Power System Dynamics
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Lecture - 08
Modelling of Synchronous Machine

Friends, we should study today the modeling of synchronous machine.

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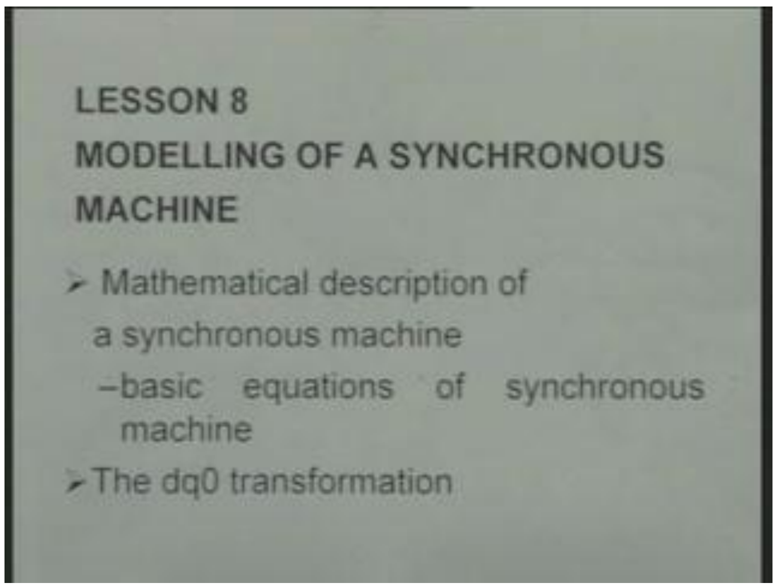

Till now the synchronous machine was model as a constant voltage behind direct axis transient reactance. The synchronous machine modeling has been a challenge all through and lot of work has been done over the years to develop more accurate models of the synchronous machine. Today in our study we will develop the basic equations of synchronous machine and then we will go to dqO transformation which is also commonly known as park's transformation.

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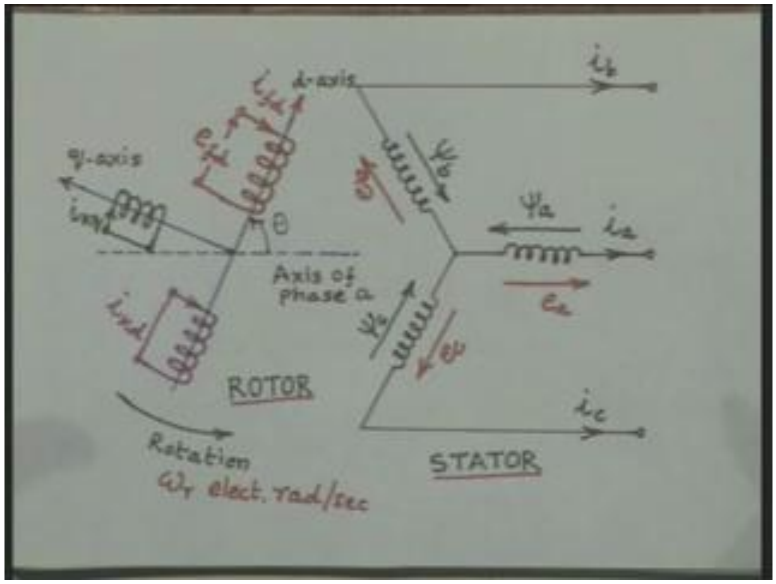

Now this synchronous machine has two major parts, stator and rotor. We shall represent stator has provided with 3 windings and we assume that these windings are sinusoidally distributed. On the rotor, we have a field winding on the direct axis and we have amortisseur or damper windings. In a synchronous generator we provide dampers and these dampers can be represented by considering considering the amortisseurs located on the d axis and on the quadrature axis.

Now here in my presentation we will presume or we will assume one amortisseur on the d axis and another amortisseur on the q axis. The convention which we will follow here is that the q axis leads d axis by 90 degrees, although there are some some you know cases where the q axis has been taken as lagging the d axis but in IEEE standards consider the q axis leading the d axis by 90 degrees.

Now here the d axis is along the axis of north pole, it coincides with the axis of north pole then we will measure the angular position of the, angular position of the direct axis with respect to the axis of phase A of the stator that is here this straight lines shows the axis of phase A and the the angular position of the rotor is measured with respect to the axis of phase A and we call this angle as theta. Further we will be following the generator convention there is the stator currents are leaving the terminals of the machine that is i_a, i_b and i_c are leaving the machine terminals. The rotor is rotating in the anticlockwise direction this is direction of rotation of the rotor which we are presuming.

Now the currents in the rotor circuits are entering the rotor circuit, if you just see here this field winding the current is entering the field winding and the applied voltage is efd the damper windings are closed circuits amortisseurs are closed circuits. The current flowing is again into the amortisseur windings closed circuit.

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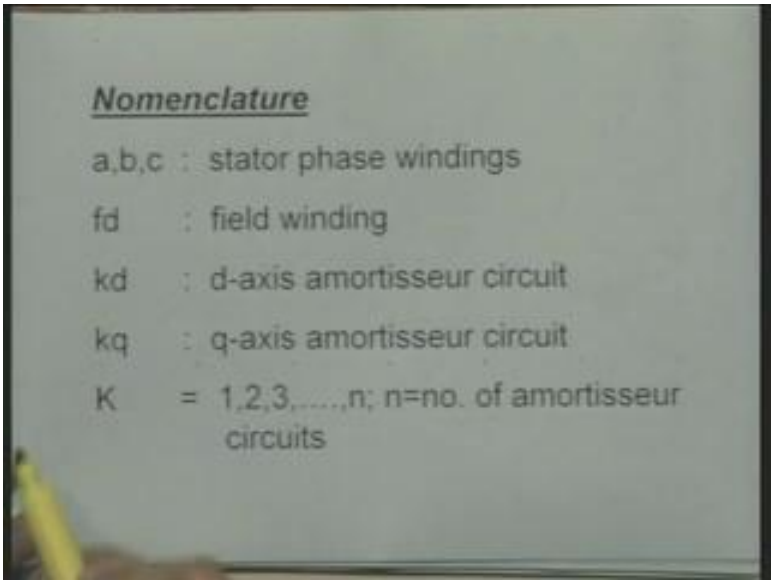

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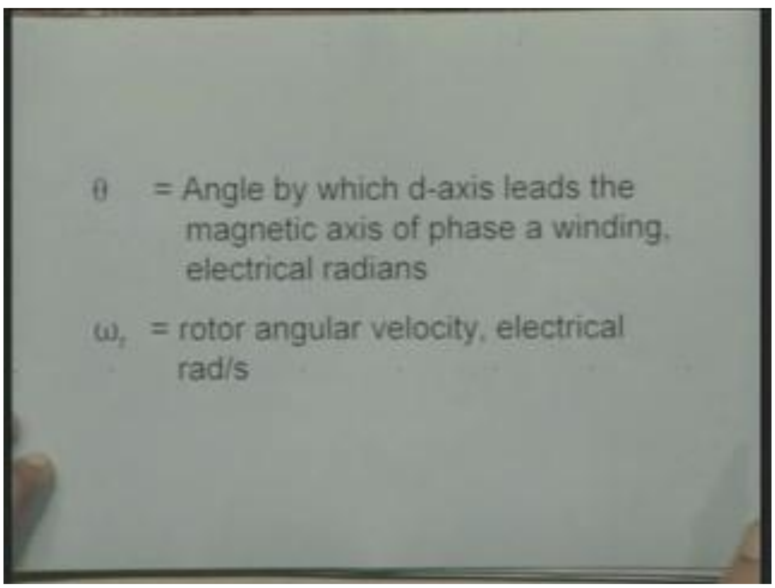

Some of the important nomenclature are ah will be use here, a, b, c stands for the stator phase windings, fd stands for field winding, kd stands for d axis amortisseur circuit, kq stands for q axis amortisseur circuit, this K stands for 1, 2, 3, n, the number of amortisseur circuits that is if I put one amortisseur circuit on the d axis, k becomes 1 I can say 1 d if there is one amortisseur on the q axis it is 1q. Okay therefore in general the amortisseurs are represented by putting substitute kd or kq, theta is the angle by which the d axis leads the magnetic axis of the phase a winding in the electrical radians and omega r is rotor angular velocity is electrical radians.

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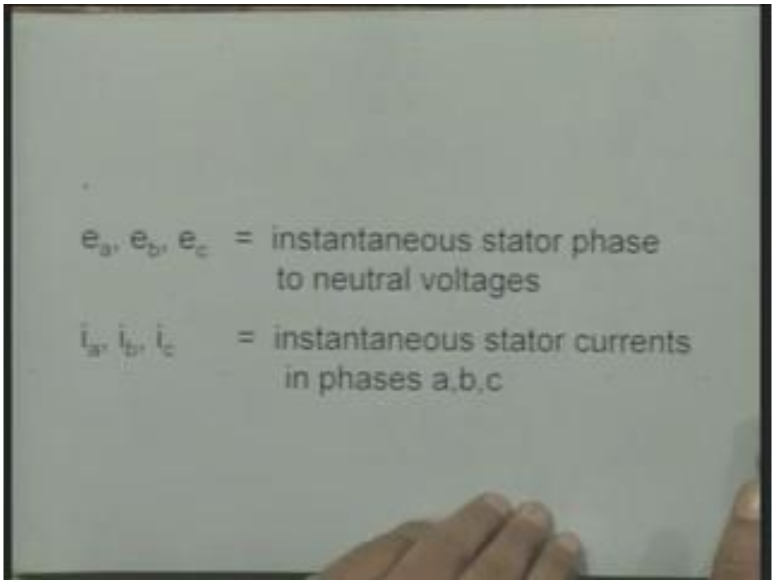

The e_a, e_b and e_c are the instantaneous stator phase to neutral voltages that is the voltages which are shown here these are the instantaneous values and they are with respect to phase to neutral there is a raise from neutral to phase, instantaneous stator currents are shown as i_a, i_b and i_c.

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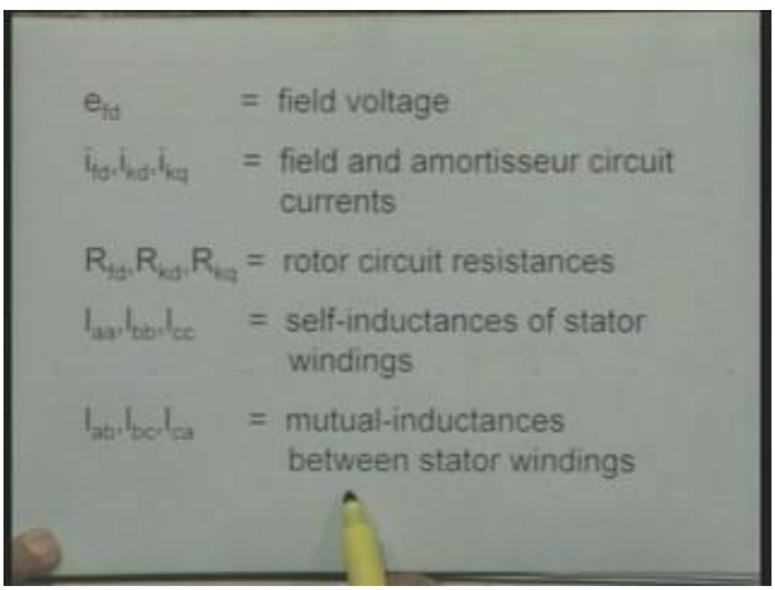

The field voltage is e_{fd}, the field and amortisseur circuit currents are denoted as i_{fd}, i_{kd} and i_{kq} the rotor circuit resistances will be denoted by R_{fd}, R_{kd}, R_{kq} with R_{fd} is the resistance of the field winding, R_{kd} is the resistance of direct axis amortisseur circuit and R_{kq} is the resistance of the quadrature axis amortisseur circuit.

Now here, we will see that we have stator windings, we have windings on the rotor and rotor is rotating and because because of this we will find actually that the, we come across various types of inductances in the synchronous machine, the inductances are the self- inductances of the stator windings, the mutual inductance between the windings of the stator then mutual inductances between the stator winding in the rotor circuits and self-inductances of the rotor circuits and mutual inductances between the rotor circuits therefore we come across different types of inductances in the stator in the synchronous machine.

The, we represent this by double circuit same circuit l_{aa} to denote that it is a self l_{aa}, l_{bb} and l_{cc} stand for self-inductances of stator windings that is we will use double circuit notation to denote the self-inductances or mutual inductances if there are self-inductances the two circuits will be same if they are mutual inductances the two circuits will be different, like say l_{ab} l_{bc} and l_{ca} stands for mutual inductances between stator winding that is l_{ab} is the mutual inductance between stator a phase and stator b phase, so on.

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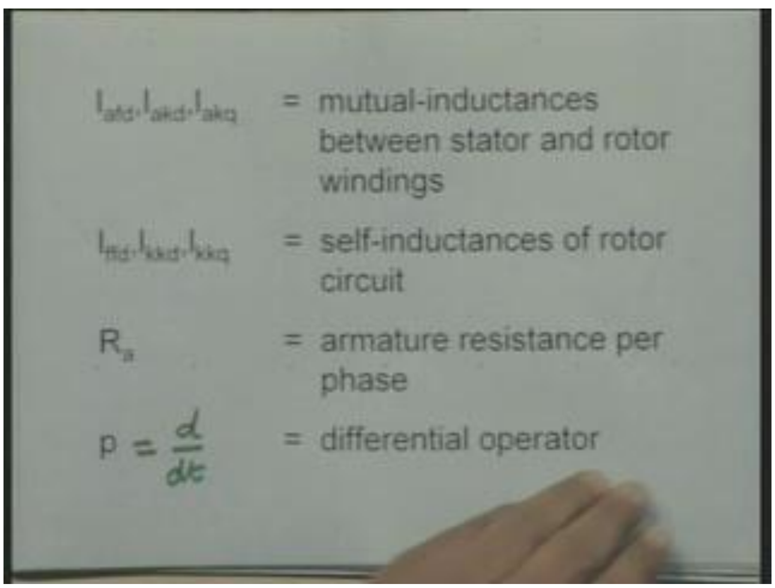

Then l_{afd}, l_{akd} and l_{akq} represents the mutual inductances between the stator a phase and rotor windings that is l_{afd} is the mutual inductance between the stator a phase and field winding l_{akd} is the mutual inductance between the stator a phase and amortisseur on the d axis and similarly, l_{akd} then l_{ffd}, l_{kkd} and l_{kkq} represents the self-inductances of rotor circuit. R_a is armature resistance per phase and we will represent this differential operator P which is your d by dt by the symbol P, P is the differential operator.

Now in the case of synchronous machine, the self-inductances of the stator winding and the mutual inductances between the stator windings and they they they are affected because of the the non-uniform air gap. As we know that the magnetic field produced by the stator winding it passes through passes through the stator core, through the air gap, through the rotor iron then air gap and again return backs through the stator core right and therefore the flux produced by the stator winding will be affected by the position of the rotor.

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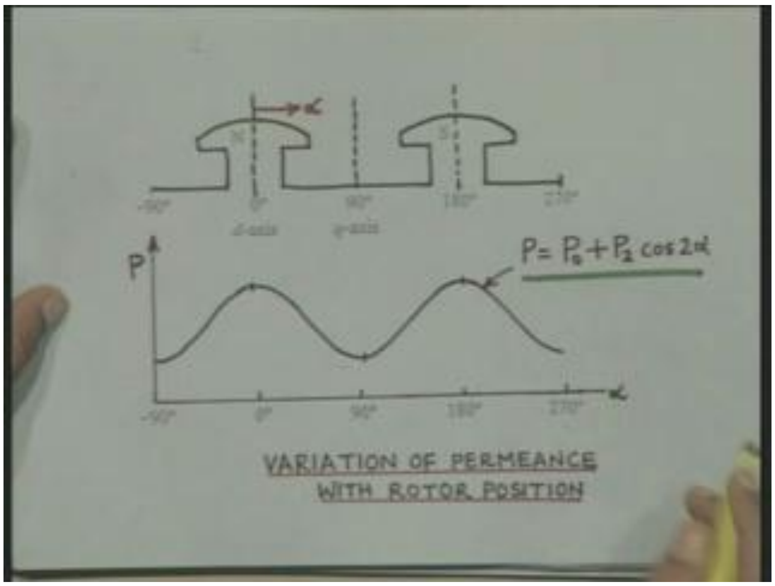

Now here in this diagram we saw the variation of permeance with rotor position means you know that permeance is the reciprocal of reluctance. Okay now here I am considering a salient pole machine and these are the pole location and we are just showing the expanded version. Now the permeance is maximum when the, when the permeance is maximum along the d axis or we can say the reluctance is minimum. This graph shows the variation of permeance as with respect to the position that is angle alpha which is measured with respect to the d axis which coincides with the North Pole axis okay.

We can easily see that this is maximum position, when it coincide with the Q axis it is minimum and it again coincides with the d axis it is maximum and this variation is of the form P equal to P_o plus P_2 cos 2 alpha that is when alpha is 0, alpha is 0 its value is P_o plus P_2 and when alpha is ninety degrees its value is P_o minus P_2 right that is cos2 alpha becomes minus 1 and it is this variation of this permeance right is having a strong bearing on the variation of self-inductances mutual inductances and so on.

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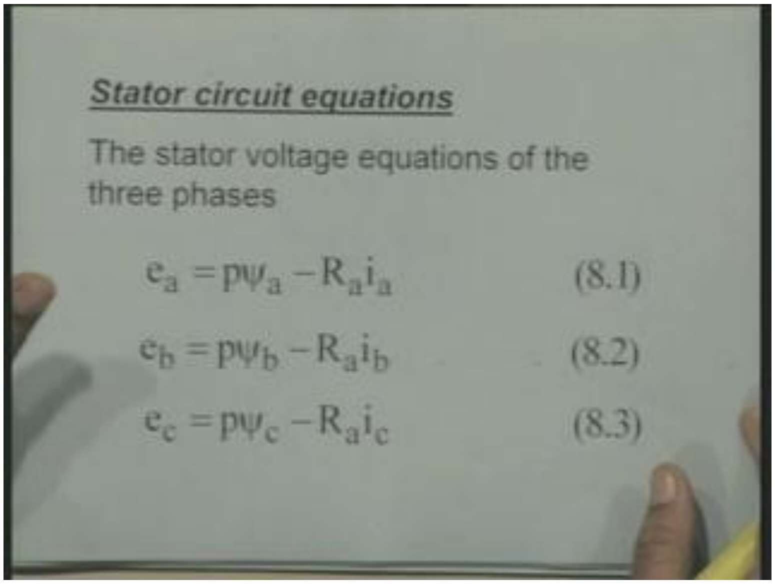

Now to understand the whole thing what we start with this we first write down the stator circuit equations. The basic stator circuit equations are e_a is equal to p, psi a minus R_a i_a, e_b equal to p psi b minus R_a i_b and e_c equal to p psi c minus R_a i_c, i_a i_b and i_c are the instantaneous value of the phase currents and p psi a stands for d by dt of psi a, psi a, psi b and psi c are the flux linking phase a phase b and phase c respectively. Okay that means straight forward that the induced emf is d by dt of psi a and this will be equal to the terminal voltage plus the resistance drop or now this equation is drawn considering the generator action okay.

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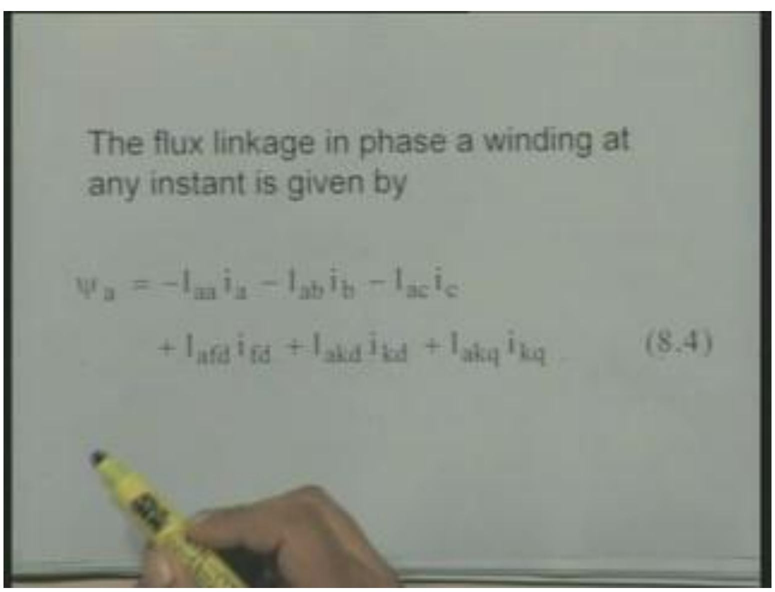

Now here, let us see actually that what determines the flux linkage in the stator phase winding the flux linkage in the stator phase winding can be written as psi a equal to minus l_{aa} i_a, now here I will explain this minus terms but l_{aa} is the self-inductance of phase a la into ia minus mutual inductance between a and b and multiplied by i_b minus i_{ac} i_c plus l_{afd} i_{fd} where l_{afd} is the mutual inductance between a phase and field winding i_{fd} is the field current similarly l_{akd}, i_{kd}, l_{akq}, i_{kq}.

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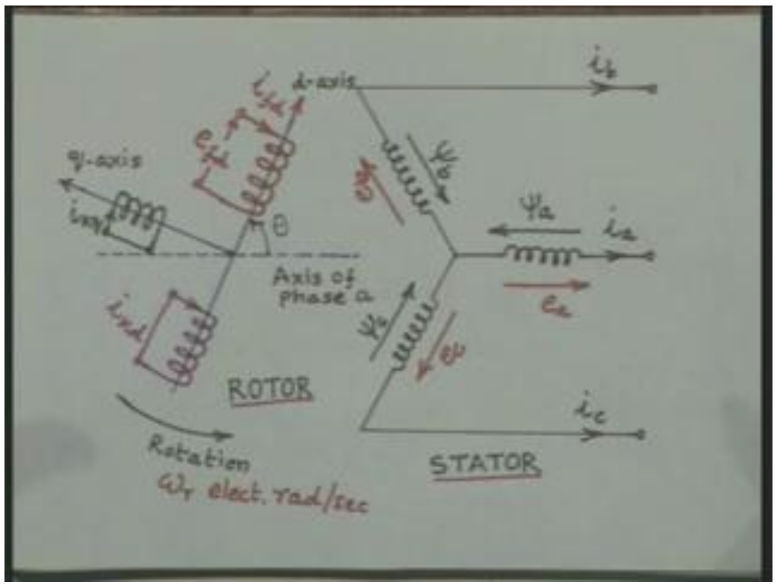

Now since we have assumed in the basic model here that the flux linkages are shown in the direction opposite to the current and that is why actually the negative signs are appearing here that is in these terms you can just see these are the negative signs while the currents are entering the other three rotor windings therefore they are the positive signs. Now we will see that that these self-inductances mutual inductances these are not constant these depend upon the position of the rotor with respect to the windings, the stator windings and we will show that these depend upon the angular position of the rotor and since the rotor is rotating the angular position of rotor keeps on changing and therefore these inductances are going to be a function of angular position theta. Okay now to understand this let us first start with the stator self-inductances, the stator self-inductances.

Now here the stator self-inductance is denoted by the symbol l_{aa} okay and how when we define this stator self-inductance, the basic definition is the flux linking the phase a winding divided by the current that is the self-inductance of phase a winding with no currents on other windings that is when only current i_a is flowing and we find out what is the total flux linking the stator winding a that is the self-inductance of stator winding a l_{aa}.

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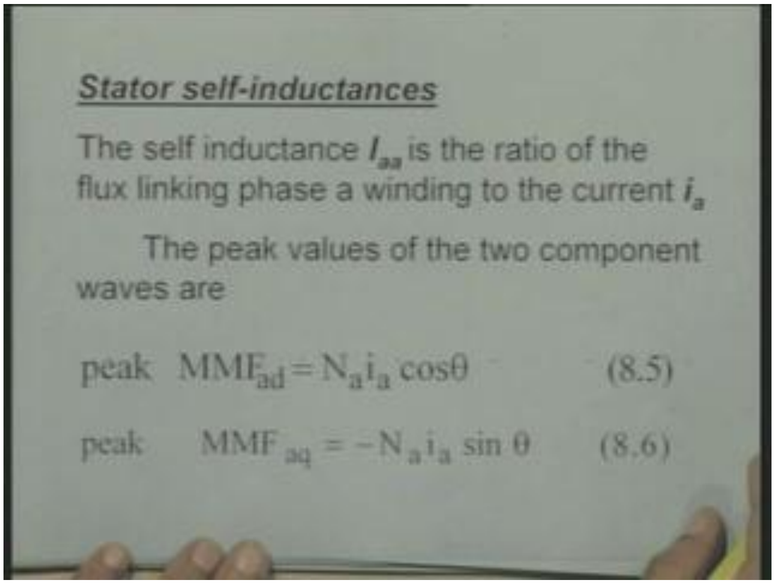

Now when the current i_a is flowing okay then the MMF, MMF which is produced due to the flow of current is N_a into i_a and this MMF is sinusoidally distributed along the surface of the stator or along the air gap okay because the stator is suppose to produce a sinusoidally distributed MMF okay and this MMF has the maximum value along the d axis right it is it is peak is along the d axis and when you go away from the d axis both sides this is going to decrease.

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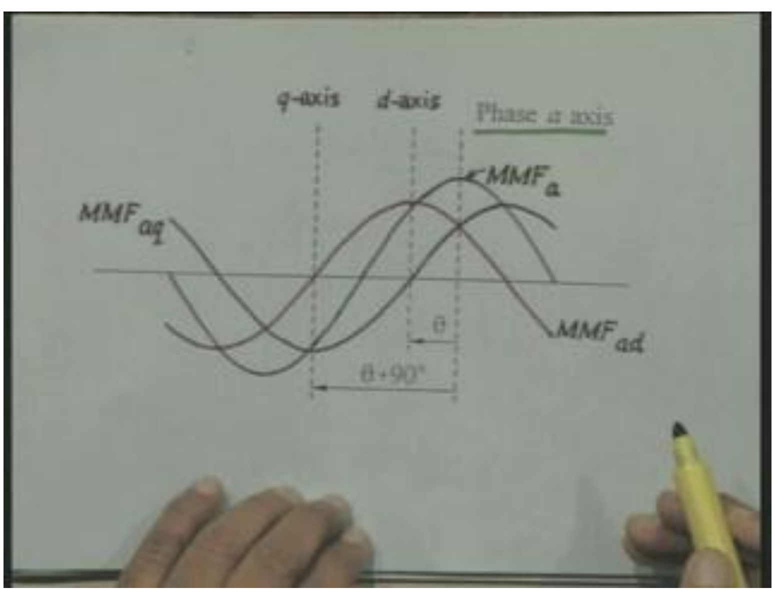

Now here this diagram shows, this diagram shows the MMF produced by the stator phase a that is the I am just showing this is the this is the axis of phase a okay and the MMF produced by the axis of phase a MMF produced by the phase a or stator phase a is having its peak along the d axis, this is the d axis. I am sorry, this is the not d axis, I am sorry this is the axis of the phase a, the axis of the phase a. Okay it is a little correction this is the axis of phase a.

Now what we do is we split this MMF into two components both are having the sinusoidal distribution, one having its peak along d axis another having its peak along q axis therefore this this graph red graph which I have shown here, this shows the sinusoidal distribution having its peak coinciding the d axis, this is the again sinusoidal distribution its peak is coinciding with q axis and the q axis is leading d axis by 90 degrees okay.

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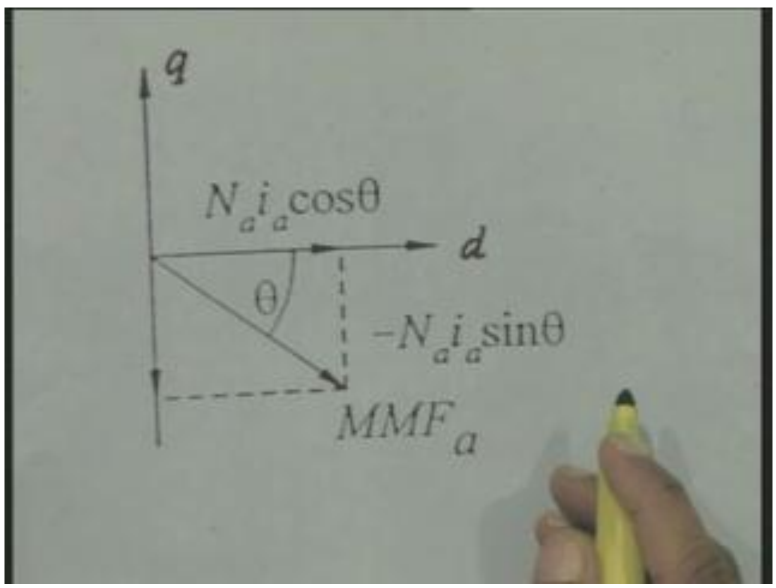

Now this can be seen here in this diagram that the MMF produced by the stator right along its own axis that is the MMF produced by a stator winding of phase a right is having its maximum value along its own axis that is axis of phase a. Now we have assumed likely that the rotor is rotating in the anti clockwise direction therefore axis of, now the d axis is shown here and q axis is leading points and what we do is that this MMF is resolved into two components one along d axis another along q axis. The d axis component is N_a i_a cos theta and q axis component is minus N_a i_a sin theta, okay.

Now with this MMF's then we can find out what will be the flux produced at the air gap along this d and q axis. Okay, now here we are showing that the MMF_{ad} that is MMF due to due to current flowing in the stator a phase and it is component along d axis ad is equal to N_a i_a cos theta and these are the peak values therefore when i_a attains its peak value this will also become this varying this is varying along as the i_a is varying, then the along the q is minus ia N_a sin theta okay.

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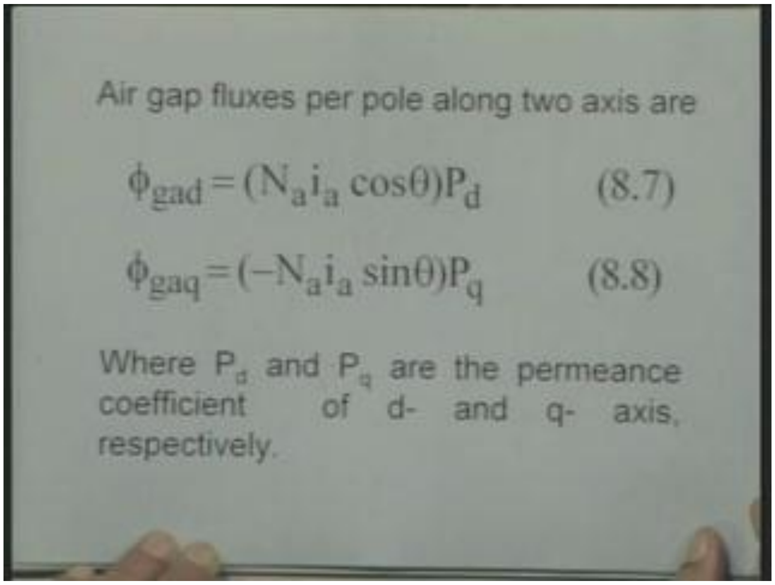

Now the flux produced long these two axis because of these MMF can be written as MMF into P_d that is phi gad, g stand for air gap or gap flux okay the phi gad is equal to N_a i_a cos theta into P_d and phi gaq is equal to minus N_a i_a sin theta into P_q. Now here this is the MMF and to relate this MMF to the flux we are using this term P_d therefore, P_d is in general a permeance coefficient we call it it is not only the absolute value of permeance but all other parameters which relate flux to MMF because this is the MMF only this is the flux okay.

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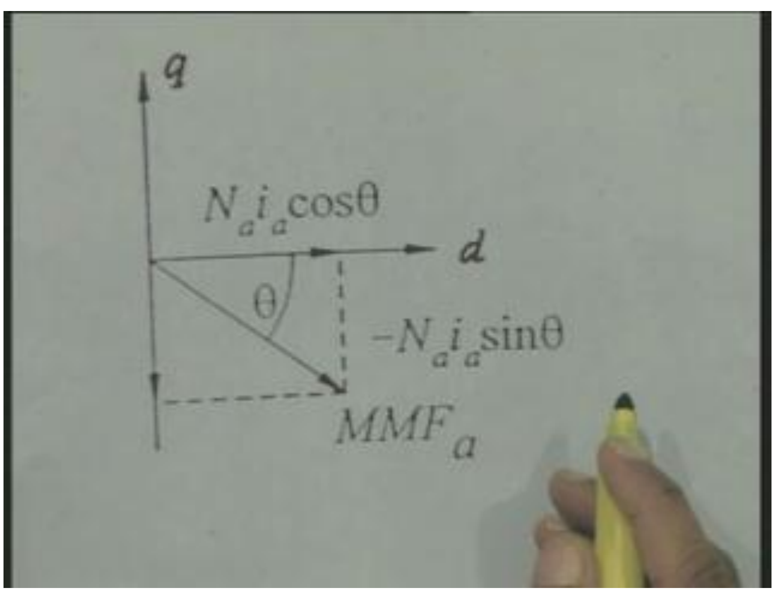

Now what is done is we again make use of this phasor diagram, the flux which is produced along d axis in the air gap, flux which is produced along q axis in the air gap, we resolve them back along the axis of phase a. that is when you resolve this right then this component will come out to be equal to phi gad cos theta and the second component comes out to be phi gaq sin theta with negative sign because there was negative sign already attached with it and therefore we can say that the air gap flux due to current flowing in the stator winding a only comes out to be equal to N_a i_a substituting these values on the previous equations in this form.

The N_a i_a P_d cos square theta plus P_q sin square theta and this expression when simplified it can be put in the form N_a i_a into P_d plus P_q by 2 plus P_d minus P_q by 2 cos 2 theta.

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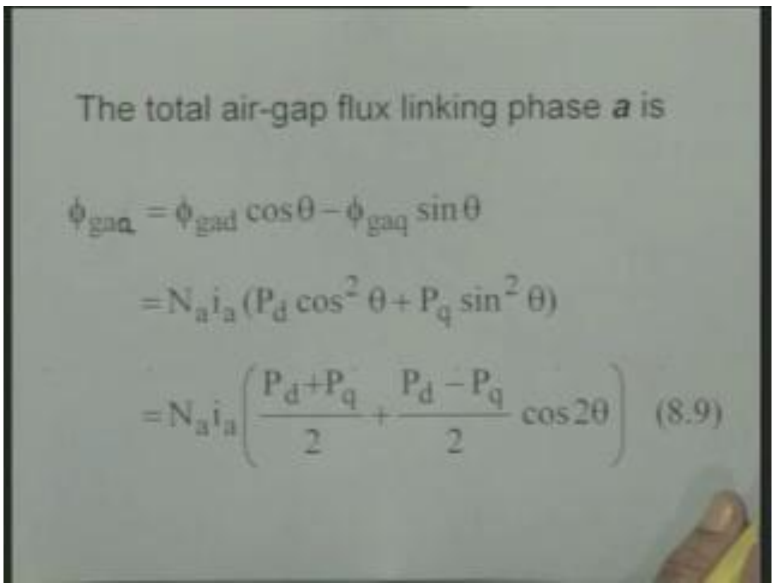

Now here this is very important point to understand that the air gap flux produced, air gap flux produced by current flowing in the stator winding of phase a is equal to is proportional to a term P_d plus P_q by 2 and another term P_d minus P_q by 2, cos 2 theta that is this term does not depend upon angular position, while this term depends upon the angular position. Now we define the inductance.

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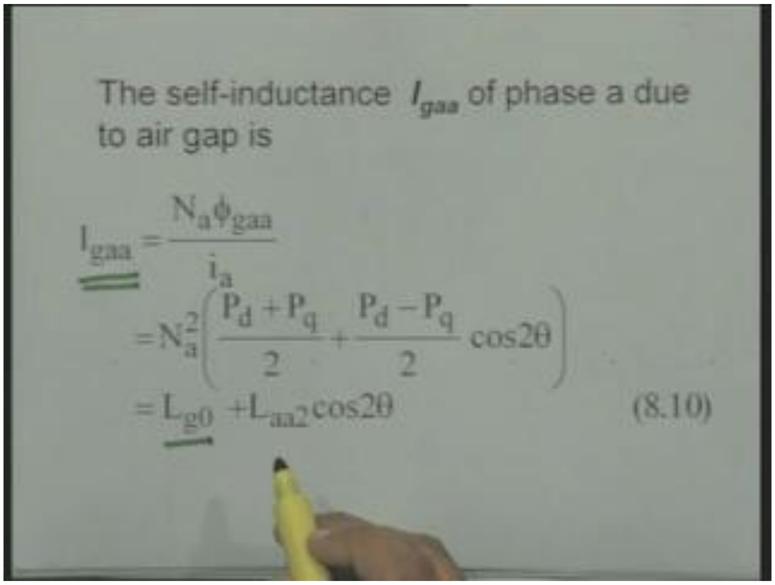

The inductance, the self-inductance of the stator phase a due to gap flux only the flux which is produced in the air gap, l_{gaa} is equal to N_a affective number of terms into the gap air gap flux divided by i_a and this comes out to be we substitute the value of phi g_{aa} it comes out to be N_a square P_d plus P_q by 2 plus P_d minus P_q by 2 cos 2 theta okay therefore this can be put in the form that is this is your L_{gaa} is the self-inductance of phase a due to gap flux only which can be put as a constant terms L_{g0} plus another term L_{aa2} cos 2 theta right because as I have seen the I have told you that the permanence of the air gap varies as a with the position of the rotor and there we found actually that it has a second harmonic variation. Here, also you find there is a constant term plus a quantity varying as a function of cosine 2 theta okay.

Now to make the whole thing more complete there is some a leakage flux which does not cross the air gap. Okay and this leakage flux also contributes the self-inductance of the stator phase and therefore, when you account for the leakage flux then we can say that the self-inductance L_{aa} of the stator phase is equal to self-inductance due to leakage flux plus l_{gaa} which I have obtained in the previous equation that is due to the gap flux and then when you combine these two terms. We can see here that this mutual inductance or the this second term will not be affected by the leakage and therefore this leakage term is combined and you find here that the self-inductance can be written as L_{aao} plus L_{aa2} cos 2 theta.

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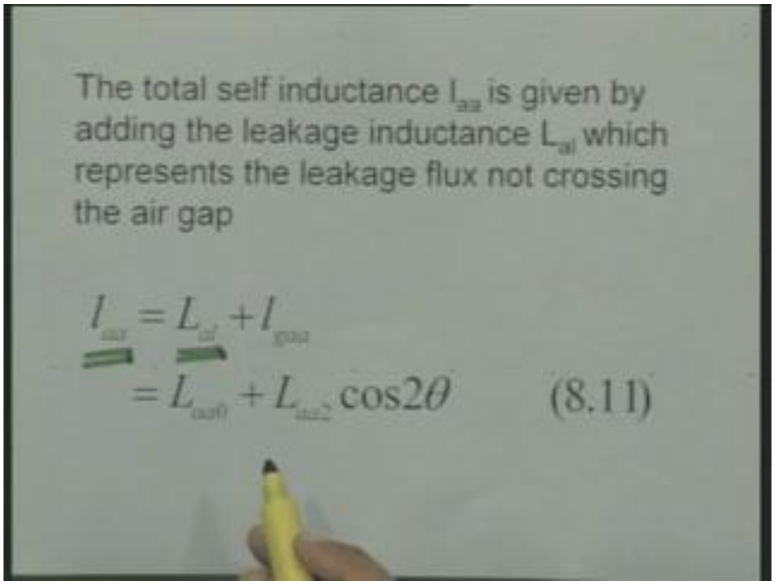

Now this is the most important equation to understand that how the self-inductance of stator phase varies as the position of the rotor varies the angular position of the rotor. Now this angular position is measured with respect to axis of phase a.

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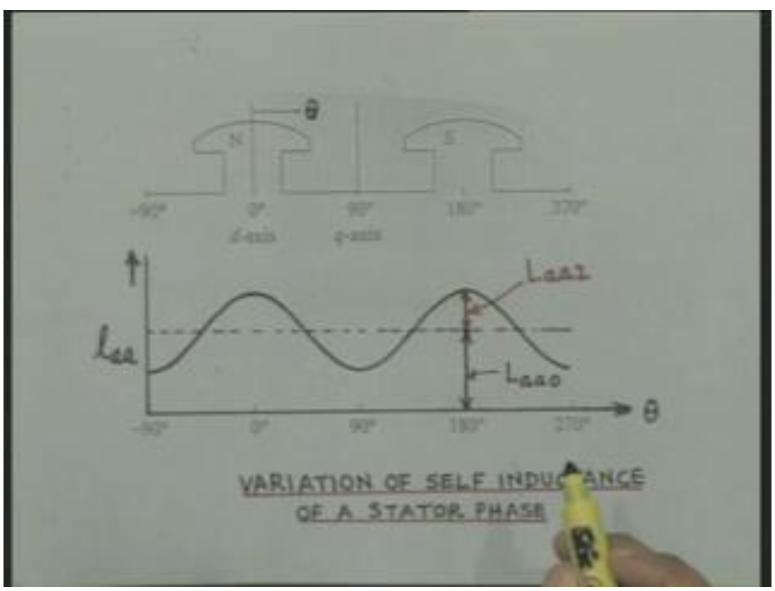

Now this graph shows the plot for the variation of the self-inductance of stator phase a as function of theta okay and you can identify here that this is the term L_{aa2} which varies this L_{aa2} is constant and this is another term which we call L_{aao} and the total inductance of the stator phase is now written as L_{aa} equal to L_{aao} plus L_{aa2}. These two terms are constant these constants these are constant they do not depend upon the angular position that mean the total self-inductance depends upon the angular position but these two coefficients are constant. Now when we perform the similar exercise for phase b and phase c, since the the axis of the phase b and phase c are displaced by 120 degrees with respect to axis of phase a right.

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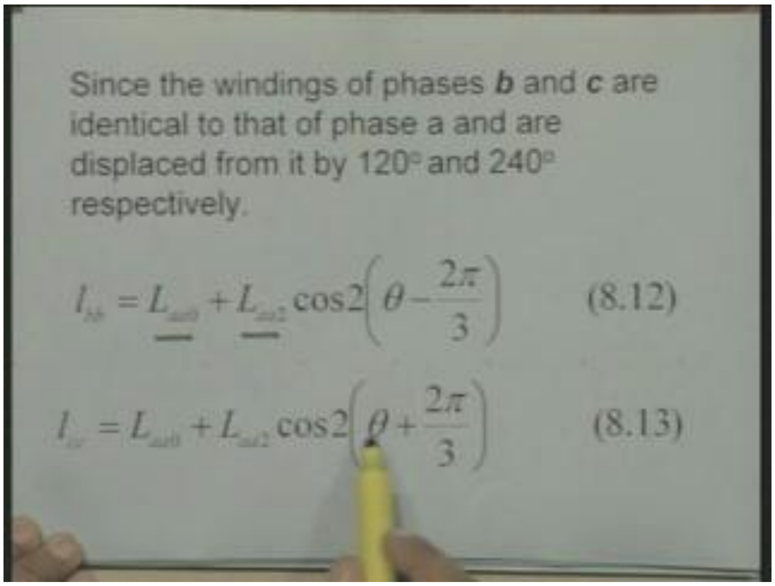

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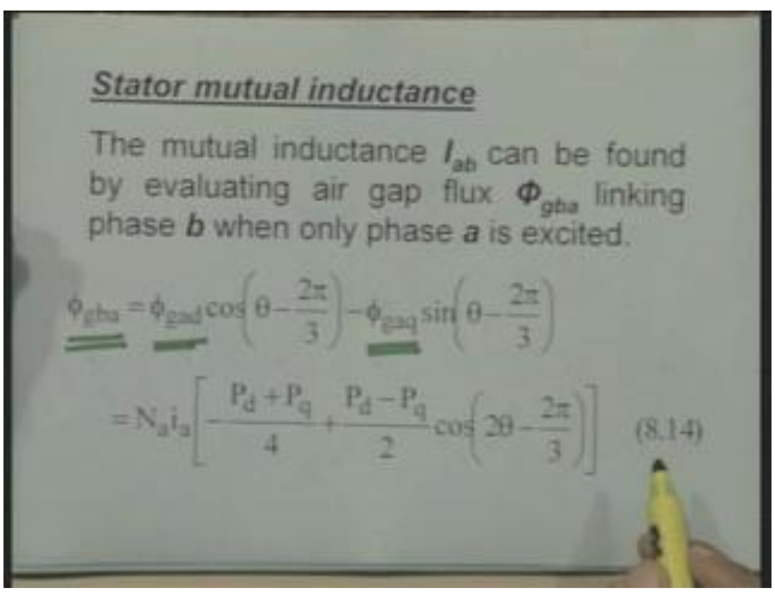

Therefore, the expressions which we have written here for self-inductance of phase b right will be of the same form except theta is replaced by theta minus 2 phi by 3 and since these the everything remains same therefore these terms are also same therefore it is not L_{bbo} but L_{bbo} is same as L_{aao} okay similarly, we write down l_{cc} as L_{ao} plus L_{aa2} cos 2 times theta plus 2 phi by 3 okay very straight forward.

Now next very important point we have to understand is the stator mutual inductances, the stator winding mutual inductances again we will see that the stator winding mutual inductances also are function of rotor position that will be function of theta. Now here, here when the when the axis of the rotor is in the middle of the axis of stator phase a and stator phase b then at that position the mutual inductance between a and b will be maximum for example the mutual inductance between phase b and c when you try to see it will be maximum when theta is theta is 30 degree minus 30 degrees and 150 degrees these they are the positions which we have to see. Okay, using this information the flux linkage is, flux linkage is of phase b.

When current is flowing in phase a is are obtained that is we want to to find out the flux mutual flux right that the flux linking flux, linking phase b due to current flowing in phase a okay and then once you find out this flux. Okay, we can find out the mutual inductance because the the inductance is the flux linkage by the current mutual inductance will be the flux linking phase b due to current in phase a and then you divide by the current you will get the mutual inductance. Here here following the same approach as we have done for done for obtaining the self-inductance the, the air gap flux flux again the gap flux linking phase b with when current is flowing in phase a is obtained in this form that is this is obtained in terms of these 2 components phi gad and phi gaq that is this is the air gap flux along d axis this is the air gap flux along q axis and after making the substitutions we find actually that mutual flux comes out to be equal to N_a i_a minus P_d plus P_q by 4 plus P_d minus P_q by 2 cos 2 theta minus 2 phi by 3, okay.

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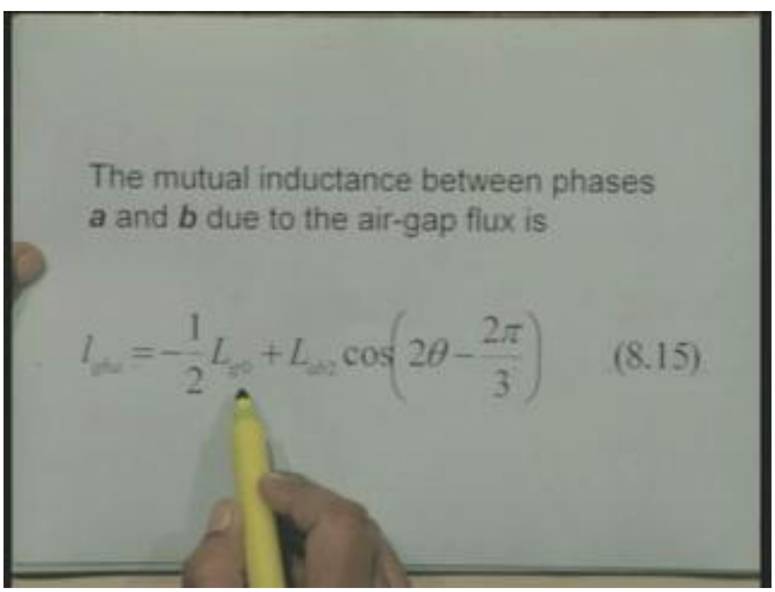

Now you can easily see here actually that if you substitute here to make this quantity one to make this quantity one. You can find it out actually ah what should be the value of theta right and since this term is minus here Pd is always greater than Pq permanence along the d axis is more then the permanence along q axis and therefore this is minus to have this also minus so that the total quantity is added up. Okay you can find out the value of this angle theta and you will find actually that when theta occupies either 30 degrees or 150 degrees it will be maximum. Now this, this mutual inductance can be obtained as l_{gba} divided by after dividing the the expression for phi gba by i_a okay.

Therefore, the expression for L_{gba} comes out to be in this form. Okay, now again it can be written as minus 1 by 2 L_{go}, L_{g0} plus L_{ab2}, now if you very carefully examine then this L_{ab2}, L_{ab2} will be of the same amplitude as L_{aa2}, L_{aa2} right.

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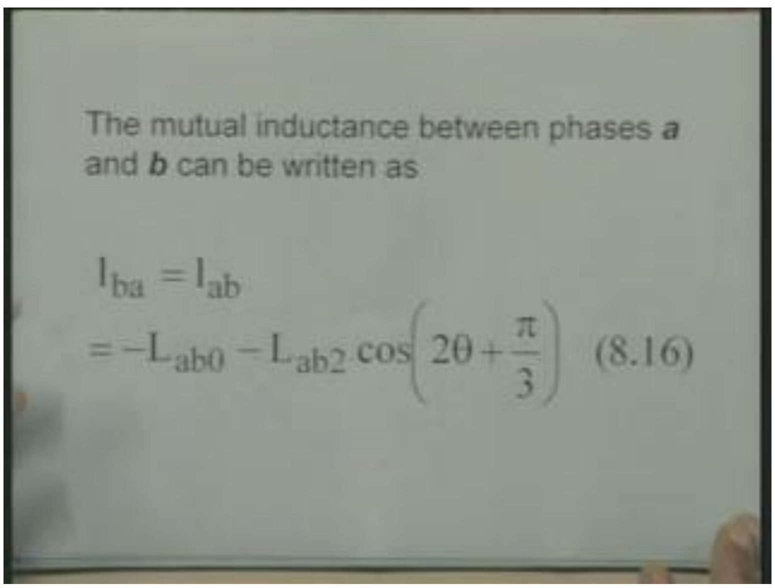

Similarly, you can find out the mutual inductance between b and a and we this ba mutual inductance between the phase a and b that is equal ba or ab, they are always equal okay and the expressions are written in the form minus L_{abo} minus, now here actually when you have written in this form what we have done is that we have accounted for some some leakage flux which also leaks to windings right because there are, there is a air gap flux and there is some flux which does not cross the air gap and once you account that we can write down these mutual inductances in this form, okay again you can see that this depends upon theta. Similarly, you can write down for bc and cb it comes out to be in the similar form and similarly l_{ac} and l_{ca} can be written like this okay.

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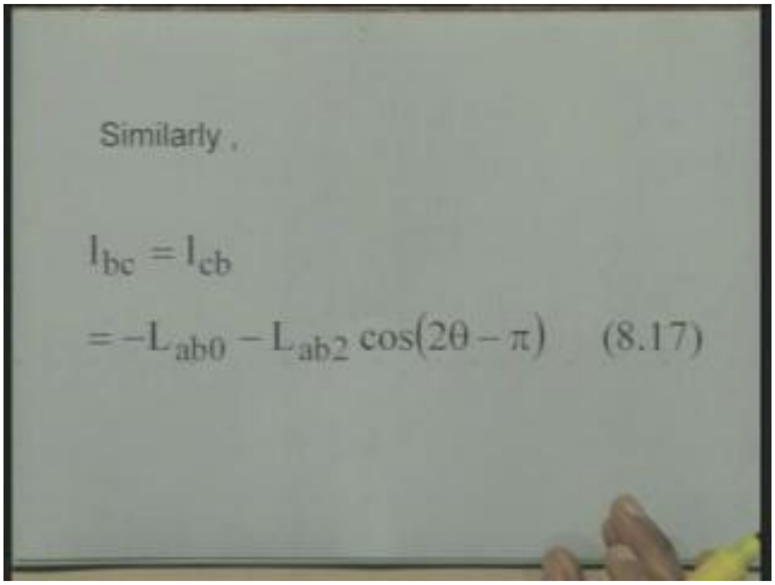

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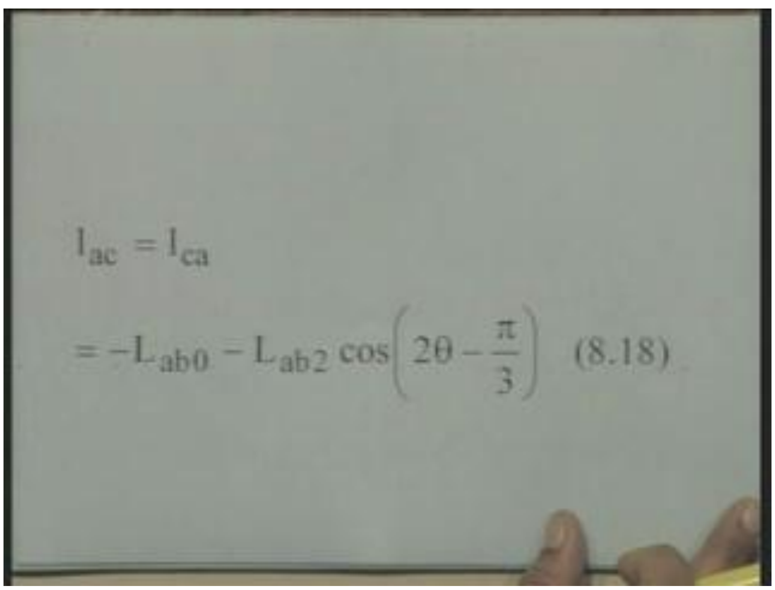

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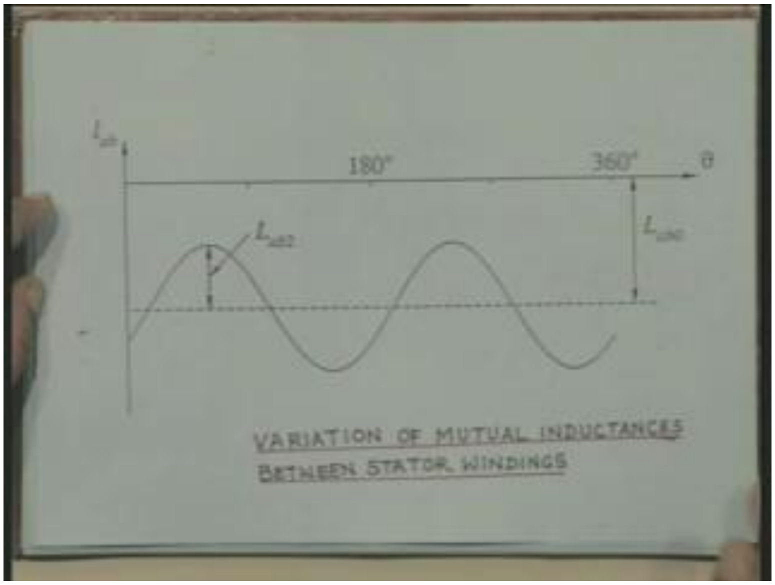

This diagram shows the variation of mutual inductance as a function of theta between the 2 stator phases that is here we have shown the L_{ab} and you can easily see that first thing which we see here is that the the mutual inductances all through negative. Okay and its variation is shown in this form therefore, this this quantity a constant quantity is L_{abo} and over this is you superimpose this sinusoidally varying quantity and variation is as a function of 2theta. Therefore what we have seen till now that the self-inductances of the stator phases or stator winding and mutual inductances between the stator winding.

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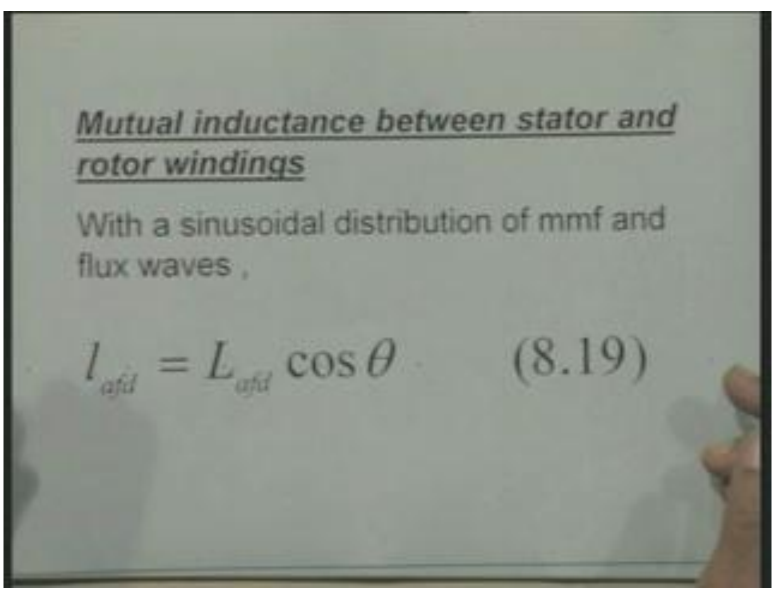

Now we will consider the mutual inductances between stator and rotor windings, stator and rotor winding. Now so far the mutual inductances between stator rotor windings are concerned that they are function of angular position but they are not because of the variation in permanence here because so far the rotor is concerned, rotor will always see the same permanence because the stator stator is having the ah a uniform shape right and therefore, so far the so far actually the rotor is concerned, rotor windings are concerned right the the there will be no variation in permanence.

Now here the mutual inductances between stator and rotor windings vary because of angular position. Now for example, if you take take the stator phase a and field winding in case the axis of these windings coincide they will have maximum mutual inductance in case the axis of stator winding of phase a and the field winding they are in quadrature, the mutual inductance will be 0 right and since the rotor is having rotating it occupies different positions therefore, when it coincides where the direct axis of the rotor coincide with the stator phase a axis or b axis or c axis they will have maximum mutual inductance and when the quadrature axis of the rotor coincides with the stator phase axis, okay phase a axis or phase b axis or phase c axis then the mutual inductance will be 0. Okay therefore, we can write down this mutual inductance Lafd equal to L, L_{afd} into cos theta.

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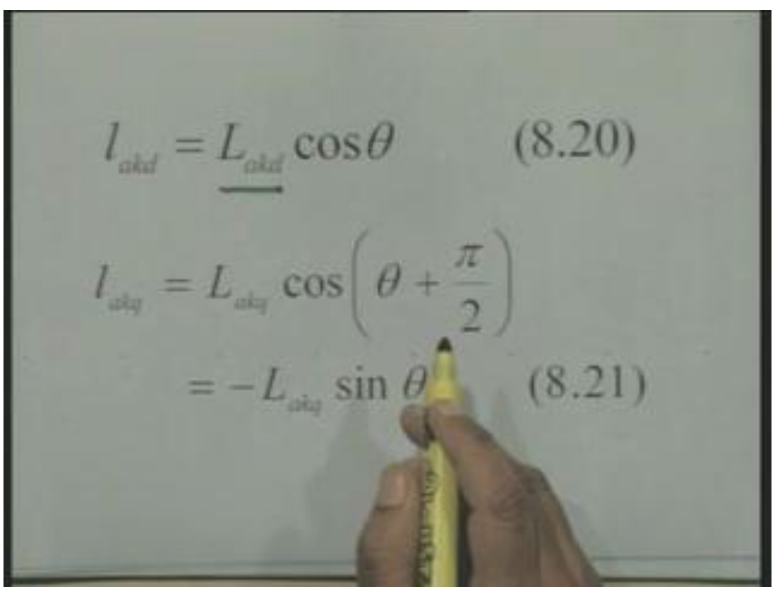

When suppose as we know that the theta is measured right considering the axis of phase a as reference and theta is the angle between the d axis and axis of phase a. Okay therefore when theta is 0, the mutual inductance between stator stator winding and the field winding is maximum. Okay and 90 degrees it is now, so the the amortisseur on the direct axis is is also going to have the inductance, mutual inductance in the form L_{akd} cos theta right because this the the direct axis amortisseur is having axis coinciding with the field winding right and therefore the variation is going to be similar.

Now the mutual inductance in the quadrature axis amortisseur and the stator winding will be written by the formula L_{akq} cos of theta plus phi by 2, why this theta is replaced by theta plus phi 2 by 2 because q axis is leading d axis by 90 degrees therefore, this can be written as minus L_{akq} sin theta.

Now what we have seen here is till now, we have obtained the expression for the self-inductances of the stator windings, mutual inductances between stator windings and we have also obtained the mutual inductances between the rotor windings and stator winding and we have seen that all these are function of angular position. Okay now we again come to our fundamental equations that is the stator voltage equations stator circuit equation ea equal to p psi a minus R_a i_a and we have seen that the flux linkage of phase a is now written as minus l_{aa} i_a minus l_{ab} i_b minus l_{ac} i_c plus l_{afd} i_{fd} plus l_{akd} i_{kd} plus l_{akd} i_{kq} therefore, now in this equation we substitute the expression for l_{aa}, l_{ab}, l_{ac}, l_{afd}, l_{akd}, l_{akq}.

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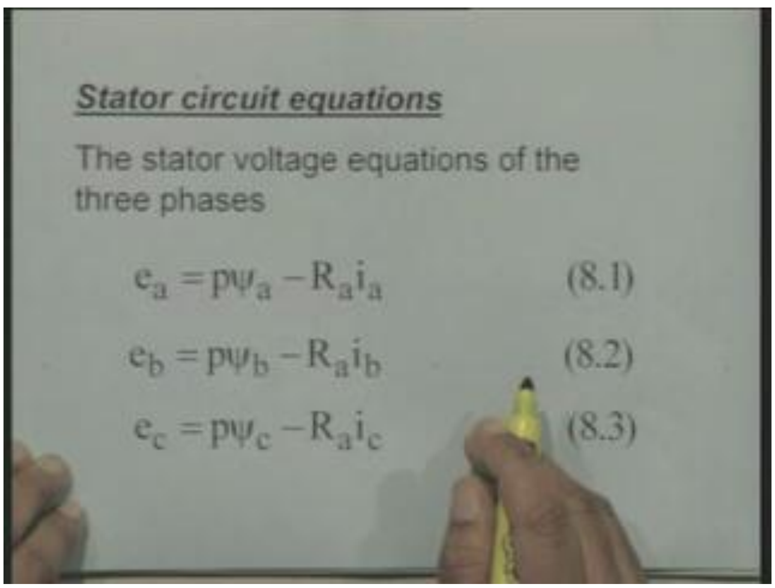

Okay, then we get the expression for flux linkage of phase a as minus i_a into L_{aa} plus i_b into L_{abo} L_{ab2} cos 2 theta plus phi by 3 this plus sign has come because there was negative sign here earlier. Okay when you see this mutual inductance there was a negative sign therefore it becomes plus here. Similarly, you have i_c into L_{abo} plus L_{ao} cos 2 theta minus phi by 3 and so on, that is what we have done is that in this in this basic equation, we have substituted value of all the inductances okay, which were all found to be function of theta. Similarly we can write down the flux linkage of phase b and flux linkage of phase c, they are exactly similar except you will find that theta is replaced by theta plus 2 phi by 3 or theta minus 2 phi by okay.

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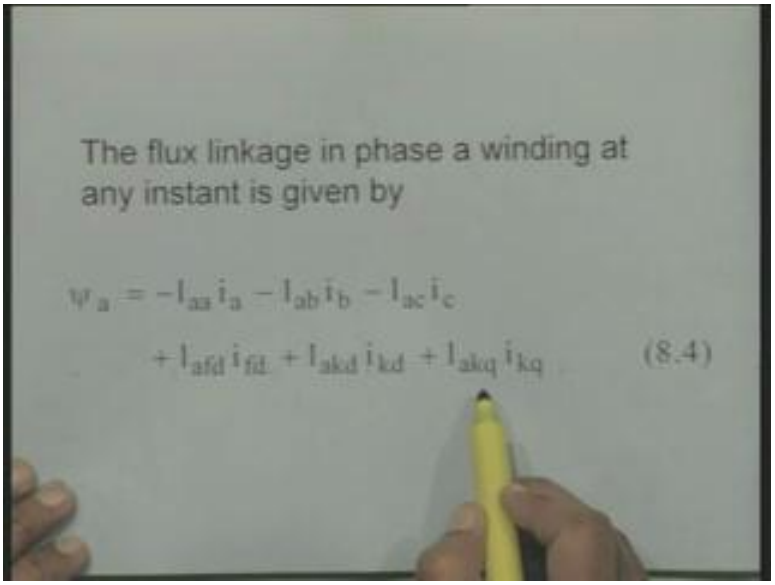

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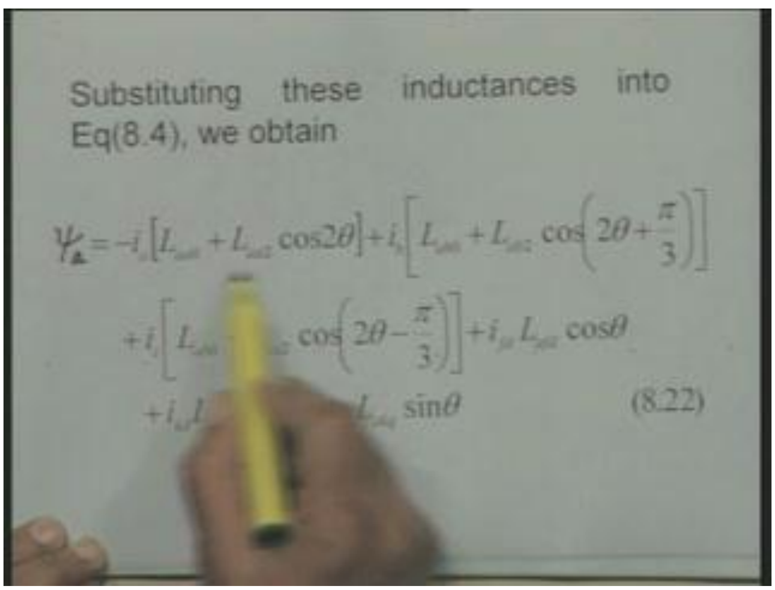

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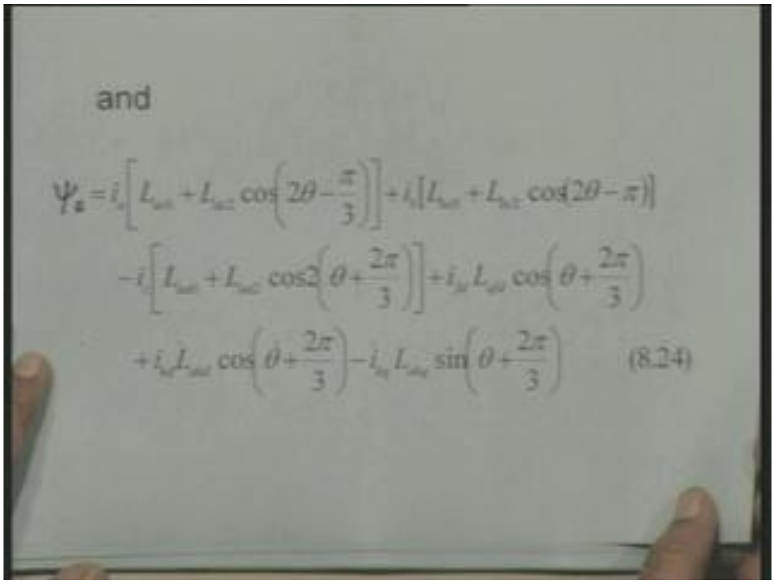

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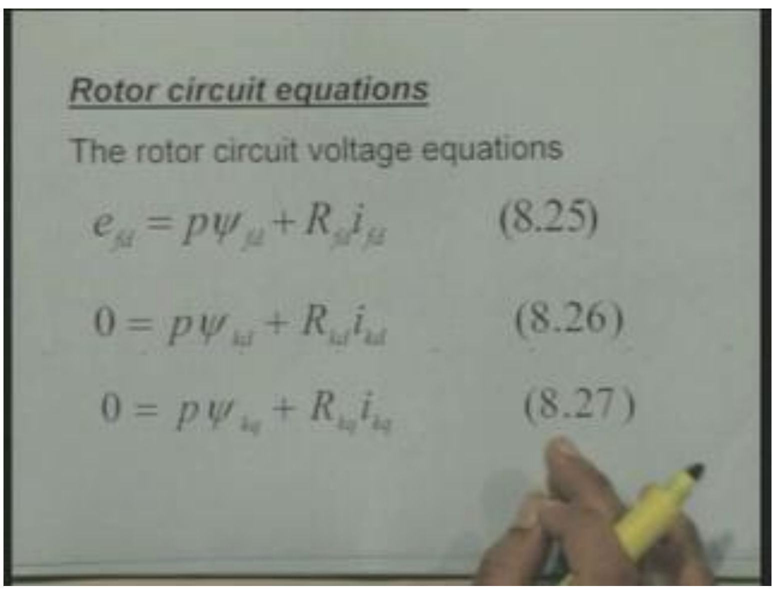

Now after having written the equations for the stator windings, voltage equation for the stator windings we can write down the rotor circuit voltage equations. The, in the rotors on the rotor we have considered 3windings, 1 filed winding and 2 amortisseurs. Okay therefore efd the voltage applied to the field winding is equal to P psi fd plus R_{fd} i_{fd}. Now here, since we have assumed that the current is entering the field winding and therefore the term here is P psi fd plus this is a simple Rl circuit.

Suppose you have Rl circuit, then the applied voltage is equal to the rate of change of flux linkages plus voltage drop in the resistance. Okay then the other 2 equations these relate to the direct axis amortisseur, winding amortisseur circuit and quadrature at the amortisseur circuit here since there is no external applied voltage therefore we have 0 term here. Okay therefore, there are 3 basic rotor circuit voltage equations we have 3 basic stator circuit voltages equations. Now let us write down the expression for these flux linkages psi f_d psi kd and psi k_q.

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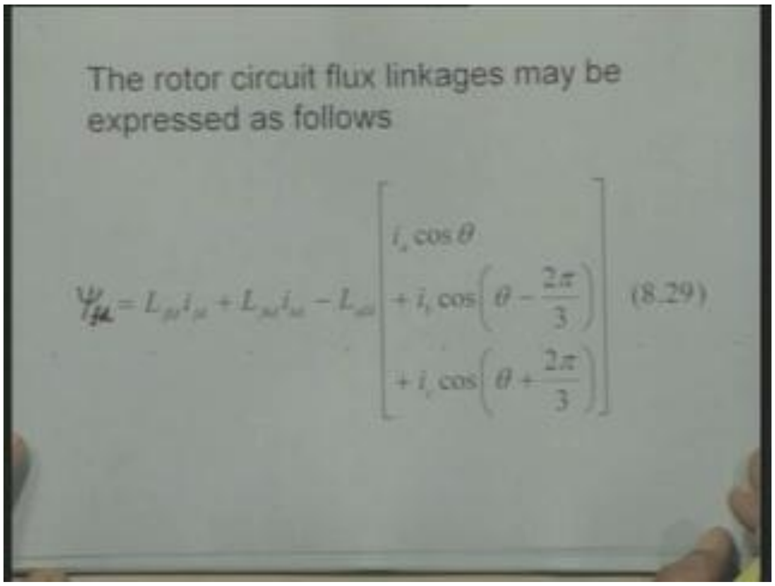

Now psi fd can be written as L_{ffd} that is the self-inductance of field winding into i_{fd} plus mutual inductance of the mutual inductance between between field winding and amortisseur that is L_{akd} into i_{kd} okay and there will be no there will be no flux linking the field winding due to the quadrature axis amortisseur because the the 2 axis are that that the the displacement of 90 degrees between the 2 axis okay and therefore there is no flux linkage contributed by by amortisseur on the quadrature axis to field axis flux linkage.

Then these 3 terms are here L_{afd} into ia cos theta L_{afd} into i_b cos theta minus 2 phi by 3and L_{afd} plus i_c into cos theta plus 2 phi by 3 that is when the 3 stator currents are carrying the values i_a, i_b and i_c and depending upon their mutual inductances this will be the flux linkage in the stator winding. Now one point which I wanted to mention here is the so far the self-inductances of the rotor circuits are concerned that is self-inductance of field winding, self inductance of amortisseurs they do not depend upon the angular position because because so far actually the the the magnetic circuit is concerned for computing the self-inductances of rotor circuits are concerned, these the self-inductances are constant and the since that we have assumed like with uniform internal surface of the stator okay and therefore no variation of reluctance so far actually the rotor circuits are concerned.

Similarly, similarly the mutual inductance between the rotor circuits there is mutual inductance between the field winding and amortisseur on the d axis they will be fixed, they do not depend upon the rotor position right. Therefore for example, L_{fkd} is a mutual inductance between field winding and direct axis amortisseur this is a constant quantity they will not depend upon the rotor position.

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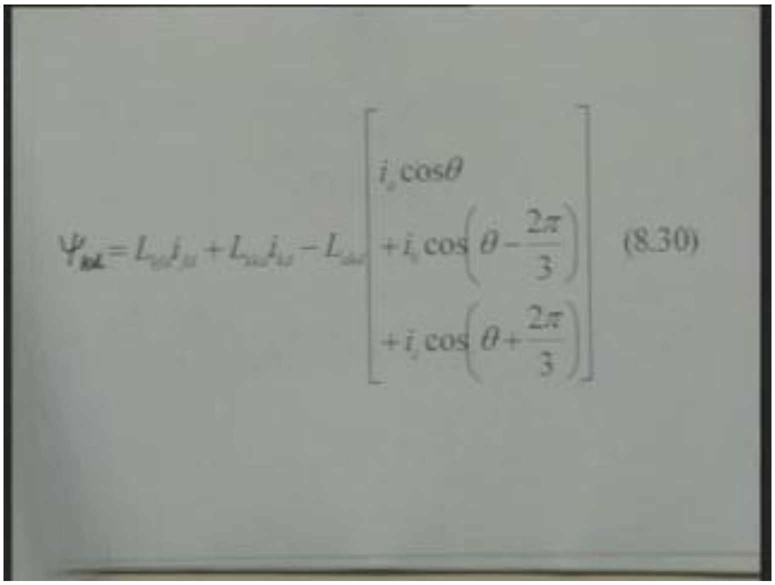

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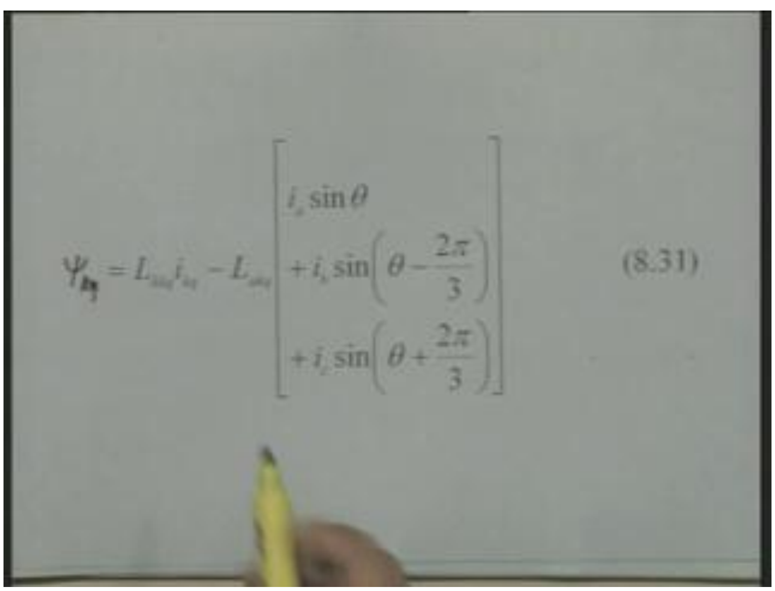

Now this similarly you can write down the flux linkage of amortisseur on d axis and flux linkage of amortisseur in the q axis okay.

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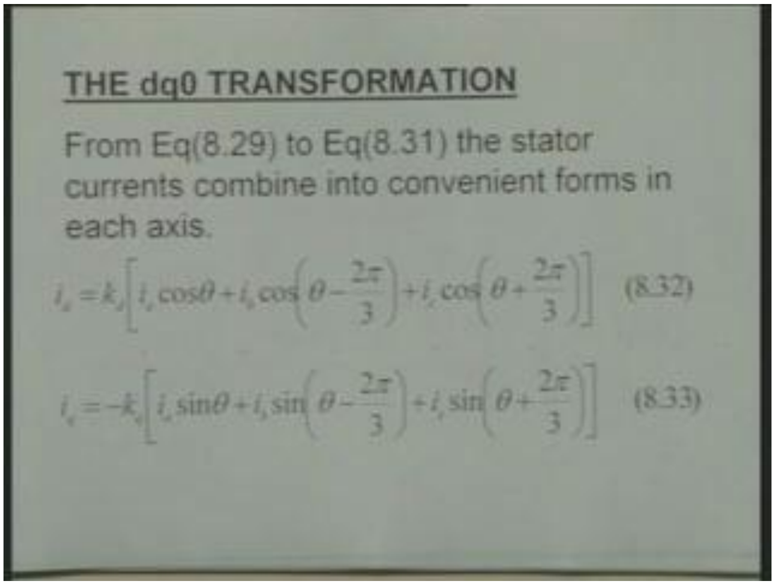

Now with this with this we have developed the complete mathematical model that we have written three stator circuit equations, we have written the rotor circuit equations we have expressed all the inductances as function of currents and I am sorry ,not all the flux linkages as function of currents and the self and mutual inductances.

Now this that is ah this is what is called complete model of the system however the basic problems which arise are due to due to the variation of these inductances with the variation of rotor angular position and to overcome this problem and seeing very carefully the expression for, you see the expression for psi fd, we find here a term Lafd that is the along with this term where i_a cos theta plus i_b cos theta minus 2 phi by 3 therefore, this has prompted us to obtain a transformation and once we go we use this transformation, we will find that the equations can be simplified and we can make these equations equations where they do not exclusively depend upon or the inductances do not depend upon the angular position.

Okay the the transformation is of this form that is we define, we define this term i_a cos theta plus i_b cos theta minus 2 phi 3 plus i_c cos theta 2 phi by 3 multiplied by some constant k_d as i_d that is these 3 terms i_a cos theta i_b cos theta minus 2 phi by 3, i_c cos theta plus 2 by 3 this complete term multiplied with some constant k_d is denoted by a term i_d.

Similarly we denote another term i_q as minus i_{kq} multiplied by i_a sin theta plus i_b sin theta minus 2 phi by 3, now this with this with this assumption or this transformation if we consider balance three phase currents that is ia equal to I_m sin omega s t, i_b equal to I_m sin omega s t minus 2 phi by 3 i_c equal to I_m sin omega s_t plus 2 phi by 3. Okay that is, we are assuming that the 3 stator currents are balanced with this 3 stator currents to be balanced, okay what we do is if you substitute and find out the expression for i_d, the i_d will come out to be as k_d into 3 by 2 I_m sin omega s_t minus theta. This is very important term that is with this transformation, this i_d current i_d is equal to k_d into 3 by 2 I_m sin omega s_t minus theta.

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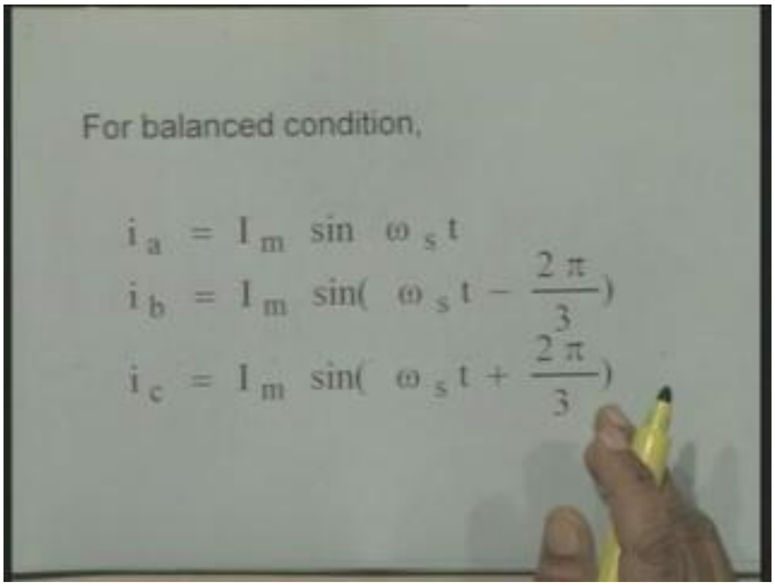

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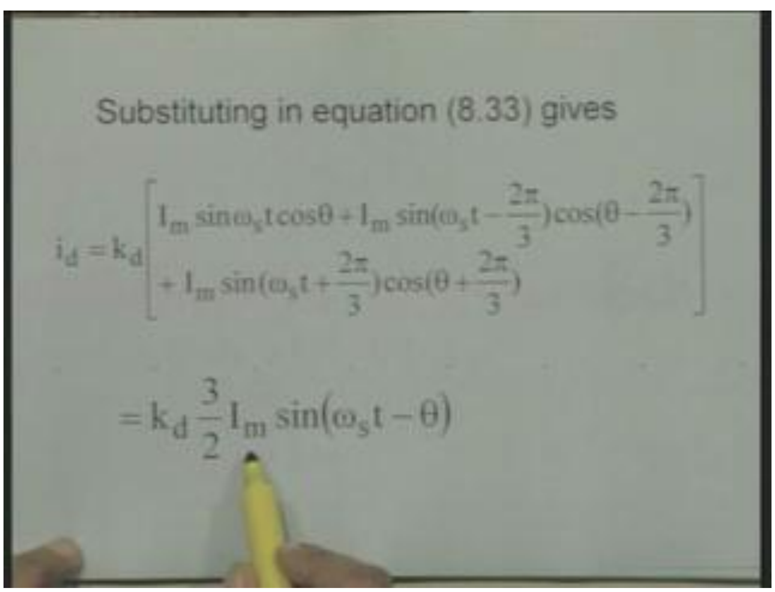

Now if you assume k_d equal to 2 by 3, if you assume k_d equal to 2 by 3 then the the peak value of i_d will be same as I_m okay and therefore in the Park's transformation, Park's transformation k_d and k_q are taken equal to 2 by 3, that is i_q will also be taking the same minus i_q into 3 by 2 I_m cos omega st minus theta.

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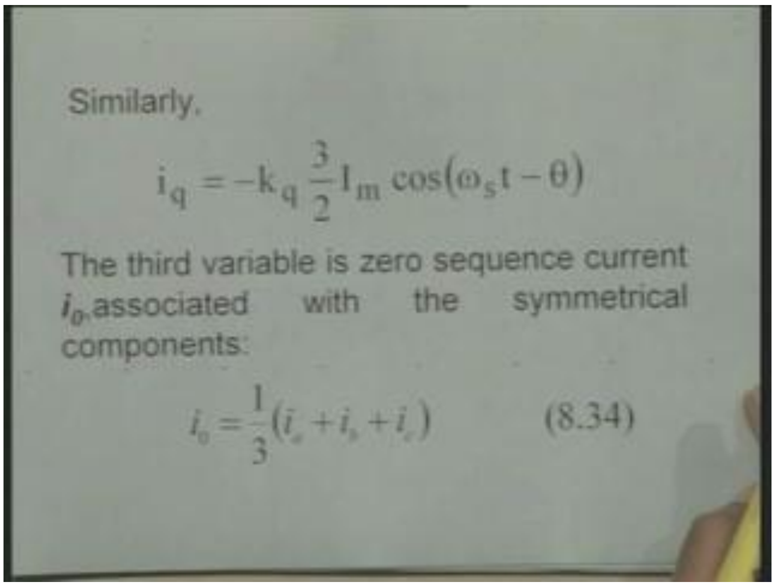

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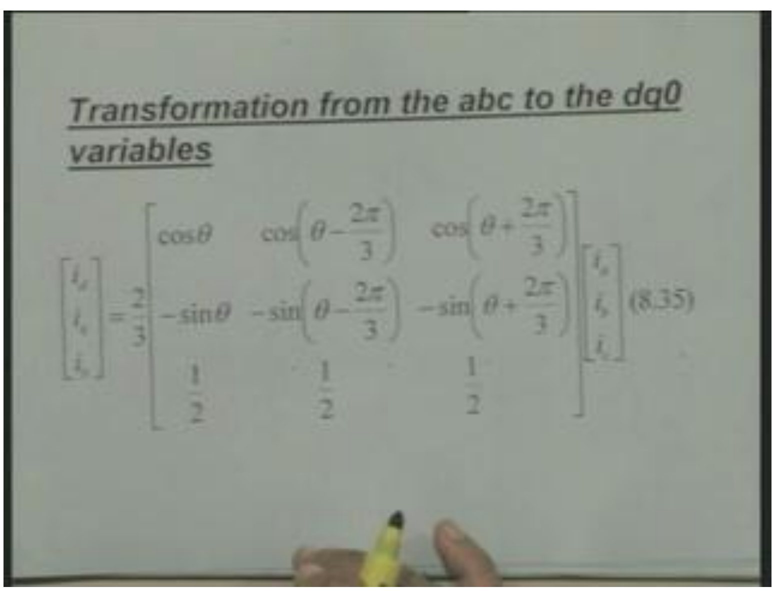

Okay and therefore, if I take kq equal to 2 by 3 then the peak value of iq will be same as I_m. Okay now to make this model complete complete and assuming that suppose the 3 currents are not symmetrical right then we can define one, 0 sequence current io as 1 by 3 i_a plus i_b plus i_c and with this definition the transformation looks like this it is very interesting thing this transformation looks likes this that we can say i_d, i_q, i_o, a vector consisting of d axis current, q axis current and i_0.

These 3 currents can be written in terms of the phase currents i_a, i_b and i_c in terms of this matrix and this is called transformation matrix that is transformation matrix is 2 by 3 the first row is cos theta cos theta minus 2 phi by 3, cos theta plus 2 phi by 3. Okay similarly similarly the second term and third term.

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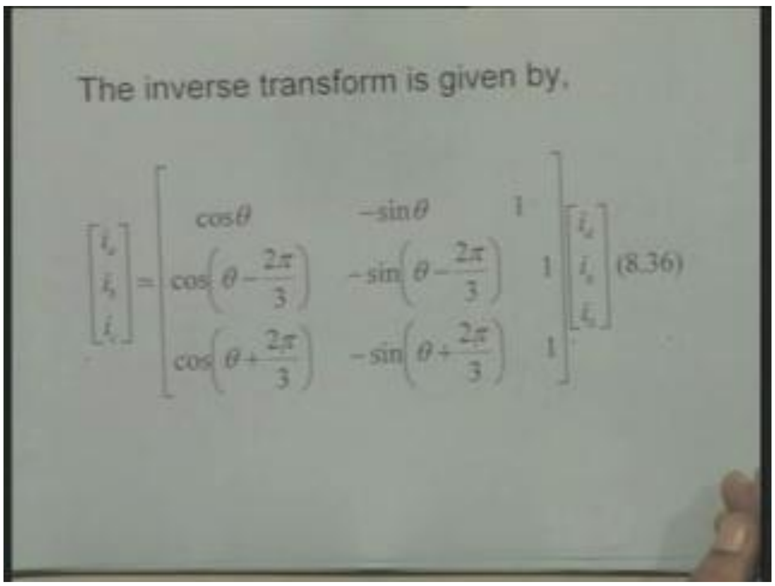

With this now inverse transformation that is if you write down the expression for phase currents in terms of the dqO currents then this can be written in this form cos theta minus sin theta 1like this this is called inverse that is sometimes if you know the value of i_d, i_q, i_o we can find out the phase currents.

Now interesting thing which happens is that if I substitute the values of the phase currents in terms of dqO components right then I get the expression for flux linkage in the d axis called psi d that is if the the all these fluxes flux linking phase a phase b and phase c right they are also transformed currents are also transformed that is by applying this transformation. We find that the flux linkage is can be written in terms of ah the constant coefficients that is psi d is equal to minus L_{ao} plus L_{abo} plus 3 by 2 L_{ao} L_{aa2} okay then L_{afd} i_{fd} plus L_{akd} i_{kd} that is here the coefficient of i_d is a constant term it does not depend upon angular position theta similarly, for psi q and psi o right we define we define these terms L_d equal to L_{ao} plus L_{abo} plus 3 by 2 L_{ao} similarly L_q and L_0 are defined.

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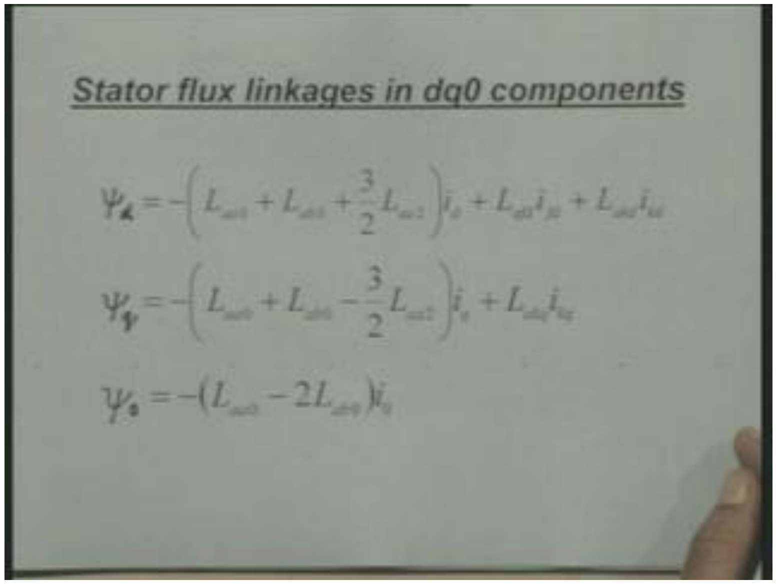

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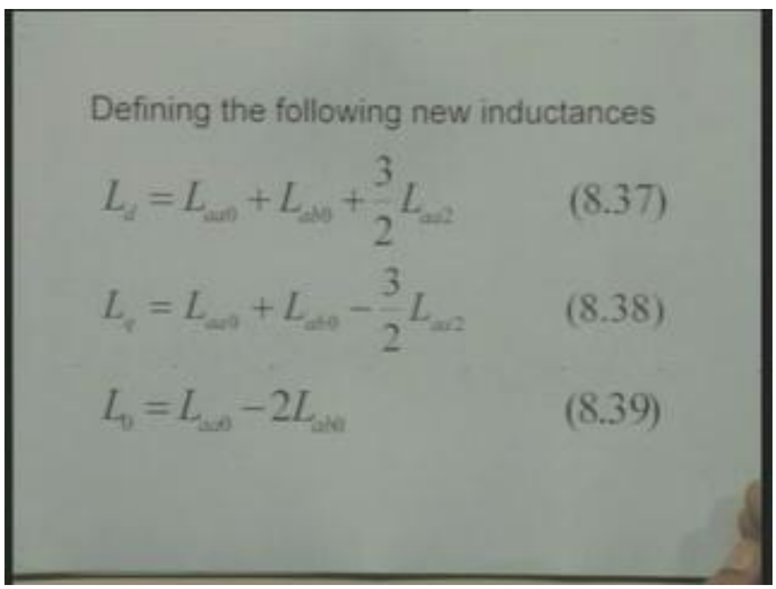

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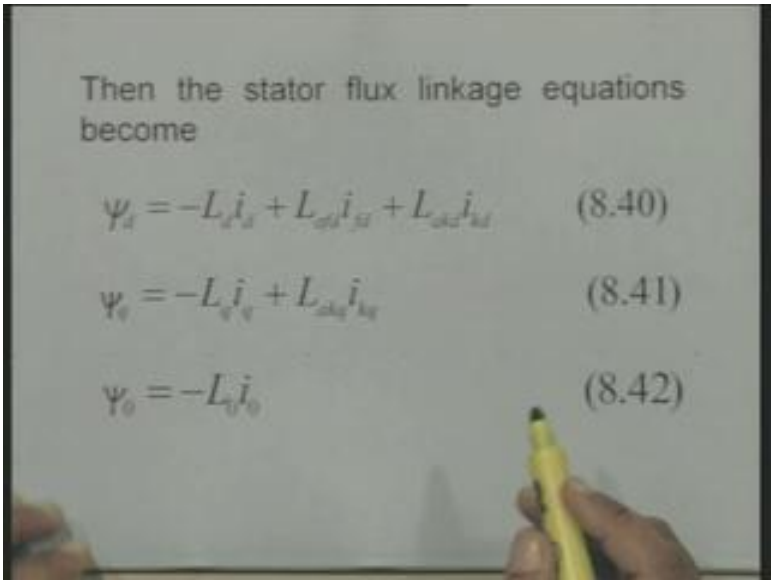

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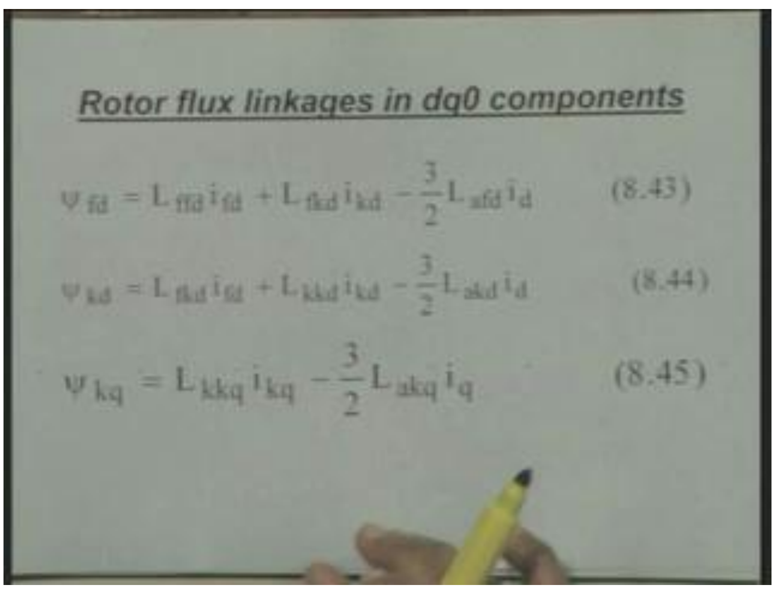

When you make this substitution we can write down the flux linkage psi d as minus L_d i_d plus Lafd ifd plus like this. Similarly, when you apply the dqO transformation the flux linking the rotor circuits are also expressed in terms of the rotor currents rotor currents rotor circuit currents and the dqO components of currents and again you find actually that these flux linkages as well as these 3flux linkages with the transform quantities are are independent of rotor angular position and this is what it helps the whole thing and once you substitute these expressions in our stator circuit equations.

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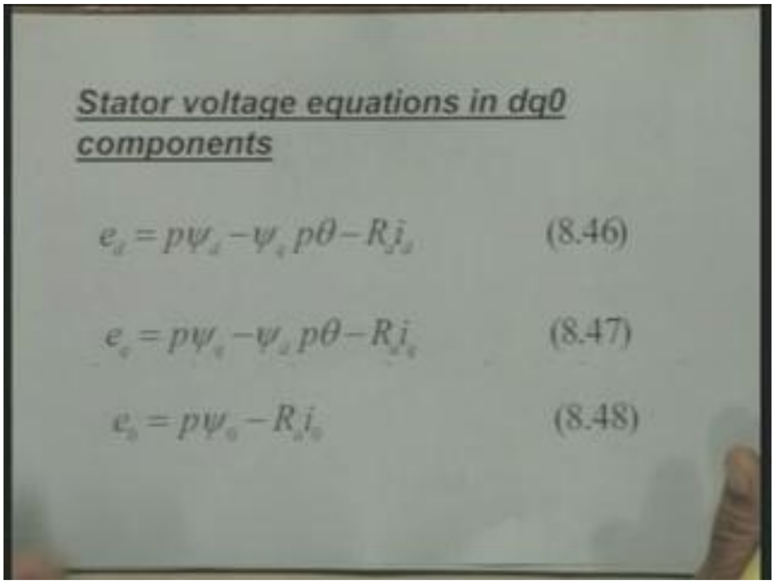

We get these equation in the form ed equal to P psi d minus psi q p theta minus R_a i_{deq} is equal to P psi q minus psi d p theta minus R_a i_q and eo equal to P psi o psi 0 minus R_a i_o. Now these are the 3 basic equations which are written in terms of transform quantities or dqO terms or sometimes in case in dq of frame of presentation. Okay today I have discussed the basic circuit equations of the synchronous machine and discuss the dqO transformation and its importance. Ultimately, we have obtained the stator circuit equations in terms of the transform quantities. Thank you!