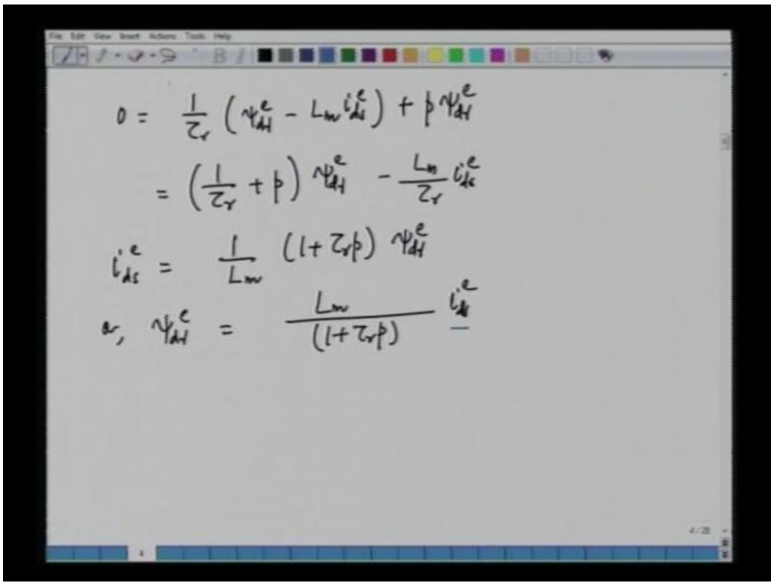

Again we can further simplify this, 0 is equal to 1 by tau r into psi d r e minus l m into i d s e plus p psi d r, e or this can be rewritten as 1 by tau r plus p into psi d r e minus l m by tau r into i d s e. But we can say here that i d s e is equal to 1 by l m into 1 plus tau r p into psi d r e, or psi r d e is given as l m by 1 plus tau r p into i d r e. So, this is an interesting equation, in the sense that if we try to change the flux component of current that is i d s e; if you want to change this i d s e we will see that the flux is not proportional to i d s e. It is basically a differential equation and when we try to change i d s e the flux will be delayed, and the time constant here is tau r.

And that is the reason if you change i d s e because we have two ways to control the torque. Either we can control i q s e or we can control i d s e, and how do we control this current? These currents can be control through inverter. We know that the inverter is ultimately injecting current onto the windings of the induction machines, and if we can control the inverter suitably we can control either i q s e or i d s e or both. So, if we do the proper inverter control and we control i d s e keeping i q s e constant the flux will be delayed. And when the flux is delayed the torque is also automatically delayed.

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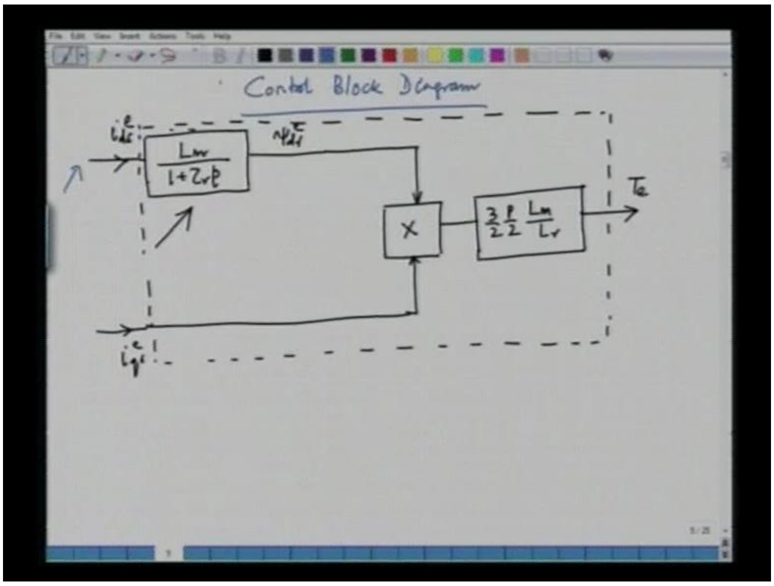

So, we can explain this by means of a block diagram; the block diagram will look like this, control block diagram. So, we will have the similar structure here, and we can control either i d s e or i q s e. And if we control i d s e the flux is not controlled proportionately; we have a delay torque here 1 plus tau r p, and this is our flux psi d r e.

And then we have a multiplier flux here, then afterwards what we have here is the gain block. It is 3 by 2 p by 2 l m by l r, then we have the torque.

So, we see that if we change i q s e the change will be instantaneous, because the i q s e goes directly to contribute the torque. Now if we change i d s e the torque change will not be instantaneous. It is basically going through a delay flux. So, if you want to increase the flux by increasing i q s e or if you want to reduce the torque by reducing i d s e the torque will change definitely, but the torque change will be accompanied by a delay. Now this can be explained by means of a control response. So, if we see the control response, we will see that the torque change will be accompanied by a delay.

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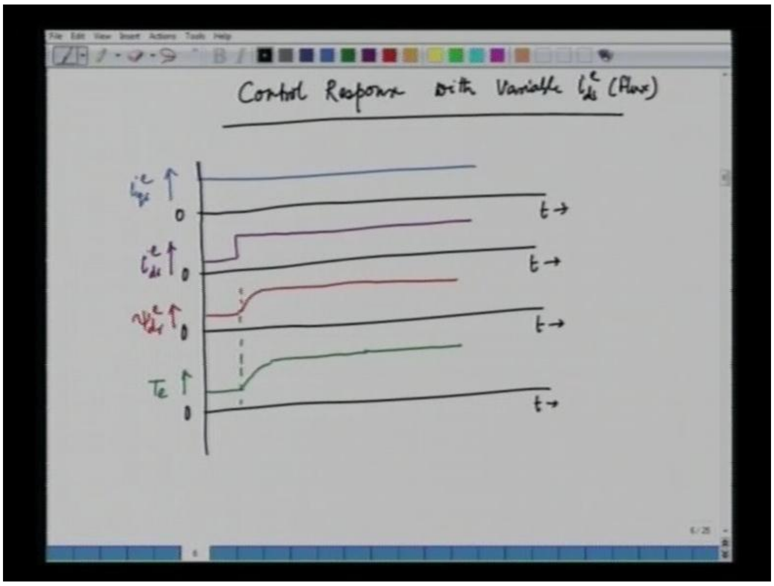

So, we can see the response with variable i d s e or in bracket we can say variable flux. So, we can see the various control response here. This origin and the x axis is the time axis, and what we will see here is that we keep i q s e constant; the torque component of current is i q s e that is kept constant. So, this remains constant here, and i d s e is given a step change. It is our y axis, and i d s e is given a step change. And moment this i d s e is given a step change the flux response, if you see response of the flux was initially here; it will be delayed.

The flux response that there is a first order delay and the delay is due to the fact that it is 1 by 1 plus tau r p. This tau r is a time constant by which the flux will be delayed. So, if we change i d s e the flux component that is psi d r does not change instantaneously that is delayed, and due to the delay in flux the torque will also be delayed. So, if we see the toque in this case this is the torque; initially the torque for some value and the torque will also be delayed. This is T e and this is psi d r e. So, this response the control response that we have shown here takes into account the variation of i d s e; we have applied a step change in i d s e, and we thought the torque will also change, but the torque change is accompanied by a delay.

And hence it is always advisable for having fast response; it is advisable to keep the flux constant. So, to keep i d s e constant and change i q s e to control the torque, and if we change i d s e the flux will change with a delay which will also delay the torque response as seen from the following control responses. So, this is what we have here, and what is the solution? Say for example, sometimes we would like to change the flux; sometimes we would like to decrease the flux depending upon the requirements. So, if we want to change the flux we have to have a compensated or a compensator to compensate for this delay. So, if we can have a compensator we can compensate for the delay in the torque response, and that is called a compensated flux response.

So, what you have here is the following that this is the reason of the delay. Now if you see that this block diagram in this case, what we have here is l m by 1 plus tau r,, and this is within the machine. So, this dash enclosure is within the machine; we cannot do anything inside the machine. The machine is running, and it is a behavior of the machine that if you change the flux component of current the torque will be delayed. So, what we do here we can add something here of course. We can add something before this that the delay can be cancelled, and we will see how we do that.

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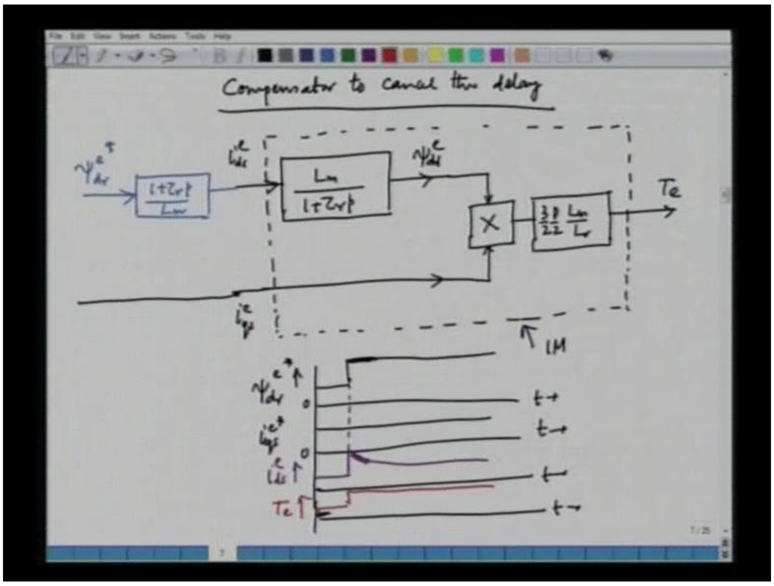

So, compensator to cancel the delay; so in this case what we have? We can draw the earlier block diagram. We have here l m by 1 plus tau r p. The flux response is delayed here; it is psi d r, we have no control over that inside the machine. So, these are multiplied, then what we have here is 3 by 2 p by 2 l m by l r. This is the torque; this is i q s e. This one is i d s e, and this is i q s e, and this dash box is inside the machine, okay. This is the machine induction machine, and what we do here we can add a compensator. Now how do you add a compensator? We can add a compensator in the following fashion. So, we can add a compensator here, and the compensator will have 1 plus tau r p by l m, and this is my psi d r e reference.

So, this shown in the blue diagram or blue color is the compensator, and the compensator is so designed that it can cancel the delay generated by the machine. We have a pole here inside the machine, and we have a 0 in the compensator. So, there is a pole zero cancelation. When we have pole zero cancelation here the delay is removed, and if we see the response in this case when we apply step change in the flux the torque also changes instantaneously proportional to whatever the change we have applied in the flux. So, if we see the response here in this case this is our time axis, and let us say we have given a step change like this in this psi d r e star and the torque component of the current is constant.

This is i q s e star; although, we have applied a step change in the flux in this case there is no delay; why there is no delay? The delay is not there, because the flux component varies like this. Due to the derivative term in the controller the the flux component will change like this, and that is how this delay is cancelled. It is my torque, and the torque will also change proportionately. So, we can see that this is the torque response, and this one is i d s e and the lower one is the torque. So, we see that when we have a compensator, the compensator have a derivative term, and the derivative term is responsible to give spike in the flux component of current. And that current kick is able to compensate for the delay in the flux and the torque varies instantaneously as you vary the flux.

So, this is an example how we can have a controller to compensate for the delay in the flux. We have already seen the response of a vector control drive and the response of a vector control drive with constant rotor flux and the response of a vector control drive with variable rotor flux and the response of a vector control drive when we have a compensator to compensate for the delay in the flux response. Now after this we will try to see that how to estimate the rotor flux; unless, we estimate rotor flux we cannot go for the compensation, we cannot go for vector control. So, we have to estimate the rotor flux.

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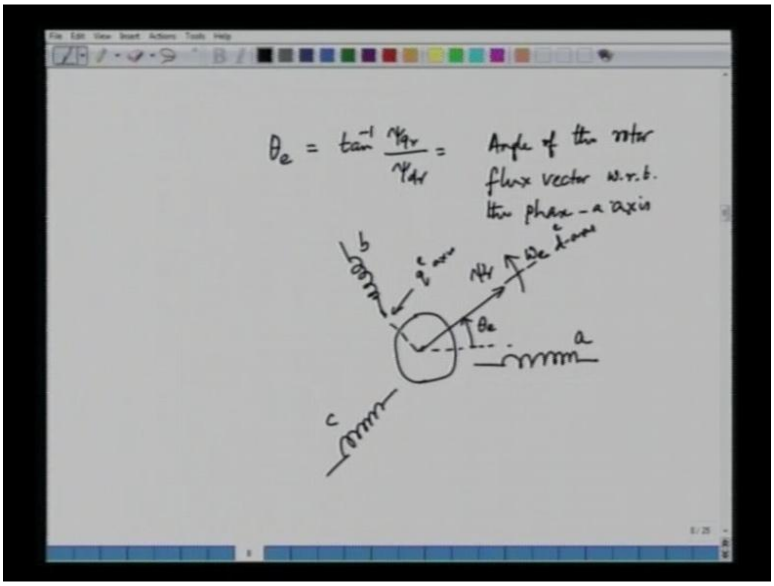

And as we know that the key to this is the following that we have to estimate this angle theta e which is tan inverse of psi q r by psi d r; so we we have to find out this angle, and this is the angle of the rotor flux vector with respect to the phase a axis. So, if we have phase a axis here these are the 3 phases of the machine, and we have the rotor. The rotor flux is rotating synchronously at a speed of omega e.

This is the vector that is psi r, and this angle we have to estimate theta e, and if we estimate this angle or if we can find out this angle, this angle can help us to transform the current components i d s e and i q s e into the actual stationary current a b c currents i a, i b, i c. So, the hypothetical currents i d s, i q s we have this is our d axis, and this is the q axis, and correspondingly we have i d s and i q s. We have to use this angle theta e to transform the currents i d s and i q s into i a, i b, i c. So, we have to find out this angle of the flux vector that is theta e, and hence we have to go for what is called rotor flux estimation.

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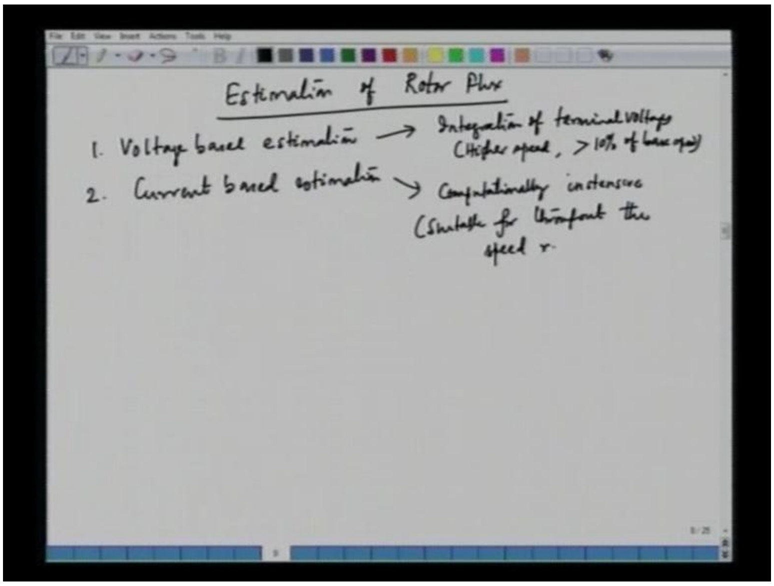

The rotor flux is not directly available; it is inside the rotor. The flux linking the rotor is call rotor flux, and we know that people have tried to find out the air-gap flux, the stator flux, but the rotor flux is difficult to measure. Putting a sensor inside the rotor is not very convenient. We cannot just put a hole or make a hole, put a sensor in the rotor, because the rotor is rotating we cannot have sensor inside the rotor. So, we have to somehow estimate the rotor flux from the terminal variables. The terminal variables are voltages and currents. If we can estimate the rotor flux it will solve our purpose. In the sense that we can find out the angle of the rotor flux vector to inside the transformation from i d s e i d s, i q s to i a i b i c.

So, in this case what we have we can have two approaches. One is called voltage based estimation, and in the voltage based estimation what we do? We primarily rely on the voltages of the machine to estimate the rotor flux. So, we take the voltages; we integrate the voltage to find out the rotor flux. So, this is one way, and the other way is a current based estimation. In a current based estimation we do not integrate the voltage. We take the currents and take the help of the current to find out the rotor flux vector. And both the approaches have their own merits and demerits. The voltage based model is suitable for higher speed, and the current based model can be applied throughout the speed range without any difficulty.

But the voltage based estimated is little easier to implement, because this requires less signal processing, but the current based method requires more signal processing, and hence it is computationally intensive. So, this relies on the voltage primarily integration of terminal voltages, and this is more suitable for higher speed typically greater than 10 percent of the base speed. And the current based estimation is computationally intensive and suitable for throughout the speed range. Now first we will discuss how to do the estimation using voltage based techniques. Right now we will be discussing the voltage based technique to estimate the flux. So, we have the terminal variables available to us.

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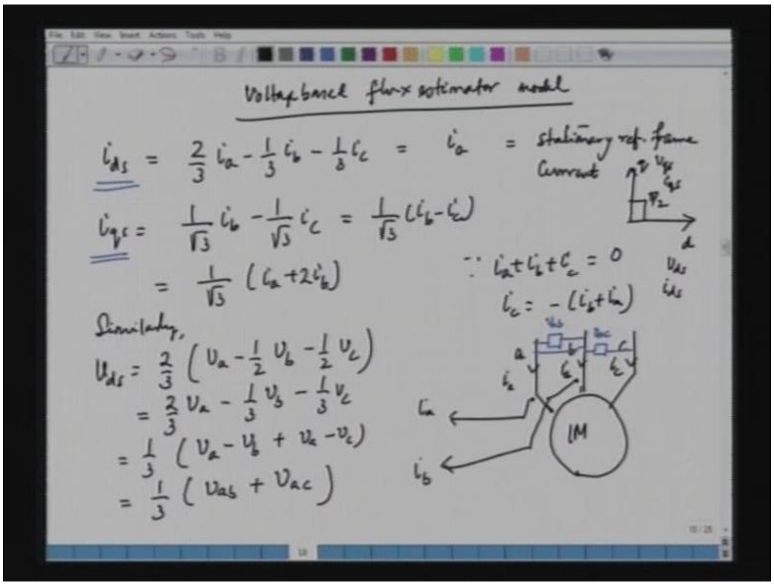

So, we have the voltage based flux estimator model. Now we can find out what is i d s? I d s is two-third i a minus one-third i b minus of one-third i c, and that is equal to i a. So, this i d s is the the current in the d q stationary reference frame. So, we can say this is the stationary reference frame. So, i d s is the stationary reference frame current, and similarly we can find out i q s in the stationary reference frame. So, we can say that i q s is equal to 1 by root 3 into i b minus 1 by root 3 into i c, and that is equal to 1 by root 3 into i b minus i c. And that is equal to 1 by root 3 into i a plus 2 i b, because we know that i a plus i b plus i c is equal to 0. We can eliminate i c; i c is equal to minus of i b plus i a. So, if we substitute for i c we can see that it is i a plus 2 i b 1 by root 3.

And what we do here we have to only measure i a and i b of the machine. So, the machine is a 3 phase machine. So, we have a 3 phase machine here. These are the three different phases. This is the induction motor, and we have here phase a, phase b and phase c. And since we have a 3 wire system we can always say that i a plus i b plus i c equal to zero. So, in that case this is the i a, and this is i b, and this is i c. We do not have any neutral connection here. We have a just 3 phase system, a 3 phase 3 wire system. So, we can say i a plus i b plus i c is equal to zero, and applying that we can find out what is this i d s and what it is the i q s.

So, if we measure if we have current sensor. So, we can have a current sensor here, and this current sensor will be giving us i a, and this current sensor will be giving us i b. So, we have i a and i b available to us; from i a and i b we can find out what it is i d s and i q s. And in z similar fashion we can find out what is v d s and v q s. V d s is equal to in a same way we can say here it is 2 by 3 into v a minus half v b minus half v c. This is actually based on the stationary reference frame transformation which you have already done a few lectures backs.

So, we know that in case of a stationary reference frame theta e is equal to zero. So, if you substitute theta equal to 0 here the angle of the reference frame is equal to 0. We can get back this as 2 by 3 into v a minus of half of v b minus of half of v c. And this we can simplify, and that is equal to 2 by 3 v a minus one-third v b minus one-third v c. So, I can take 1 by 3 out. So, I will say here it is v a minus of v b plus v a minus of v c; that is equal to one-third of v a b plus v a c. So, what it is v a b? V a b is the line voltage between a and b. So, if I can have a voltage sensor, if I can have a voltage sensor here this is a voltage sensor. This voltage sensor will be measuring v a b.

And if I have a voltage sensor between a and c this will be measuring v a c. So, I can have a two current sensors, and i can have 2 voltage sensors to find out i d s, i q s and v d s, v q s. Please remember that this i d s and i q s, v d s and v q s has the variables in the stationary reference frame. In other words the reference frame in which we are calculating the variable for finding out the flux linkages are not rotating at the stationary reference frame.

It means if I have my reference frame the reference frame has the d axis, and the reference frame has the q axis, and the d and q axis are stationary in the space. They are not rotating. They are stationary in the space, and correspondingly this will have v d s, i d s; this will have v q s and i q s. That is how we are computing from that terminal variable; they are the voltages and the currents. And from this we can find out the flux linkages. Now how do you find out the flux linkage? The easiest flux linkage is the stator flux linkage.

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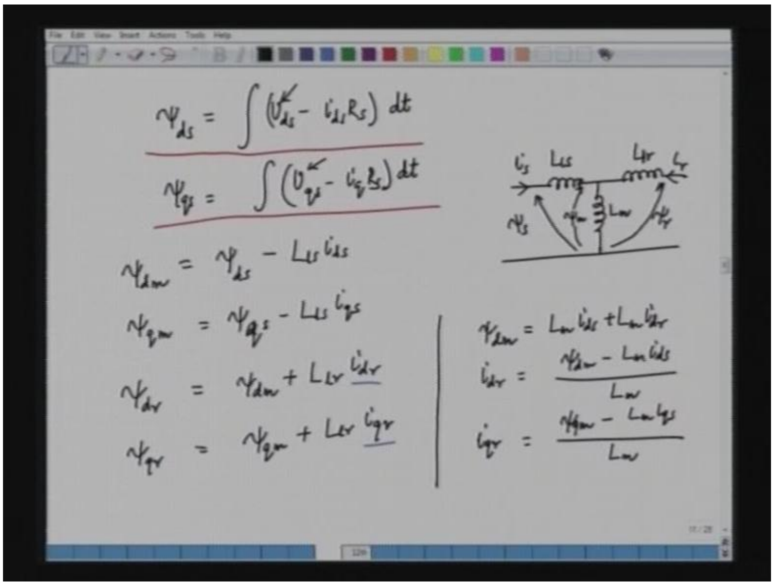

So, we can say that psi d s is equal to integration of v d s minus i d s r s, alright. So, this is what we can say very directly. So, we can evaluate the stator flux linkage by integrating the voltage v d s minus i d s r s integration of that will give me psi d s, and in a similar way I can find out psi q s is the integration of v q s minus i q s r s. So, the integration of the induced e m f; the induced e m f behind the stator resistance, the integration of that will be giving me the stator flux linkages psi d s and psi q s, but I do not need the stator flux. What I need is the rotor flux, because our vector control aims are the orientation with respect to the rotor flux vector. So, I have to find out the information about the rotor flux. So, we will go stage by stage.

Now we have been able to evaluate the stator flux linkage. So, from that we can evaluate the air-gap flux. As we have already seen that in case of a machine if we only represent the inductance part, this is the stator leakage inductance, this is the rotor leakage inductance, and this one is the magnetizing inductance of our induction machine power phase circuits. And this one is the stator flux. We can call this to be psi s, and this flux linking the magnetizing inductance is called the magnetizing flux or the air-gap flux, and the flux linking the rotor is the rotor flux that is psi r. So, what we have done here we have been able to find out the stator flux linkage that is psi d s and psi q s. From that we can evaluate what is the air-gap flux linkage or the magnetizing flux linkage psi d m and psi q m.

So, we know that psi d m is equal to psi q s minus psi d m is equal to psi d s minus the stator leakage. So, this is l s i d s. This is the stator current, this is the rotor current, and similarly we can evaluate psi q m is equal to psi q s minus l l s into i q s, and we have to go again further; what we need here is the rotor flux. So, if we want to find out what is psi d r, psi d r is psi d n plus the rotor leakage flux l l r into i d r. Similarly we can have also in the q axis psi q r is equal to psi q m plus l l r into i q r.

So, we are proceeding stage-by-stage, step-by-step; ultimately, what we need? We need psi d r and psi q r, and if we need psi d r and psi q r we can find out the rotor flux vector angle. So, to evaluate psi d r and psi q r what we need here is this. The rotor currents are not available to us. We can always measure the stator current. We can find out easily i d s and i q s by by measurement, but can we find out what is i d r and i q r? I d r and i q r are not available to us. They are inside the rotor, and sometime the rotor is the cage rotor a squirrel-cage rotor.

If the rotor is a cage rotor we cannot have any idea about the rotor current. So, we have to express the rotor current in terms of other variables which are measurable. This i d r in the following fashion; we know that psi d m is equal to l m into i d s plus l m into i d r. So, what we do here we calculate, we evaluate what is the i d r. I d r is psi d m minus l m i d s by l m. So, we can evaluate what is i d r, and then similarly we can evaluate what is i q r. I q r is equal to psi q m minus l m i q s by l m. So, we can find out what is i d r and i q r in terms of i d s and i q s which are measurable, and then we can substitute this back here to find out what are the rotor forms. So, this is the way in which we can evaluate the rotor fluxes from the terminal variable.

Now this actually is very appropriate when the speed is high, and the main bottle neck of this method is that whenever we have low speed operation, when the speed is very low it is difficult to integrate the voltage to find out the flux linkage. Now this is the difficulty in the measurement; as we are going step by step we are evaluating the air-gap flux or the magnetizing flux from the stator flux. So, the stator fluxes are evaluated by the integration of the voltages v d s and v q s, and whenever we have a integrator we have a practical integrator the integrator will be having some offset.

And the offset is usually very small when the voltage is significant; voltage is large compared to the offset. Say for example, offset can be in the order of few millivolts, but if the voltage is very large in the order of few tens of volts or hundreds of volts this offset can be ignored. But as we are talking about low speed operation the speed is close to 0, the voltages will also be very very small, because we understand that when the speed reduces, voltage also reduces with the speed. So, at low speed operation the difficulty of this method is the following.

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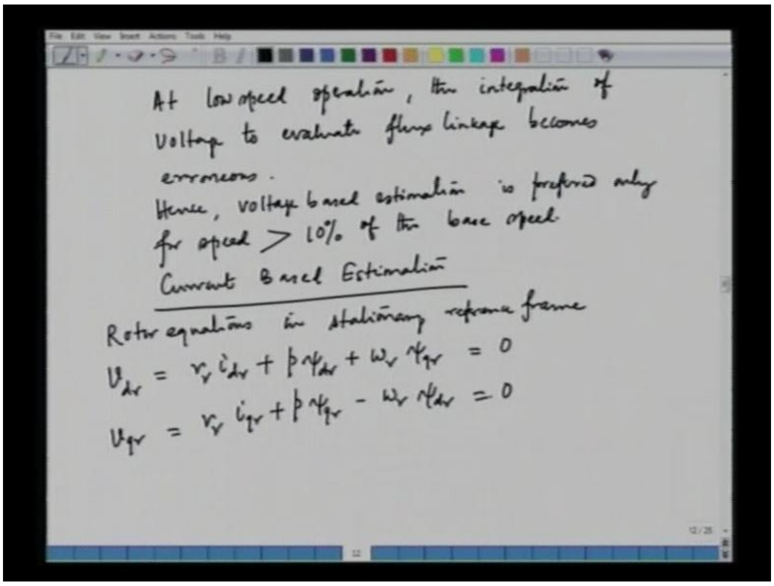

At low speed operation, the integration of voltage to evaluate flux linkage becomes erroneous. So, at a low speed the voltage becomes small, and the voltage is comparable to the offset of the integrator. And then the integration become erroneous and if the integration is not correct the flux linkage will be also incorrect. And hence we cannot get a good estimate of the flux at low speed, and due to this this method is applicable for a speed higher than 10 percent of the base speed. Hence, voltage based estimation is preferred only for speed greater than 10 percent of the base speed. So, this is basically the limitation of the voltage based method. Now to overcome this limitation we have another method called current based estimation technique.

So, we will discuss current based estimation after deriving the equation for the step. So, we will be discussing about the current based estimation technique. So, in this case what we will be doing here, we will be taking the rotor equation and from the rotor equation we will be deriving the current base estimator. So, we have the equations as follows. We can say that the rotor equations in stationary reference frame can be given as follows; say for example, we can say that psi d r equal to r r i d r plus P psi d r plus omega r psi q r. and similarly we can write down in the q axis that is equal to zero. V q r is equal to r r i q r plus p psi q r minus omega r psi d r that is equal to zero. So, these are the currents in the stationary reference frame, the rotor equation in the stationary reference frame, and this will be useful for deriving current based estimation technique.

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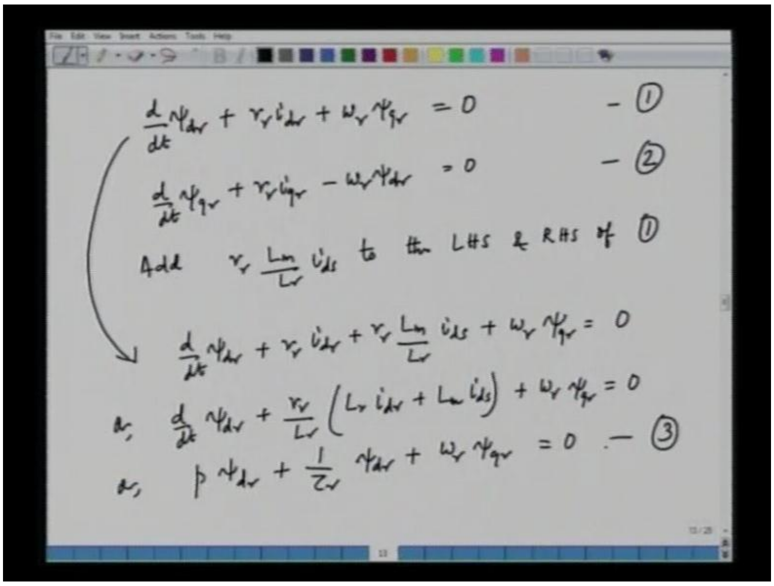

Now we will see how we do that. Now if we simplify this equation we will have the following equation. D by d t of psi d r; this is equation number 1 we can say, and similarly we can have d by d t of psi q r plus r r i q r minus omega r psi d r; that is equal to 0, this is equation number 2. So, what we do here? We add in this case r r into l m by l r into i d s to the left hand side and right hand side of equation 1. So, if we add this quantity in the left hand side and the right hand side of equation 1, we get the following equation. So, from this equation we can get back a new equation by adding this particular term, and this equation is the following. So, we have d by d t of psi d r plus r r i d r plus r r l m by l r into i d s plus omega r psi q r equal to zero.

And we can further simplify this. What will do here we will take this r r by l r common. We have here l r into i d r plus l m into i d s plus omega r psi q r that is equal to 0, or we can just write down this p; p is the derivative operator, psi d r plus r r by l r is 1 by tau r, and this quantity within the parenthesis l r into i d r plus l m into i d s that is psi d r plus omega r into psi q r that is equal to 0. So, this equation can be called equation number 3.

This is the equation in the d axis. So, from this we can find out the information about the rotor flux in the d axis.

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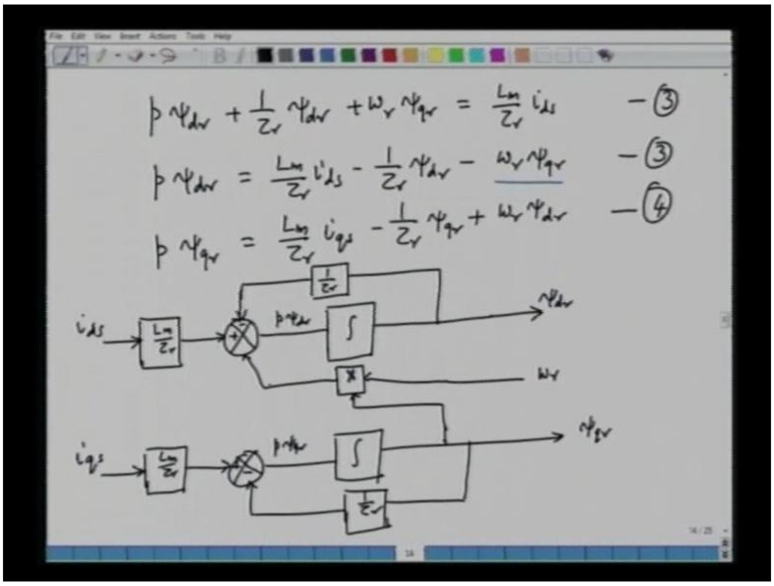

So, we can just rewrite this equation once again. P psi d r plus 1 by tau r psi d r plus omega into psi q r is equal to that is the right hand side term also here, and the right hand side term here is l m by tau r into i d s. So, this is in the right hand side l m by tau r into i d s, l m by tau r into i d s; that is equal to l m by tau r into i d s. So, this is the equation number 3 that we have already derived. And after we simplify this equation we can get this p psi d r is equal to l m by tau r into i d s minus 1 by tau r into psi d r minus omega r into psi q r; this is the same equation. So, this equation is the equation in the d axis. Similarly, we can have the equation in the q axis and simplify, and we will have a similar equation in the q axis as well.

So, in the q axis we have p psi q r that is equal to l m by tau r into i q s minus 1 by tau r into psi q r. This speed induced e m f will have a different sign. So, we have plus omega r into psi d r; this is the equation number 4. So, from equation number 3 and 4 we can evaluate the rotor flux linkages. So, this can be explained by means of a block diagram. If we draw a block diagram it will be easy to understand how we can estimate the rotor flux from these equations. So, we have a summer here, and here what we have in this case is l m by tau r, and this one is i d s coming from outside. Similarly in the q axis we have again another summer. This is l m by tau r. So, this i q s; so this is plus, and then what we obtain here out of this is p psi d r, and we use an integrator here, and what we obtain here is psi d r.

Similarly, out of this we obtain p psi q r. We use an integrator here, and then what we obtain here is psi q r. And we have to do some readjustment in this case. Here is the setback loop. We have to setback the flux linkage vector, but the flux linkage 1 by tau r that is obtained from this. So, here is the negative sign. Similarly we have a feedback mechanism here as well 1 by tau r, and here we feeding back 1 by tau r in the psi q r, and here we have the speed. This is omega r as an input, and this is fed to this place after suitable multiplication.

So, in this case we see that we have a term called omega r in the psi q r. This is my omega r, and this is the psi q r. So, this is omega r into psi q r. Similarly I have another multiplier here. This will go in this case, and this will be this is minus, and this will be plus. So, this is coming from psi d r, and this is the speed that is coming from here. So, this is again fed back to this particular block. So, this is the complete estimation. So, this is actually a current based estimation technique, and this does not integrate any voltage; currents are always available. So, we can integrate the currents, and if we integrate the current we can find out the flux linkage psi d r and psi q r.