**Power System Dynamics and Control**
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**Lecture No: # 14**
**Modeling of Synchronous Machines**
**dq0 transformation (Contd)**

We continue our discussion on the dqo transformation on the flux equations of a synchronous machine. Recall, that the dqo transformation is a time variant transformation and the basic reason why actually we go for dq transformation is to get a set of time invariant equations, as far as, the flux relationships are concerned.

In the previous lecture we began transforming even the differential equation, that is, the Faraday's law applied to the flux of the machine and we noticed, that there were, whenever we apply a time variant transformation in the flux equations in the new variables, we do get, what is known as a speed EMF term. We will just recap what we have done first before we proceed further in this lecture.

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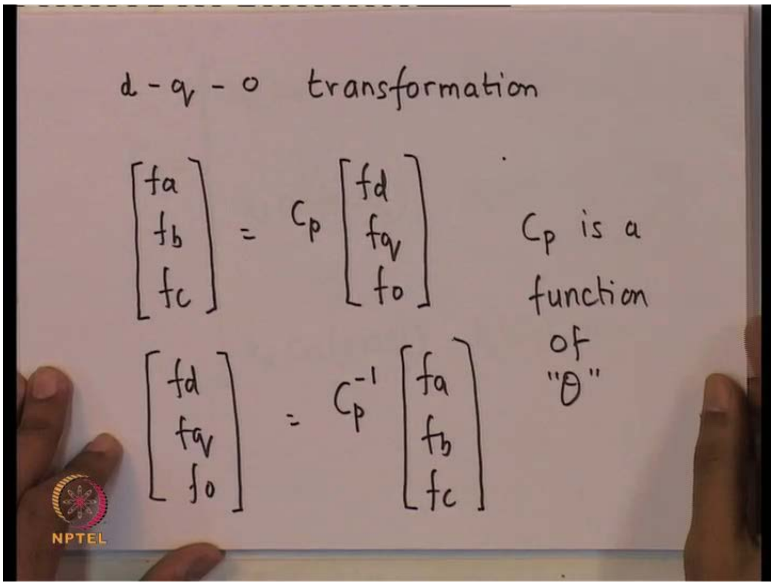


So, today's lecture is we continue to see the implications of the d-q-o transformation on the machine equations. Now, recall, that the d-q-o transformation, essentially, transforms any a, b, c variables, the phase variables a, b, c using a transformation matrix C p into f d, f q and f 0, which are known as the d-q-0 variables. C p is a function of theta, theta is of course, the electrical angle, which we have discussed before. Similarly, of course, f d, f q and f 0 are equal to C p inverse of f a, f b, f c. So, we assume, of course, C p inverse does exist. In fact, we can verify that it does exist, remember that by doing a transformation.

We are just, re, we are going to reformulate the equations in the new variables. So, we are not writing any fundamentally new physical equations, but we are just reformulating the existing, we are just reformulating the existing flux relationships, as well as, the flux differential equations in the new variables. So, once we can do the analysis in the d, q, 0 variables, which is presumably going to be simpler. After we do the analysis, we can transform back to the a, b, c reference frame using this transformation. So, that is the basic idea of the transformation.

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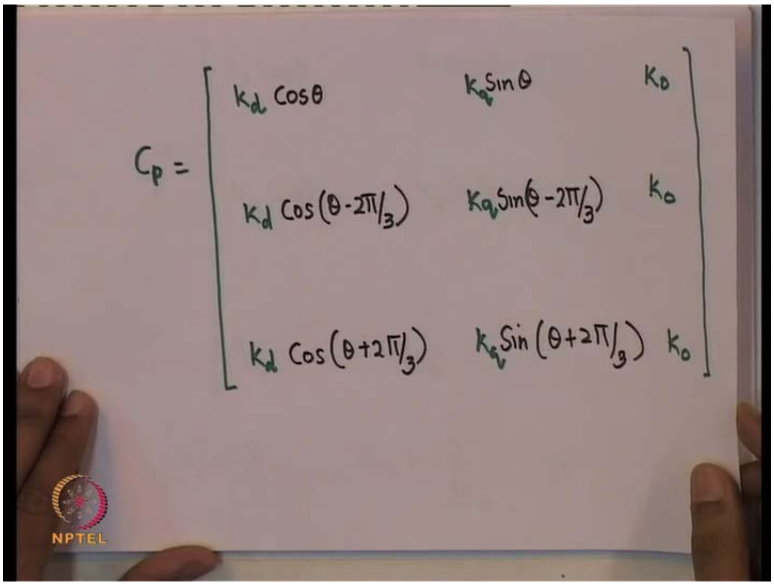


Now, C p, of course, is this. This K d, K q and K 0 are non-zero constants, three non-zero constants, which are used in the transformation. Now, the reason why I have not put any numerical value on this K d and K q and K 0 is, that it is not essential to the, the values of K d, K q and K 0 can be arbitrary, but non-zero.

If they are 0, of course, you will not get C P inverse, C P inverse will not exist. So, K d, K q, K 0 are in fact, non-zero constants and whatever be their value, as long as, they are not zero, they satisfy our purpose of trying to convert the time variant flux relationships into time invariant flux relationships in the d, q, o, 0 variables.

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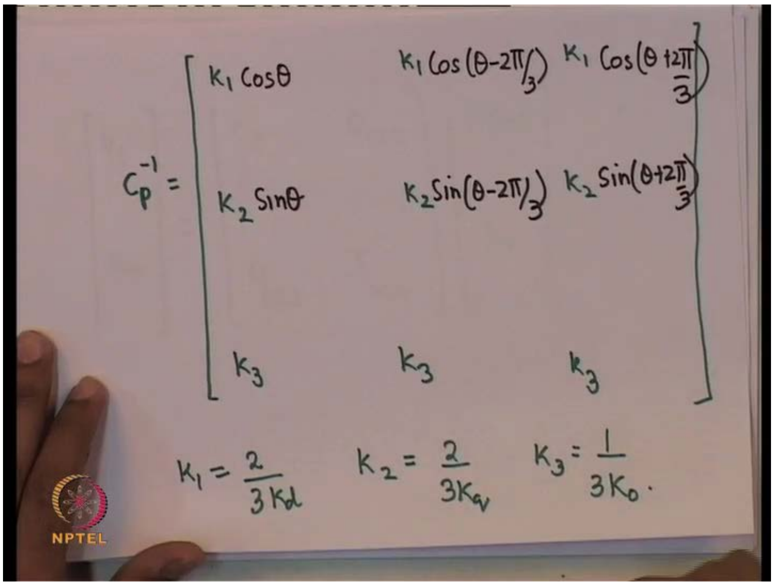

C p inverse, in fact, looks like C p transpose. In fact, if you look at the structure, you will see, that you have got cos theta cos theta minus 2 pi by 3 and cos theta plus 2 pi by 3. These constants K 1, K 2 and K 3 are related to K d by this relationship, K 1 is equal to 2 by 3 times K d, K 2 is equal to 2 by 3 times K 2 and K 0 is equal to 1 upon 3 times K 0. So, this is basically the inverse, you can just verify this, of course, at leisure by multiplying C p with C p inverse and just verifying that it does turn out to be an identity matrix, which will, of course verify, that C p inverse is indeed the inverse as I have written it down here.

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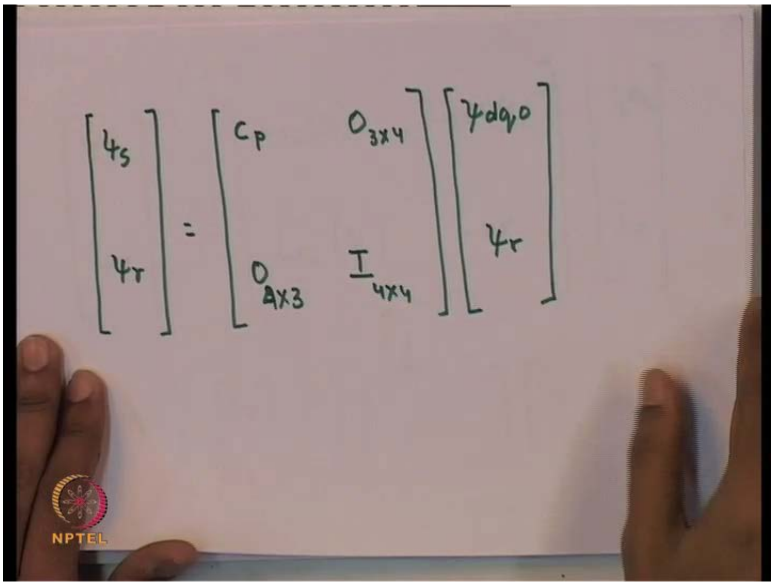

Now, the basic idea here is to convert the flux equations. So, what we will do is try to convert the a, b, c. The size, remember, is nothing, but psi a, psi b and psi c and psi R of course, is psi f, psi h, psi g and psi K psi dq. So, what we do is try to change the variables a, b, c to dq0. Of course, psi R we will keep unchanged. So, the transformation, if you look at it, is C p.

The sub matrix C P, the sub matrix of this larger matrix had got this element as C p, this is 3 by 4 null matrix, this is 4 into 3 null matrix and this is an identity matrix, which is 4 into 4.

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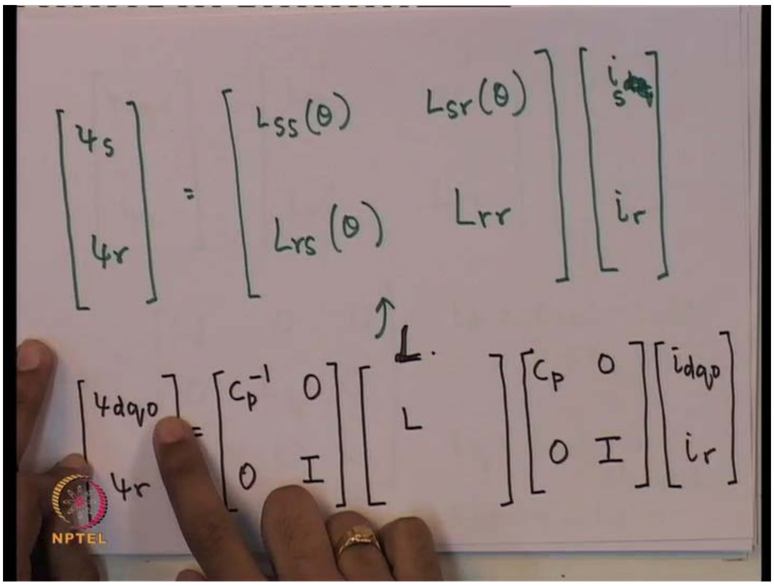


So, what I will do is apply the transformation to these variables. Remember, that the flux current relationship is psi s is equal to L ss of theta L sr of theta L ss of theta into i s into L sr of theta into i r and similarly, psi r is expressed in this fashion.

Now, if I call this the L matrix, I will call this L, it is, it is easy to see, that psi, if you try to reformulate this particular equation, we are just reformulating it in the new variables. So, psi dq0 psi R will be this into L, L is nothing, but this matrix. Remember, of course, these are sub matrices, so this into L into this transformation into i dq0 and i r. Now, the good thing, which we saw in the last lecture was when we work out this, we did work out one particular term in this L matrix, but I encourage you to actually try out to evaluate the complete L matrix.

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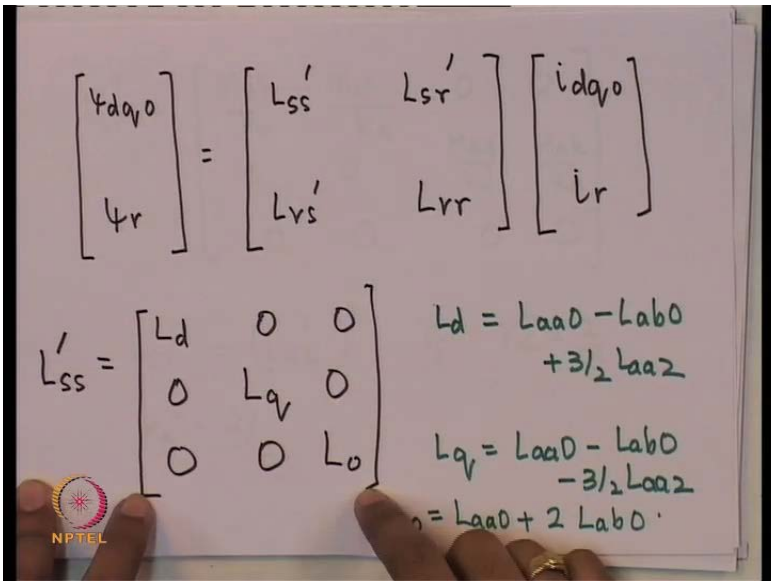


The complete L matrix, if one evaluates one will find, that the, of course this, you get this new relationship where this dash, I have called this L ss dash, L sr dash, L ss, L rs dash and L rr and L rr of course, remains unchanged. So, L ss dash, so this should be L ss dash, is nothing, but it turns out is a diagonal matrix, it is an interesting thing. It is a diagonal matrix where L d, L q and L 0 are not functions of theta. So, that is, the basic beauty of this transformation is that the relationships in the d, q, 0 variables are in fact, the flux current relationship in the d, q, 0 variables are in fact, independent of theta, not only that, as you see L d for example, if I just expand this, you will find, that psi d is equal to L d into i d plus 0 into i q plus 0 into i 0.

So, there seems to be decoupling in the flux relationship. That is also an interesting thing, which happens because of the fact, that this is diagonal.

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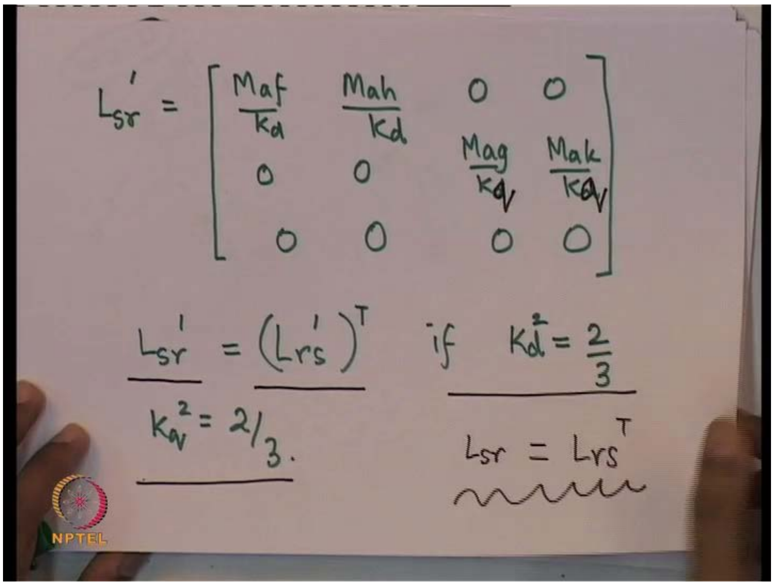


In fact, L sr dash is this, M af by K d, M ah by K d, 0, 0, 0, 0, M ag by K q, this is wrongly written, so I will write this as K q and M ah by K q.

And the last column of course is, the last row is 0. Now, L sr dash is equal to L rs dash, only if this is true. So, it is not true in general. See, remember L sr was equal to L rs transpose, but this is true only if we choose K d and K q, such that they satisfy this relationship. K d square is 2 by 3 and K q square is equal to also 2 by 3.

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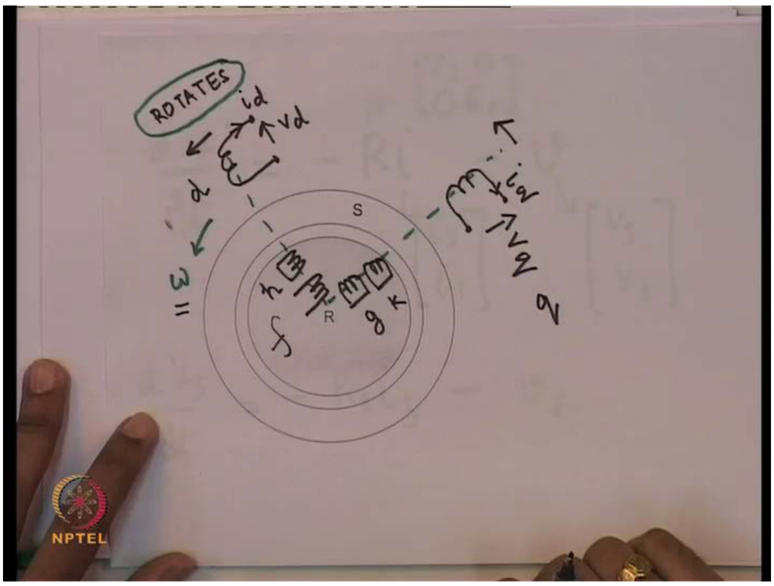

Now, what we see here is, of course, there is a complete decoupling between what are known as the d-axis coils. What are the d-axis coils? f, h and the stator coil, which is transformed into the d q frame. So, if you look at this will be f, h and d on this and g, k and q here on the q-axis. So, the basic idea here is that basic thing, which comes out is, that the fluxes in the coils of the d-axis including this, you know, this fictitious coil, we will call it the d, d-axis coil, is not dependent on the q-axis currents. So, that is a very interesting thing.

In fact, it is tempting to think, think, that this transformation, what it essentially has done is represented the three stationary stator coils in the a, b, c frame for reference. It is, kind of, converted this three stationery a, b, c coils into two rotating d, q-coils, which are also rotating at this angular frequency omega. This is tempting, but as we shall see soon, the, when we write down Faraday's equation we will see, that the emf induced in this will be dependent on the fluxes caused in this axis.

So, you know, we should remember, that although this gives a nice picture of you know, the decoupling of the fluxes and the currents in the d and q axis, the emf equations of course, have a coupling. So, what do I mean by that?

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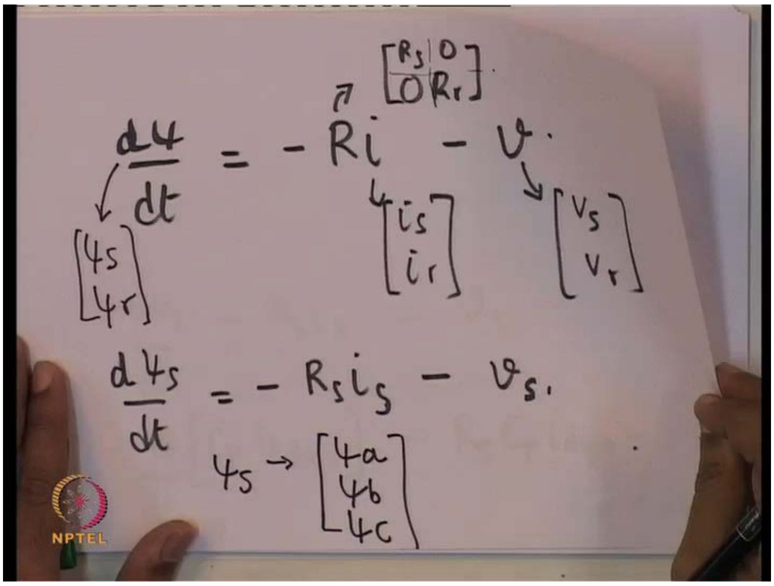

We did this in the last class; we have seen the d psi by dt. Psi, of course, is nothing, but psi s and psi r, is equal to minus of R i minus of v, this is what basically our flux equation were, which we did in, you know, about two classes back.

R of course, is the diagonal matrix, which has sub matrix R s and R r; R s and R r. R r, of course, are the, it is a diagonal matrix containing the resistances of the f, g, h and k coils; i of course, is i s and i R; v is nothing, but v s and v r. So, what you have if we just take out the psi s equations? We will have d psi s by dt is equal to minus R s i s minus v s. Of course, psi s, you know, the subscript s actually denotes psi s is nothing, but actually psi a, psi b and psi c.

And similarly, i s and v s are i a, i b, i c and v a, v b, v c.

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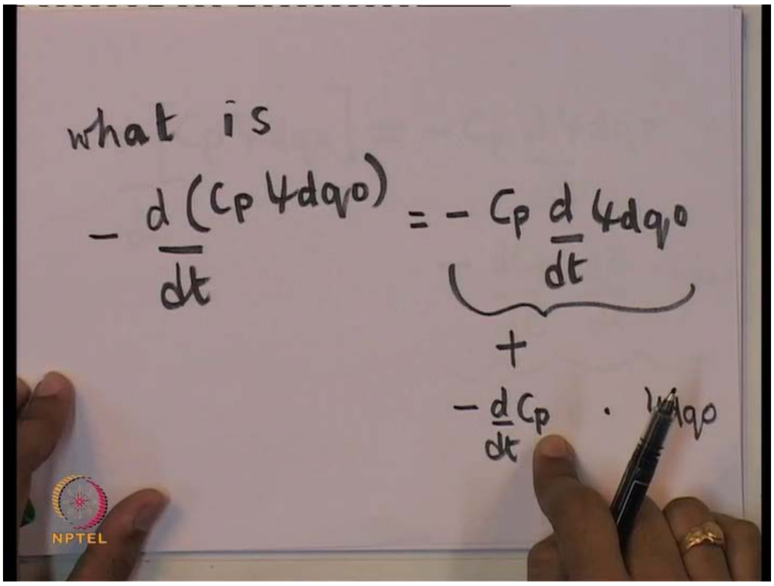


Now, if you look at this equation, we can substitute psi a, psi b, psi c as nothing, but C p into psi dq0. So, our equations, in fact, become this, so I have just re-written the equations. These equations, these ones I have re-written it like this and the re-written equations are substituted for i s, which is nothing, but i a, i b, i c, I substituted it by dq0 variables, so v s is nothing, but C p into v dq0, ok.

So, if you recall our discussion in the previous class, I had asked what is C p psi dq0? In fact, it is minus of C p minus of this is nothing, but minus of C p. This is, you are applying the chain rule plus this extra term. Remember, that C p, unlike some other transformations we did in the first few lectures of this course, C p is in fact the function of theta. Theta, in a synchronous machine, is a function of time, it cannot be considered. Even in the steady state conditions you will find, that theta is, in fact, varying continuously. So, dC p by dt, in fact, had to be evaluated, we gave to apply chain rule. So, what we will get is this, in fact, is having two terms.

So, your flux relationship, so I will just, this has been rewritten again, this particular term dC p by dt can be written as dC p by d theta into d theta by dt. So, this extra term, as we discussed in the class, previous class, comes out because of being mathematically consistent while applying the transformation of variables, ok.

This extra term, in fact, denotes, see what we, you know, this rate of change of flux of course, is common with a, b, c equations, but we have got extra, what is known as P d M f term.

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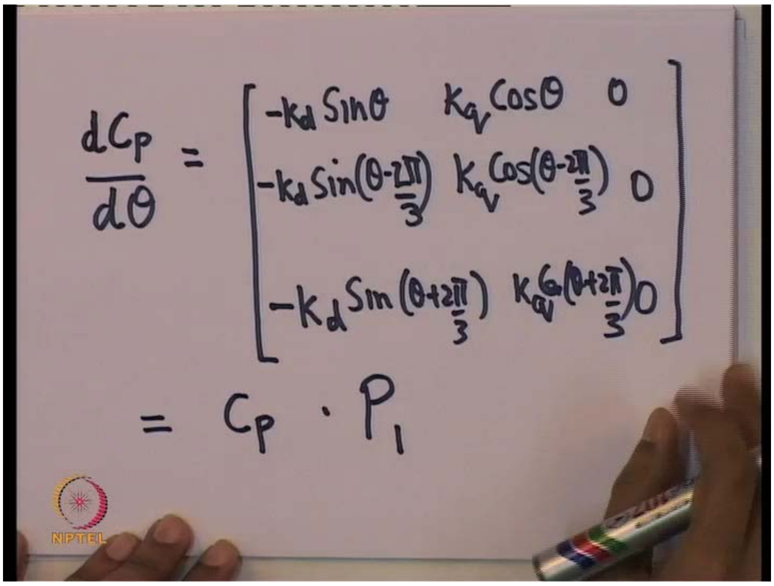


So, if we look at this dC p by dt, if we actually evaluate it, in fact, so we carry on forth from last time. dC p by d T d theta is equal to, it is easy to see this, you take the derivative of the transformation, so you will get minus K d sine theta K q cos theta and of course, K 0, when you take the derivative, you will get zero. So I will write 0 here and you will have minus K d sine theta minus 2 pi by 3. It is difficult to fit it in the paper, but we will try to do that. K q into cos theta minus 2 pi by 3 and this will be, sorry, this is, yeah, minus K d sine theta plus 2 pi by 3. And this term here is K q cos theta plus 2 pi by 3. So, this is basically what we have I will just read out term it might not be very clear here. It is, K q cos theta plus pi by 3 and this is of course, a distinct term here.

Now, it is very easy to see, it is not too difficult, you know, how, what C p looks like? C p looks like this, sorry, this is C p inverse, I am sorry, C p looks like this.

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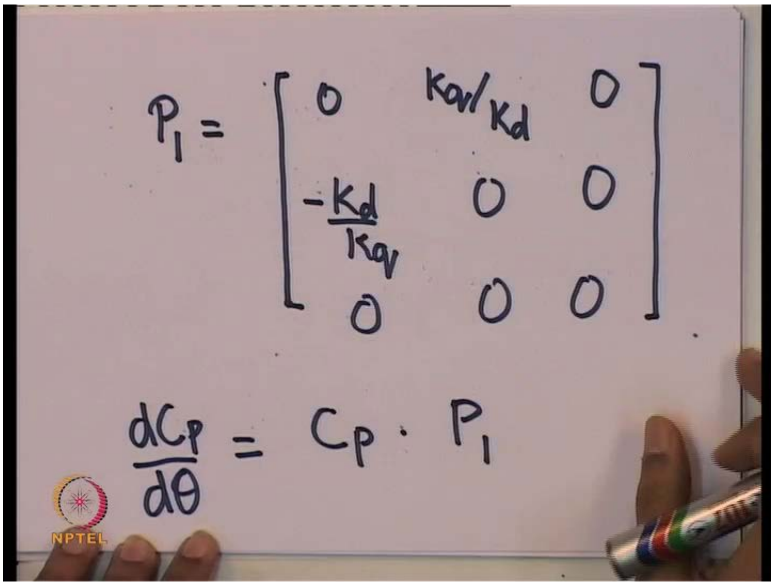


So, it is very, by inspection you can really make out, that this is nothing, but C P into matrix P 1 where P 1 is nothing, but 0, K q by K d, 0, minus K d by K q, 0, 0 and this is 0, 0, 0. So, what I have, so let me just repeat dC p by d theta is equal to C p times P 1, ok, where P 1 is this.

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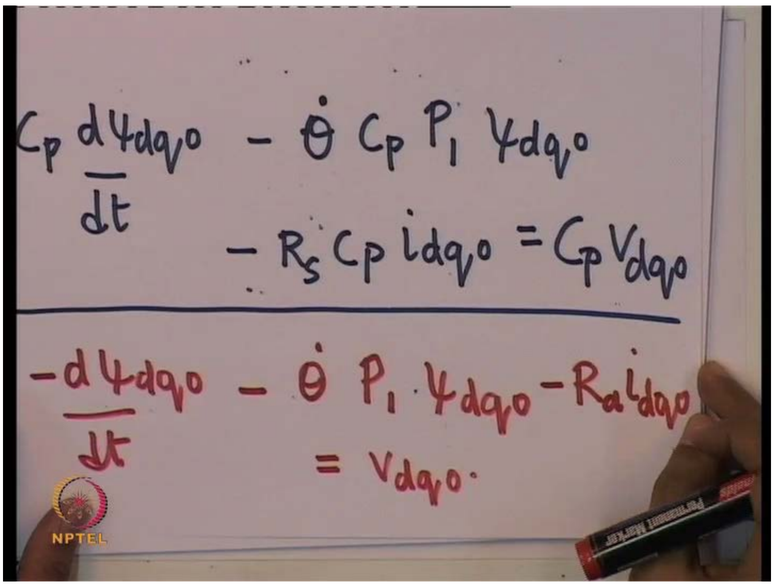

So, our final equations, flux equations, come out to be minus of C p d psi dq0 by dt minus d theta by dT. So, I will just call this theta dot C p P 1 psi dq0 minus R s into C P i dq0. It is nothing, but C p into v dq0. So, your flux equation becomes, in fact, I will just multiply, pre-multiply both, both sides by C p inverse, you will get minus d psi dq0 by dt minus theta dot into P 1 into psi dq0 minus R s. Of course, remember, is a diagonal matrix containing R a, R b and R c.

Of course, if all the coils are identical I can just say, R a into i dq0 is equal to v dq0, which leads us to, if I really write this down separately, you know, because it sometimes is not very evident, that what we are getting unless we write down all the equations separately. So, what I will do is I will write down the dq0 equation separately.

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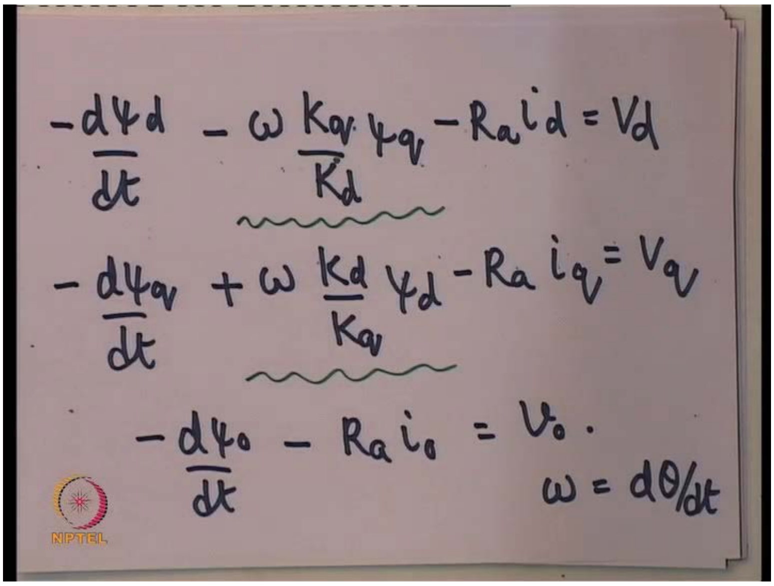


So, the dq0 equation separately turns out to be minus d psi d by dt minus d theta by dt, in fact, or theta dot is nothing, but, it is nothing, but omega, angular frequency, electrical angular frequency and this is K q by K d psi q minus R a i d is equal to v d. Minus d psi d q by dt plus omega K d by K q psi d minus R a i q is equal to v q and minus d psi 0 by dt minus R a i 0 is equal to v 0, where omega is equal to d theta by dt or d theta dot.

So, if it is not clear I am just panning this a bit. Now, one interesting thing you should see here is that there is what I mentioned sometime back, this P d M f terms, in fact, although we saw, that there is complete decoupling between the d and q axis. So, recall, we had a complete decoupling between the d and q axis.

Recall this equation or the flux equations, in fact, we had, I had had mentioned sometime back, that psi d is dependent on i d i f and i h, but it is not dependent on i q, i 0 or i g and i k. It is not dependent on the q-axis also, the flux current relationships. There is a complete decoupling between the d and the q-axis coils, so I call this the d-axis coil. So, the fluxes in the d-axis coil are not dependent on the q-axis currents, none of the currents, but importantly, when you look at the flux equations, there are speed emf terms. So, the flux Faraday's law, when you apply to psi d, psi d, you have to put this extra term, which comes because of applying the correct mathematics to the transformed equations.

So, although sometimes it is tempting to start from a kind of a physical model of rotating windings, when we come to obtaining the flux equations in the d coil or the flux equations in the q coils, remember that there are speed emfs in the d coil due to the flux in the q-axis. This cannot be explained by just from the starting of this model.

So, one of the things, which you should keep in mind is it is a good idea, as I mentioned in the previous class, to first work out the mathematics. The correct mathematics give you the, give you, gives you these equations where there are extra speed emfs terms, these speed emf terms come because we apply the derivative to the time varying transformation as well. These are the correct equations.

So, please remember, that there is coupling coming between the d and q axis coils because of these extra, what I call as, speed emf terms.

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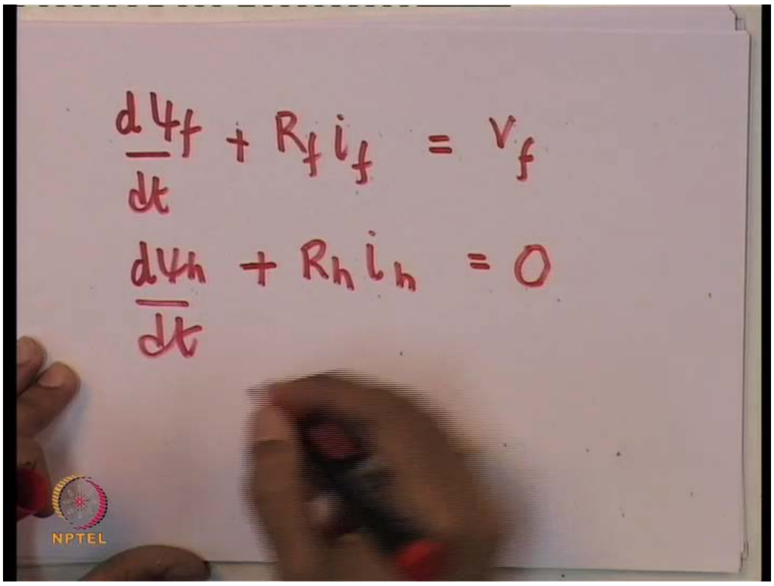


Now, these are, as far as, the stator equations are concerned, the rotor equations, of course, we know.

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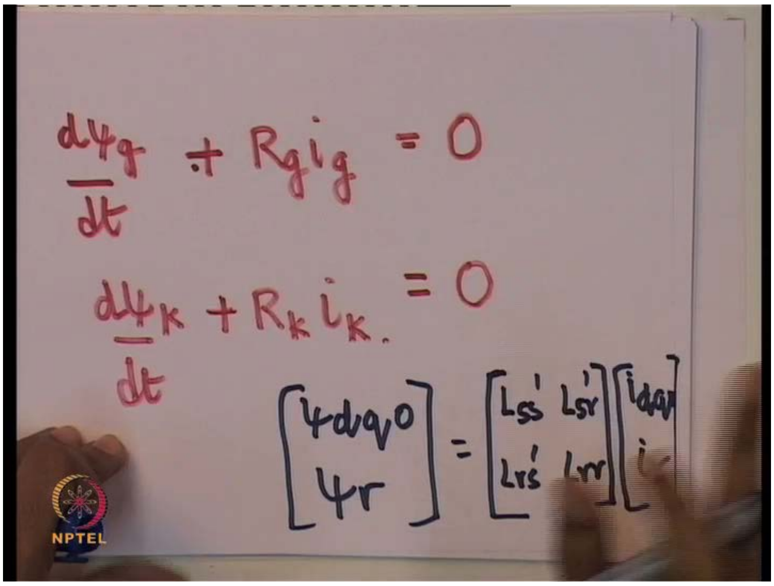


And d psi g by dt is equal to, sorry, plus R g i g is equal to 0. So, just remember these are the remaining equations. In fact, if you know the flux, if you know the flux and current relationships and these equations relating to the emfs, the rotor flux equations on the d-axis and the q-axis, we, in fact, have got the complete flux description, so if I know of course, I should, the relationship psi dq0 psi r.

I know this relationship as well, dq0 and i r and this is nothing, but L ss dash L sr dash L rs dash and L rr. So, we have in fact, got a complete picture of the system. In fact, you can substitute for i g, i k, i f, i h, as well as, i dq0 by psi dq0 and psi r using the relationship and you will get finally, things in the state space form. We will do it on a separate sheet.

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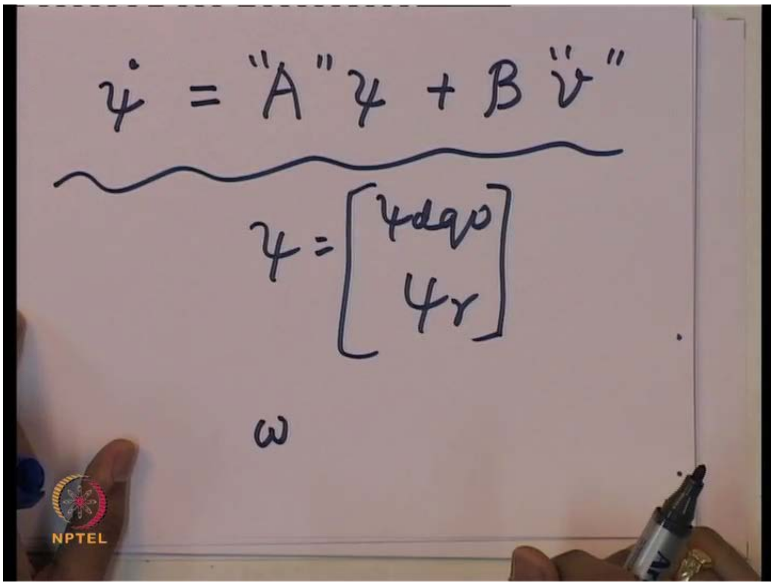


So, you will get, you can, of course, write it as psi dot is equal to some A matrix into psi plus B into v. So, you can get it into this, this form, where psi is nothing, but psi dq0 and psi R. This A, in fact, does not have time coming in explicitly; you do not have time or theta coming in explicitly. Of course, A does contain omega, remember that, because of the fact, that the equation flux have the speed emf term.

A is a function of omega, but if omega is a constant, then this A becomes linear, this particular equation becomes linear time invariant. So, that is the beauty of applying the dq0 transformation. It consists speed, of course, this becomes a linear time variant equation, there is no explicit dependence on theta, which itself changes with time. So, this is one of the main, you know, important thing, which really comes out of applying the dq transformation.

Now, in general of course, whenever you have linear time variant system, it is not obvious, that by transforming it in a certain way you will get a linear time invariant system. It turns out, that the machine equations have special, special structure, which permit the use of this transformation C p, ok, which make the system time invariant.

Now, one of the things, which we have not discussed now, we will shortly again discuss it, this feature of making the, you know, equations of, flux equations of a machine's time invariant, is not dependent on the specific values of K d, K q and K 0, it could be absolutely arbitrary choice. Of course, K d, K q, K 0 should not be 0; none of them should be 0. So, there is some flexibility in the choice of K d, K q, K 0.

Now, before we go on to discussing this particular point again, let us just look at what happens to the torque equations. Now, if you look at the torque equation, just recall what was the equation for torque?

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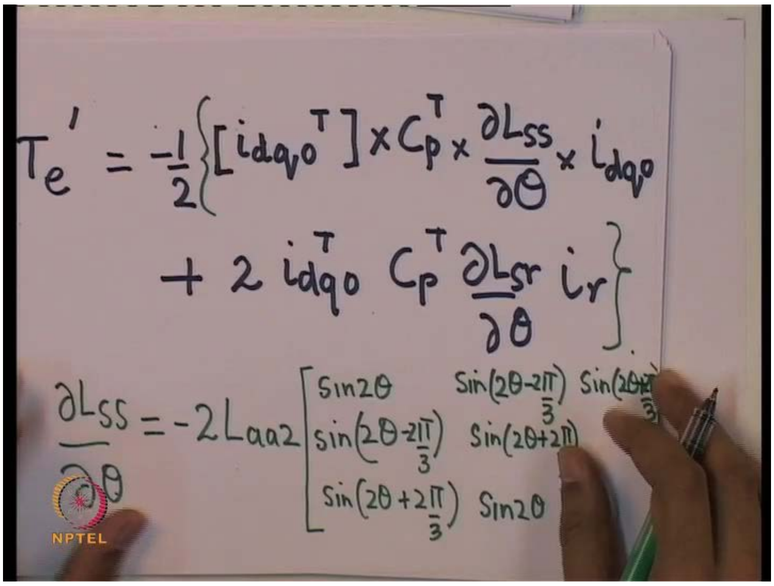


If you recall what we did some time back, I will just show you the equations first, so you can recall what we have done. This was the torque equation in the previous lecture where T e is nothing, the minus of the partial derivative of the co-energy with respect to the mechanical position.

Torque T e is, of course, in this direction, theta is measured in this theta M and theta e are both measured in this direction, the anticlockwise direction. Here, the co-energy is expressed as a function of currents. You have got this particular formula and of course, eventually we did get this, so T e, which is the electrical torque, is nothing, but the minus of P by 2 into P is the number of poles into d by derivative, partial derivative, of co-energy with respect to theta, which is the electrical angle.

So, we call, of course, T dash as this. So, T dash turns out to be this, so this is what our equations are. I basically took out the derivative, partial derivative of co-energy with respect to this. So, now, if I want to get this expression for torque T e dash, remember T e, the actual torque is actually minus P by 2 times this. So, we will have T e is equal to T e dash, the actual torque. Remember, it gets P by 2 minus P by 2 times T e dash. So, T e dash is nothing, but 2 by P times T e, half, so I substitute here. So, I have got i s transpose here, so I will have to write, i s remember is i a i b i c, so I can write this as i dq0 transpose into C p transpose into the partial derivative of L ss with respect to theta.

L ss, remember, is the sub matrix of the original L matrix into, there is not much space here, so I will just, we can write it here I guess, i dq0. i s here is C p into i dq0, inadvertently we have just written i dq0. So, remember, i dq0 is row, rather a column i d, i q, i 0, so this is a neat way of writing it, plus, plus, in fact, this is 2 times i dq0 transpose C p transpose d L sr by d theta into i r, closing of curly bracket.

So, what we get is this, you can just work out, you have already, about two lectures we took out, what L ss is actually. So, I will just write down what L ss by d theta is nothing, but minus of 2 L aa 2, this is a time varying part or the theta varying part, into sine of 2 theta sine of 2 theta minus 2 pi by 3 sine of 2 theta plus 2 pi by 3 sine of 2 theta minus 2 pi by 3 sine of 2 theta plus 2 pi by 3 here sine 2 theta. And of course, this is, this will be, I just, this is, it may not be clear, I will just read it out, sine of 2 theta plus 2 pi by 3, it is not very clear here, so maybe, we will just write it down again.

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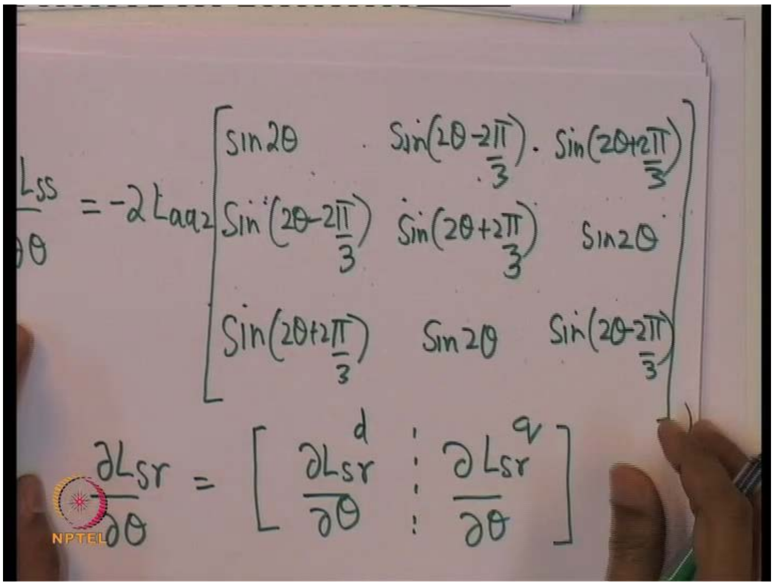


This is (( )) theta is equal to minus, sine of theta, sine of 2 theta sine of…

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This is this, L ss by L theta d L sr by dt will partition into d L sr d by d theta and d L sr q by d theta.

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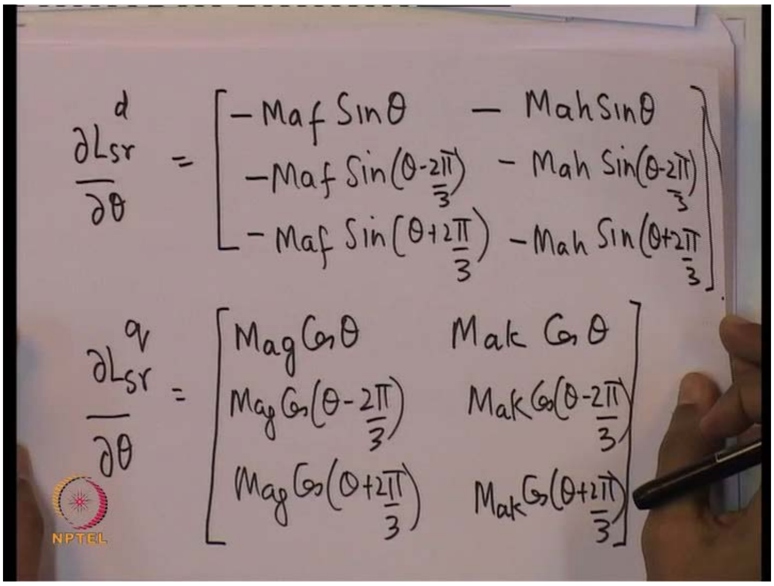


So, that turns out to be, Maf sine theta minus Mah sine theta…

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So, better book keeping is required, but as we shall see soon, that finally, what we get is the torque expression after using these formulae is quiet neat. So, this is what d, if we know dL sr is this, so we have found out the sub matrices, which I mentioned some time back.

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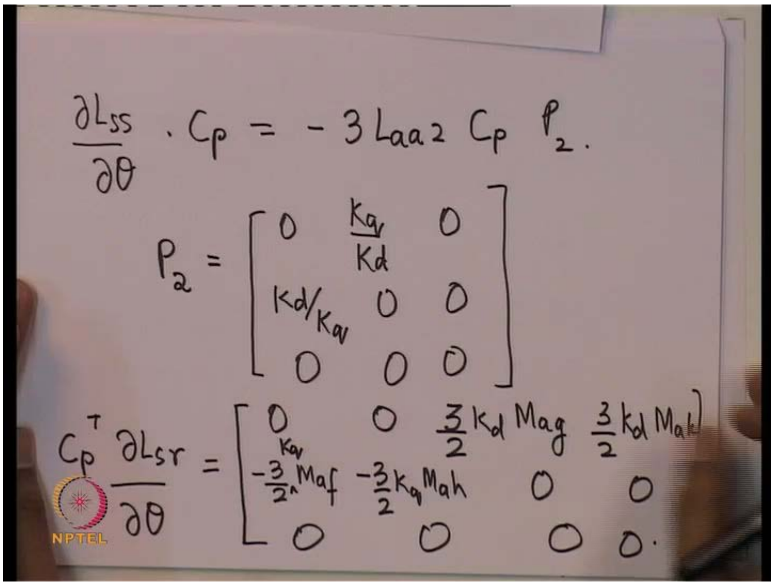


Now, you can see, that dL ss by d theta into C p is nothing, but minus of 3 L aa2 into C p into P 2, where P 2 is 0, K q by K d, 0, K d by K q, 0, 0 and 0, 0, 0. So, you can rewrite this. So, if you look at structure of d L s s by d theta if you look at the structure of it you can write it as, in this fashion.

Therefore, and further, you will find, that C p transpose of dL sr by d theta is nothing, but in fact, it gets stripped of all the thetas eventually, 0, 0, 3 by 2 K d Mag 3 by 2 K d M a K and this becomes minus 3 by 2 Maf minus 3 by 2, sorry, this is K here, so there is a K q, K q Mah, 0, 0 here, 0, 0, 0 and 0.

So, it is a bit complicated, but this is how it comes out to be, we can verify this.

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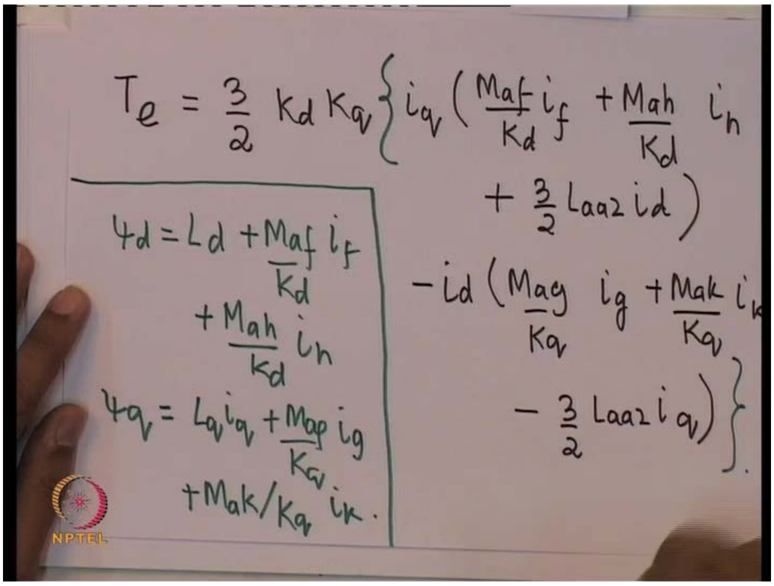


So, eventually, we get, we will just, I will just write down the torque equation. T e comes out to be 3 by 2 K d K q into i q into Maf by K d i f plus Mah by K d i h plus 3 by 2 L aa2 i d. So, I close this bracket, then continue, minus i d times Mag by K q i g plus Mak by K q i k minus 3 by 2 times L aa2 i q, close this bracket and close this bracket. So, this is the expression for torque.

But we know that, so I will just partition this here, we know, that psi d is nothing, but L d i d, this comes out from the flux equations, psi d is equal to L d i d plus Maf i f by K d plus Mah by K d i h and of course, psi q is nothing, but L q i q plus Mag by K q i g plus Mak by K q i k.

So, what do we understand form this?

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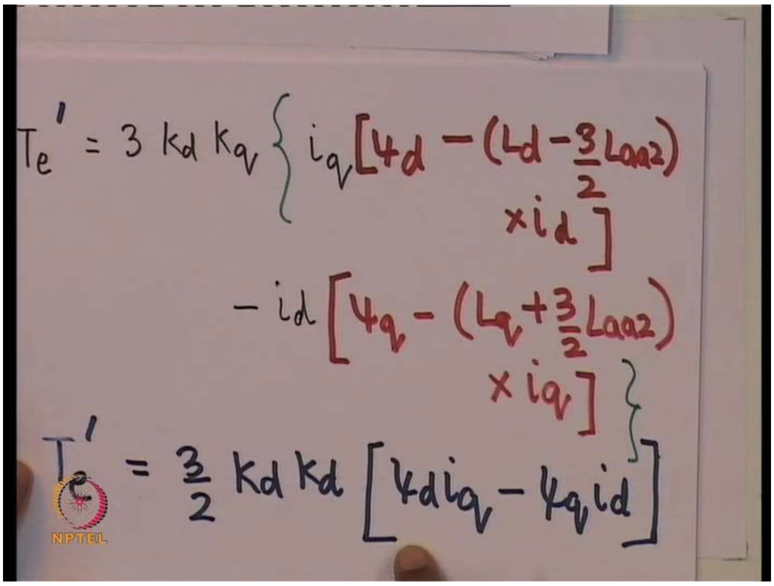


If you look at these equations, look at this and you look at this, so one can directly infer from this, that T e is nothing, but 3 by 2 times k d k q, again we will put a curly bracket here, i q into psi d minus L d minus L aa2, we will rewrite this again.

You can rewrite, T e is equal to 3 into k d into k q into, a curly bracket here, into i q into, we will put a square bracket here, psi d minus L d minus 3 by 2 L aa2 into i d and I close the square bracket minus i d into psi q minus L q plus 3 by 2 L aa2 into i q. So, I close this bracket and I close this bracket. So, if you, from this it is very easy to see, you know, I, you can cancel off this term here you will get really after all the manipulations, finally it yields, 3 by 2 times K d K q psi d i q minus psi q i d. In fact, this is small correction here, so I should be calling this T e dash, T e dash, so that is nothing, but T e dash; so, T e dash is this.

So, what we have here is basically a very neat expression, which is again, devoid of any of the thetas, they are all in term, so for d and q variables only. So, that is one interesting thing. So, our equations are turning out to be extremely neat. Now, in fact, if you write down the equation in d, q variables, you will find, that your equations will no longer have theta explicitly appearing in them, they are much easier to handle. The flux current relationship is brings out the de coupling between the d and q-axis, fluxes and currents.

The flux differential equations, of course, bring out the coupling between the d and q axis fluxes, there is a coupling. We now get the torque equation, remember what the torque equation was? If we recall where we were sometime back, this, so T e dash we have actually found out right now, which is, which I said was the function of theta, but of course, because we applied the d-q transformations, it turns out, that it is not explicitly coming, the theta does not come out explicitly. If you express T e dash in terms of the d-q variables, so it is a very, very interesting, you know, very neat expression we get for torque.

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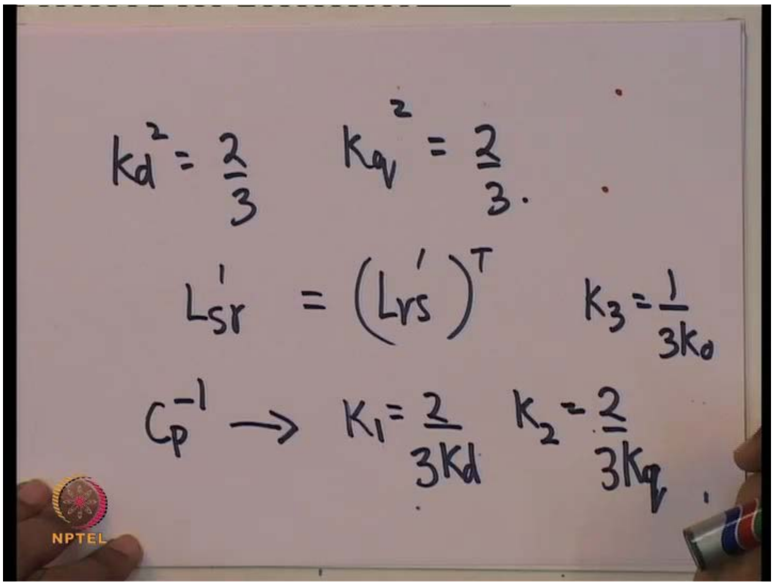


Now, one thing about the choice, the last topic in this particular lecture, about the choice of K d and K q. We saw of course, that if we put K d square is equal to 2 by 3 and K q square is equal to 2 by 3, one interesting thing happens, that is, L sr dash becomes equal to L rs dash transpose.

Also, if in fact, we saw some time back, that when we take out C p inverse, it is in terms, it has got elements K 1, K 2 and K 3, where K 1 is nothing, but 2 by 3 times k d and K 2 is 2 by 3 times K q. In fact, K q is in the denominator and K q is also in the denominator and K 3 is equal to 1 upon 3 K 0. So, these are the coefficient of the sines and cosines in the C P inverse matrix.

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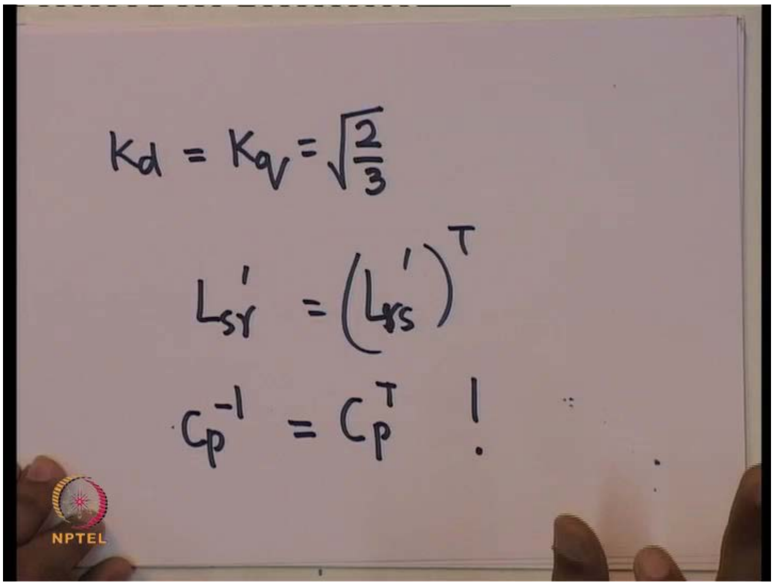


If you look at, you know, these relationships, it appears, that it is not a bad idea to choose K d equal to K q is equal to root 2 by 3. So, that is an interesting and important point here. Of course, there is absolute freedom of choice of K d and K q in so far as our main objective is of getting a time invariant set of equations. Remember, that K d, K q do appear in the flux current relationship, as well as, the flux differential equations, as well as, in the torque expression here. Sorry, this should be K q, but the fact remains, that although K d, K q do appear, theta does not appear. So, whatever be the value of K d and K q, as long as, they are non-zero, we do end up with what we have set out to do, that is, get a neat set of equations, which are invariant with respect to theta. So, if we choose K d and K q root 2 by, it is a very special choice, it will lead us to Lsr dash being equal to L rs dash transpose, it is just convenient; it is very convenient.

Also, we will find, that C p inverse will be equal to C p transpose. So, it is easy, of course, it is easy to remember would be one advantage of using k d and k q in this fashion. So, it is easy to remember, that C p inverse is equal to C p transpose.

But let me repeat, K d and K q could be arbitrary in so far our main objective of getting time invariant equations as concerned. So, let me just summarize, but before I do that, it is K d is equal to K q is equal to root 2 by 3 is a kind of a, is our, it is a special choice and that is the choice, which I will really follow in this particular course.

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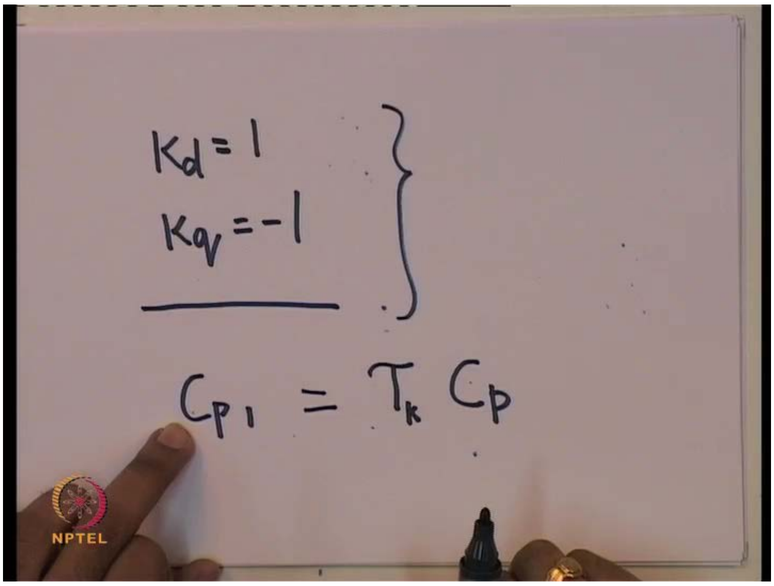


It is, in fact, the, the same choice is used in K R Padiar's book. In fact, I, we look at the other literature the literature or many industry papers. They follow dimension K d is equal to 1 and K q is equal to minus 1, so they, they follow this choice. In fact, of course, I did not talk about K 0, K 0, if I want this to be true. In fact, I should have told you before.

You have to choose K 0 is equal to 1 by root 3. So, K 0 also gets refined if I want to have this to be true. So, just remember this again, that many industry papers, as well as, you know, in books by Kundur and many other books they follow the convention, k d is equal to 1 and K q is equal to minus 1. In this particular course, I shall follow Padiars convention, which is or the IEEE convention actually, which is kd is equal to K q equal to root 2 by 3 because it gets us some benefits.

In fact, you will notice, that in this torque equation if I choose K d and K q as root 2 by 3, this, this you know, this whole coefficient gets becomes equal to 1. So, I do not have to remember these. Coefficients because this, this if I put K d equal to root 2 by 3 and K q equal to root 2 by 3, this coefficient effectively becomes 1. So, there are certain advantages in choosing this, but, as I mentioned back, the choice is arbitrary, it is not hampered of, referred to get a time in variant set of equations.

Of course, the question then arises, if I, if we have got industry papers or papers or books, which follow this convention, I will call this people who follow this convention, I will call this, people who are using this as a transformation using a transformation C P 1. And we, in fact, apply a transformation C p where K d and K q are root 2 by 3.

In such a case one can transform the equations, which they have used the people who are using these this set of values of K d and K q by again a kind of matrix T k. So, I can, actually the variables, which they have defined are different from my variables because the coefficients k d k q have been chosen by one have been 1 and minus 1 And we are going to choose root 2 by 3.

So, whenever I am going to use their equations and I get answers with their variables, I would need to use this transformation matrix T k to transfer from their variables to my variables. This will leave this as an excessive to find out what is T k is T very simple constant matrix.

So, to summarize this particular lecture finally, obtain the equations of the synchronous machine in the d-q frame of reference and the equations are neat in a sine theta, they are not functions of theta. In fact, you can, if in fact speed of the machine is constant, d theta ny d T is equal to constant, the flux equations, the flux differential equations are linear time invariant equations. Of course, if speed is not constant, in fact, in general, it need not be a constant.

You have a coupling between the mechanical equations and the flux equations, flux differential equations. In fact, the coupling is non-linear. Remember, the torque is psi d i q minus psi q i d. So, there is a product terms, there also there is a product when you are talking about the speed emf terms in the flux differential equations, therein also, there is a product.

So the mechanical equations and the flux equations are in fact coupled in a non-linear fashion, but the flux equation themselves for a constant speed are in fact, time, linear and time invariant, that makes at least some of our analysis much, much simpler.

So, now we move on to, to, you know, trying to interpret the equations which have come, correlate with parameters obtained by measurement and thereafter, the most important thing of course, in this course is to draw inferences, what equations you have got and correlate to actual power system.