Power System Dynamics Control and Monitoring
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Lecture – 17
Power System stability (Contd.)

So, in the previous lecture we have started network equation we came up to equation 252, but again to begin with we are starting from I mean from the beginning.

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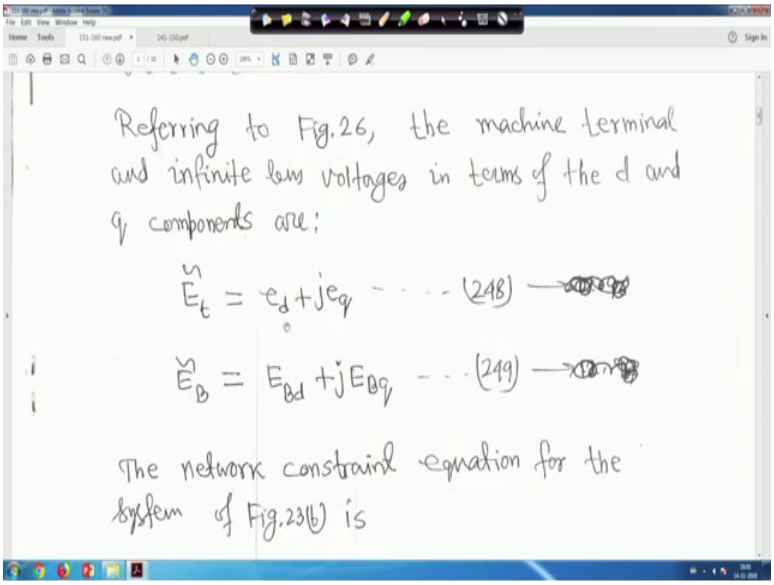

That, referring to your figure 26 the missing terminal and infinite bass volts is in terms of the d and q components are; the Et tilde is equal to e d plus jeq this is equation 248 and E B tilde is equal to RBD plus jEBq equation 249. So, let us go to figure 246.

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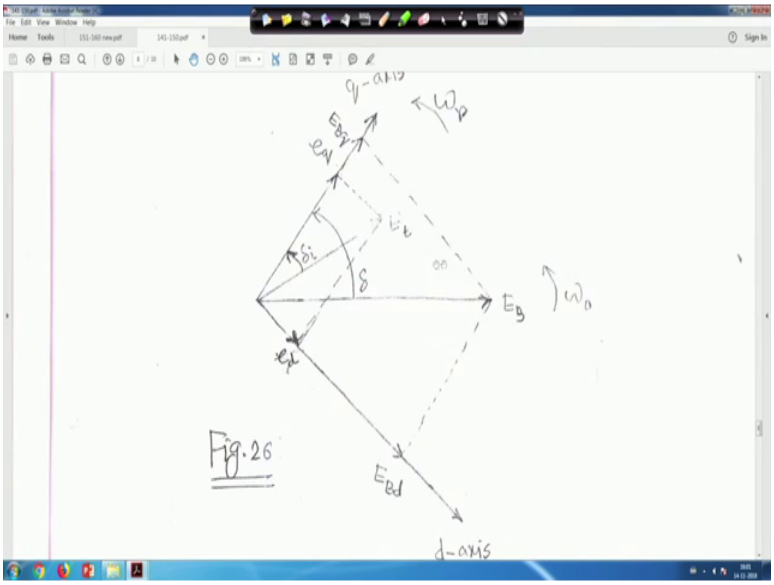

So, this is your sorry figure 26. So, this is your figure this EB is the reference right. So, from here we can make out that this is my this is my Et this is my Et right. So, an Et is equal to ed plus Et is equal to your ed plus jeq right. Similarly another thing if you see that EB EB is equal to this is your this direct axis component that is EBd plus jEBq right.

So, this is my EBq and this is my EBd right and another thing is that that EBq is equal to because these things later we will need that EBq is equal to EB cos delta EB cos delta right. Similarly, EBd is equal to your EB cos 90 degree minus delta; that means, your sin delta because this is delta. So, this angle is 90 degree minus delta right. Similarly, if you look about eq eq will be et cos delta i and small eq and small ed will be your what you call that Et your cos ninety degree minus delta i. So, Et sin delta i right. So, this is your figure this thing and your this thing and this thing and this thing and this had been used for the derivation of those equations right. So, let me clear it. So, let us write

So, Et tilde is equal to ed plus jeq and E B tilde E Bd plus jE Bq the network constant equation for the system of figure 23 b. That means, that Thevenin equivalent 1 right E t then x t your x e all are given and E B is that your infinite bass voltage the Thevenin voltage right. Therefore, from that figure we have not going to that figure that figure is understandable to you. So, E t tilde will be E B tilde plus RE plus jXE it tilde right.

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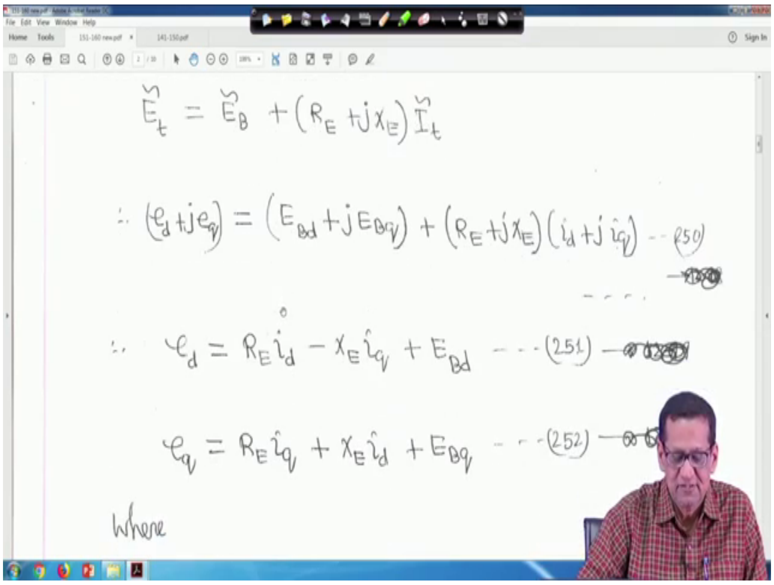

So, E t tilde e d plus j eq and E B tilde E Bd plus j E Bq and RE plus jX E and it tilde id plus jiq this is equation 250. If you multiply this if you multiply this second term right and you are collect real and collect real part and imaginary part then e d will be is equal to REid minus capital XEiq plus capital E Bd this is equation 251. And e q will be REiq plus XEid plus E capital capital REq this is equation 252 where, just we have given that EBd is equal to E B sin delta and E Bq is equal to E B cos delta this is equation 243 and 244.

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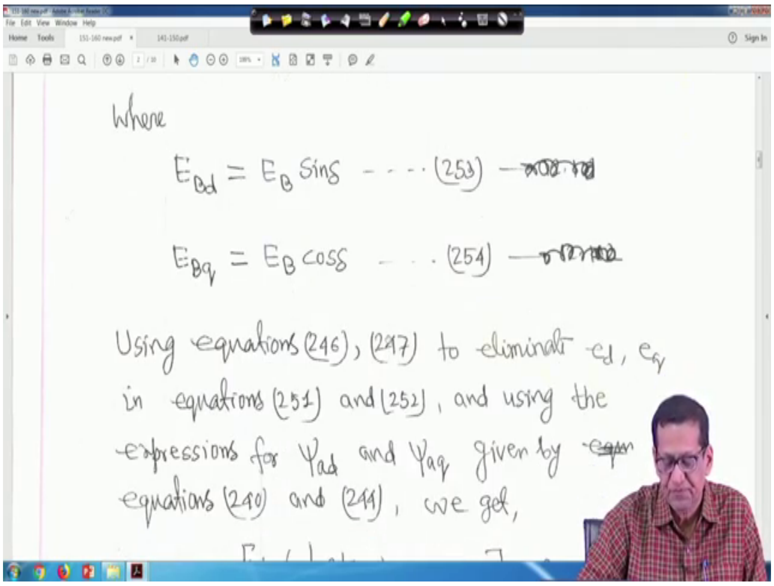

Now using equation 246 247 to eliminate ed eq in equation 251 and 252 and using the expression for psi ad and psi aq given by equation 240 and 244 we get listen.

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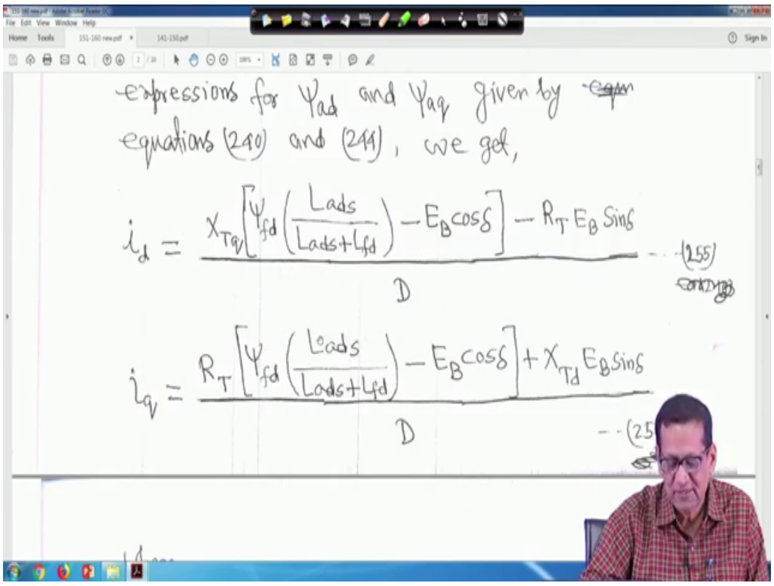

I mean just hold on thing is that a this derivations actually this derivation that using equation you use 246 247 to you have to eliminate e d e q in equation 251 and 242 and using the expression for psi ad and psi a q given by 240 and 244 you find out the solution for id and i q. There is no need to remember this, but question is that, but I suggest you please derive it. If I give all the derivations here then it will consume more time, but no need to remember, but you please just of your own whatever has been said everything I believe everything is a correct 1 if you find any typographical error or anything you just my writing error you please let me know right.

I can rectify myself, but I believe all these things are and just you derive and find out the expression id and i q because we need small perturbation thing. So, id is the function of X Tq is equal to X Tq in brackets psi f d in bracket Lads upon Lads plus L fd minus E B cos delta bracket is close minus RT EB sin delta divided by D. What is D? We will give right. Similarly, i q will be RT psi fd lads upon Lads plus L fd minus E B cos delta plus your X Td EB sin delta right divided by D 1 D is here so, right. So, because we need small perturbations and these equations actually what you call the day your expression are very lengthy right.

So, once you get these after making this mathematical manipulation i d and i q this is equation 255 this is 256. Now I have to give the term X Tq then your R T then D all this terms so, R T is equal to R A plus RE right.

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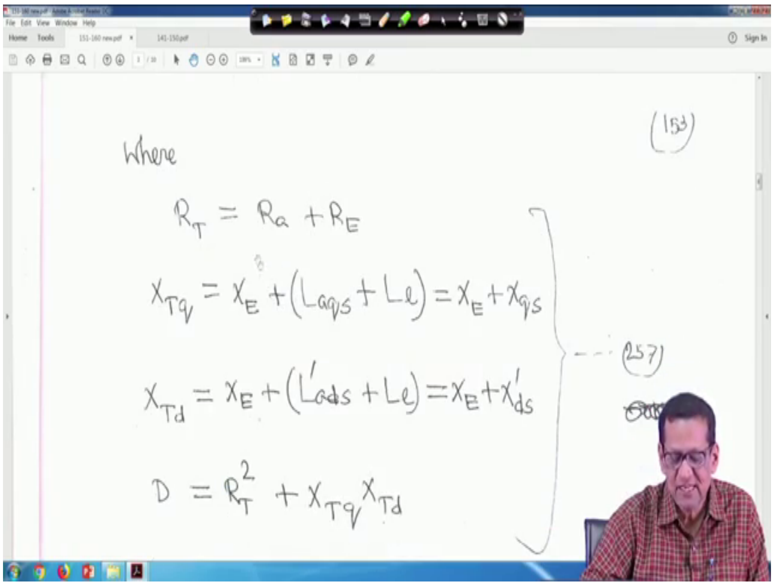

And that is R total is equal to your R A plus R E right in the X Tq will be X E plus L aqs plus L l is equals to X E plus X qs because in per unit system in per unit system I told you inductance and reactance are same. So, this term that is your X qs is equal to L aqs plus capital L small l suffix right so, that is why this term in Xqs. Similarly, X Td is equal to X E plus bracket Lads dash plus L l is equal to X ds dash. So, X ds dash actually is equal to this term your Lads dash plus your L l right because in per unit inductance and you reactance they are same.

Similarly, D is equal to R T square plus X Tq into X Td this expressions are not difficult 1 just put 1 after another and give those expression this is equation all this is equation collected together so, total is given 257.

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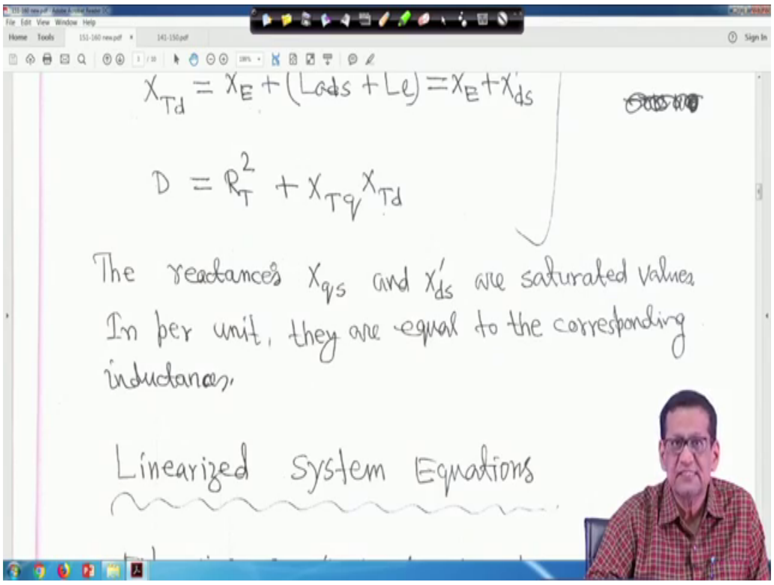

The reactances your X qs and X ds dash are saturated values in per unit they are equal to the corresponding inductances that I told you. Now, we have to find out the linearized system equations. So, expressing equation 255 and 256 in terms of perturbed values we may write that is equation 255 and 256 that is this equation 255 and 256 you take the small perturbation value that delta id is equal to find out perturbed value and delta i q you know the perturbation thing right.

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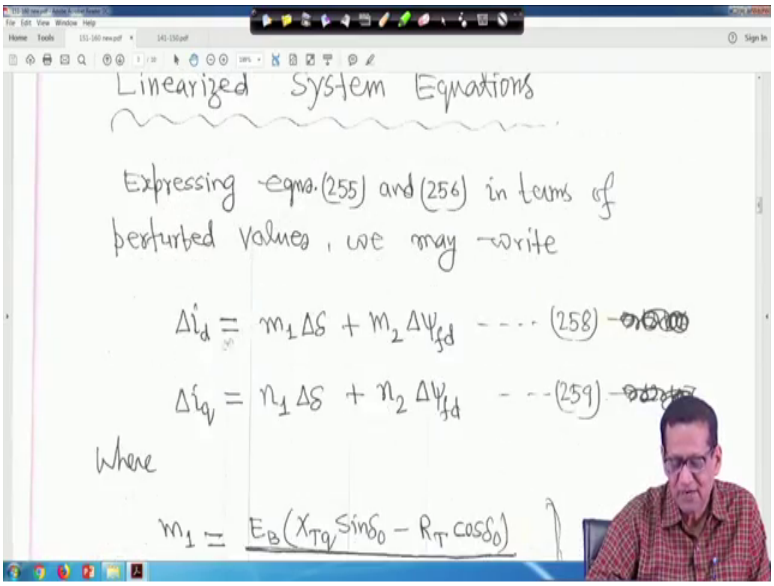

So, if you do so it will come in this form that delta id will becomes say m 1 into delta delta plus m 2 into delta psi f d. Actually in equation 256 and your 2 your 56 and 255 right so, 2 variables are here 1 is psi f d another is delta right here also psi f d delta other things are constant. So; that means, if you do so, it will be in this form delta id is m 1 delta delta plus m 2 delta psi f d in this form will come this is 258 and delta iq will become n 1 delta delta plus n 2 delta psi f d this is 259. Now, when you do the small perturbation thing then what is m 1 m 2 and n 1 n 2?

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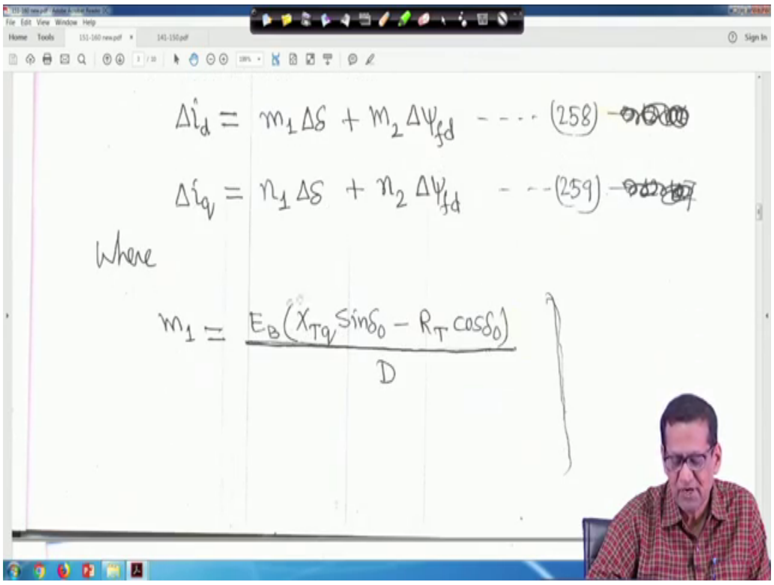

M 1 will become E B into X Tq sin delta 0 because around an operating point delta 0 we are perturb we are taking the perturbation right, I mean delta tends to your delta plus delta 0 right. So, m 1 will become your X Tq sin delta 0 minus R T cos delta 0 upon D right. Similarly, your n 1 will be E B R T sin delta 0 plus X Td cos delta 0 by D similarly m 2 is equal to X Tq upon d lads upon Lads plus L fd.

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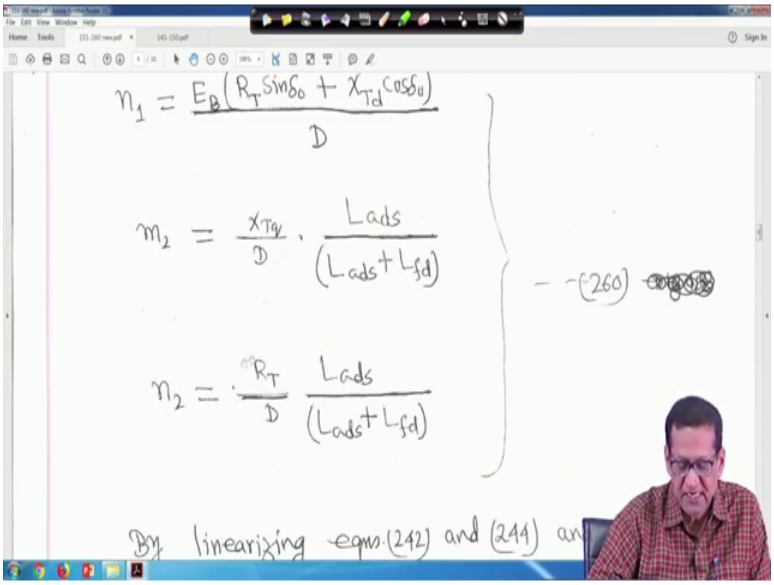

And n 2 is equal to your RT by D Lads upon Lads plus L fd collecting all these thing this is your marked as equation 260. Therefore, small perturbation model small perturbation expression for id and i q like delta id is this 1 and delta i q is this 1 this is 258 and 259. I suggest you do this thing otherwise this derivation if I put it here it will never, it will be an unending story then right. So, you please do it you please do it once and I just you can remember m 1 delta delta m 2 delta psi f d n 1 delta delta if anything is given m 1 m 2 n 1 n 2 will be supplied rather than computing because, I know it is difficult to remember all sort of things all right.

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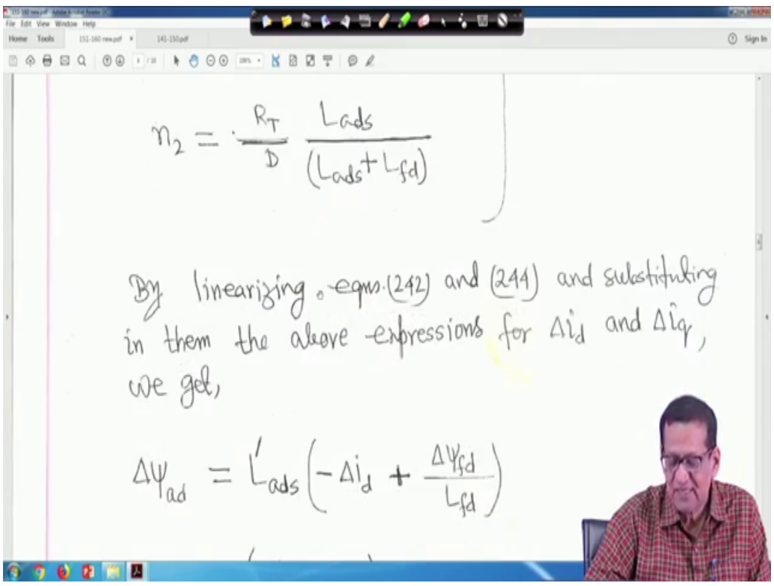

So, by linearizing equation 242 and 244 and substituting in them the above expression for delta psi d and delta i q we will get. So, we have to linearize equation 242 and 244 for psi id and psi q. So, here just hold on equation your we have to linearize again 242 and 244 so, I think it will here only that is expression for this thing just hold on that is your this is 236 just hold on this is 242 and 244. So, this is 242 that this equation for psi id you have to again take small perturbation this is 242 and this is 244.

These 2 equations you have to take the small perturbation 242 and 244. So, if you linearize now that equation 242 and around some of operating point say and substituting in them the above expression for delta id and delta iq you will you will get that your delta psi ad will become L L ads dash bracket minus delta id plus delta psi f d upon your L fd right.

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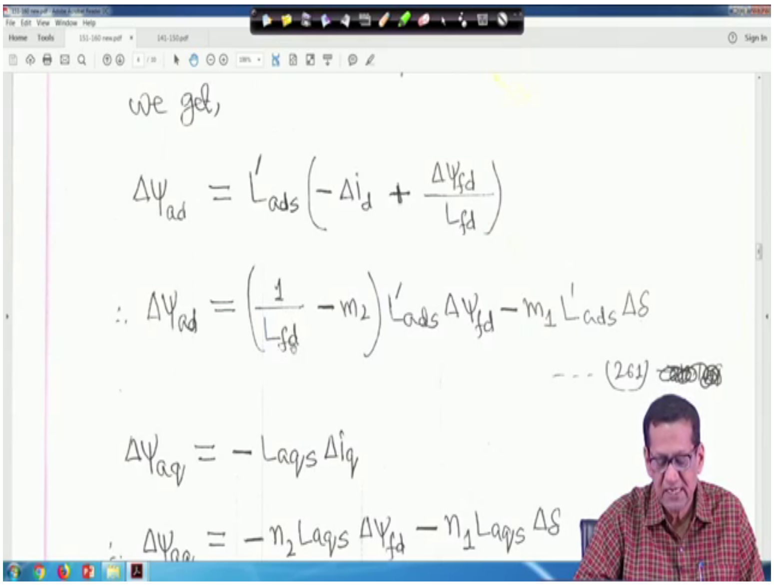

Or delta psi ad will become 1 upon L fd minus m 2 bracket close L ads dash delta psi f d minus m 1 L ads dash delta delta this is equation 261. Basically what you have to do is you substitute the expression for delta id from this equation from this equation right. And m 1 m 2 are given m 1 your what you call m 1 and m 2 are given this is m 1 and this is m 2 right all are given. So, if you do. So, it is becoming in terms of m 1 and m two. So, delta psi ad 1 upon L f d minus m 2 L ads dash delta psi f d minus m 1 L ads dash delta delta this is equation 261.

Similarly, for this 1 if you take that is linearize equation 244 so, it actually this equation is your linearizing equation 244 this equation your linearizing that is your 244, that is your because there it was given psi aq is equal to minus L aqs i q. So, this delta psi a q is equal to minus L aqs delta i q and delta i q we have got it. So, just what you do is that you substitute right that you substitute for delta i q it is simpler only multiplies by L aqs this is your delta psi a delta i q right this 1 you substitute.

And what you call and this is your minus n 2 L aqs delta psi f d minus n 1 L aqs delta delta this is equation 262 right. Now linearizing equation 241 and substituting for delta psi ad from equation 261, now we have to linearize equation 241. So, before doing this we will go back to this equation 241 that is your this equation that (Refer Time: 13:42) equation this 1 also you linearize right you just linearize this equation because delta i fd will be psi f d minus psi ad upon L fd right. Therefore, you linearize equation and substituting for delta psi ad from equation 261 right.

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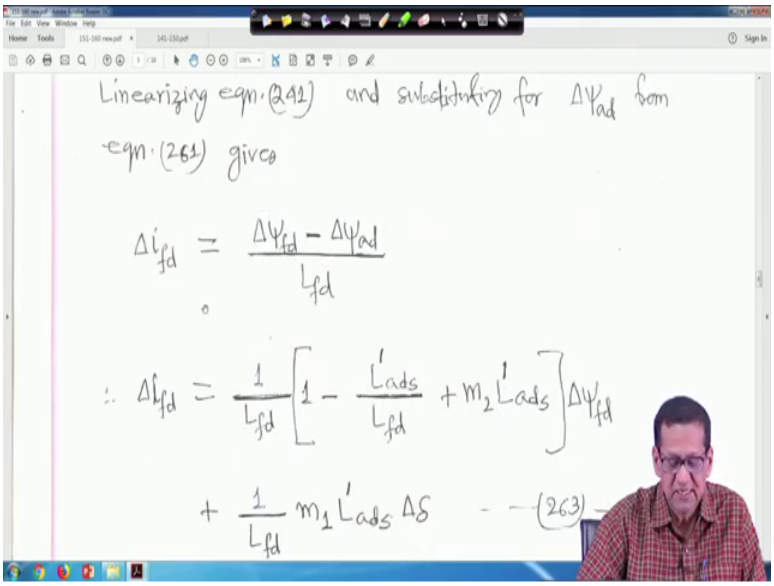

So, delta i fd then delta psi f d minus delta psi ad divided by L fd and this expression for delta psi ad I mean this equation 261 this delta psi ad you substitute here you substitute here if you do so, you substitute here.

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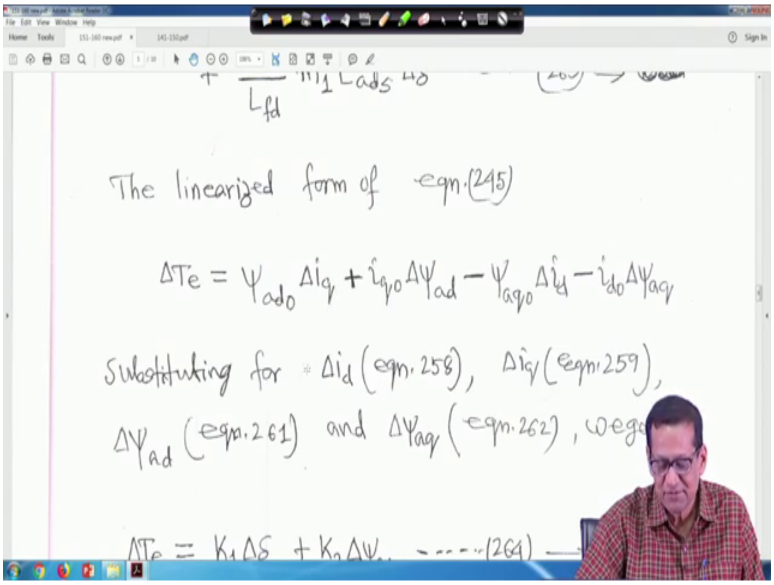

You will get it is your delta I i fd is equal to 1 upon L fd in bracket 1 minus lads dash upon L fd plus m 2 L ads dash into delta psi f d plus 1 upon L fd m 1 L ads dash delta delta this is equation 263 right. So then again you linearize the form of equation 245 that is a torque equation you have to linearize you go to 244 245 rather where the torque equation t expression is given and that 1 also you linearize around some operating points say I id 0and iq 0 and psi ad 0.

So, you will get delta T e is equal to psi ad 0 delta plus i q 0 delta psi ad minus psi a q 0 delta id minus id 0 delta psi a q just you take the small perturbation right in equation 245. So, I am not going to the expression again, but just when you listen to this video just keep those equation and just try yourself once only once right.

So, now in this expression you substitute for delta id that is from equation 258 delta iq from equation 259 because all these things are given before right and delta psi ad from equation 261 and delta psi a q equation 262. That means, you substitute here delta expression for delta i q from equation 259 then substitute for delta psi ad from equation 261 and substitute for delta id from equation 258 and substitute psi a q from equation 262 and simplify.

Then you will get in this form that delta T e will be K 1 delta delta plus K 2 delta psi f d this is equation 264 right because, in our synchronize machine model will in the K is constant will try to develop the model there are 6 constant say K 1 K 2 K 3 K 4and K 5

K 6. So, now it is K 1 and K 2 so, delta T e will be K 1 delta delta plus K 2 delta psi f d this is equation 264.

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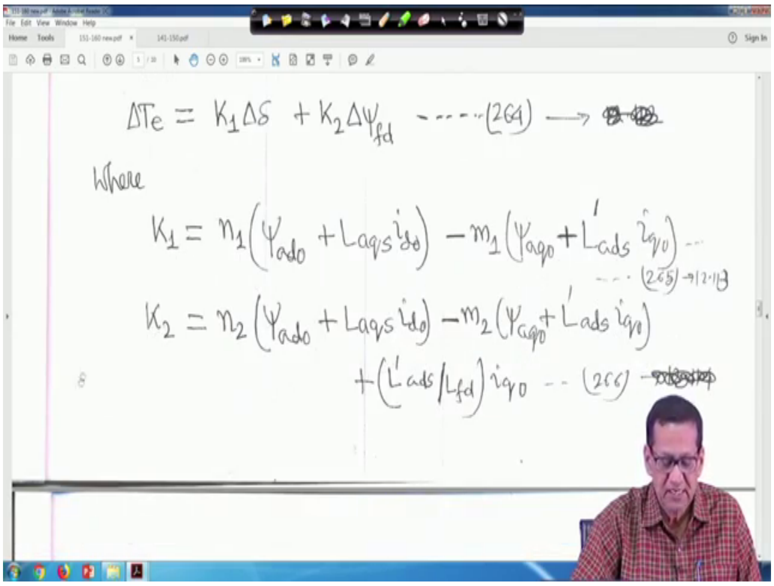

Where, if you substitute and simplify your K 1 will become n 1 n 2 psi ad 0 plus L a q s id 0 minus m 1 in bracket psi aq 0 plus L a d s dash iq 0 this is equation 265 right. Similarly, your K 2 will be n 2 psi ad 0 plus L a q s id 0 minus m 2 in bracket psi aq 0 plus L a d s dash i q 0 plus L L a d s dash upon L fd into iq 0 this is 266 these are your what to call these are your expression for K 1 and K 2 right.

So, in otherwise in otherwise how one can find out the K 2 for example, suppose psi fd is constant suppose you want to find out K 1 suppose psi fd is constant; that means, delta psi fd becomes a 0. For example, if psi fd is constant in that case K 1 will be is equal to delta T e upon delta delta. Similarly, if your delta is constant then your K 2 will be delta T e upon delta psi fd right.

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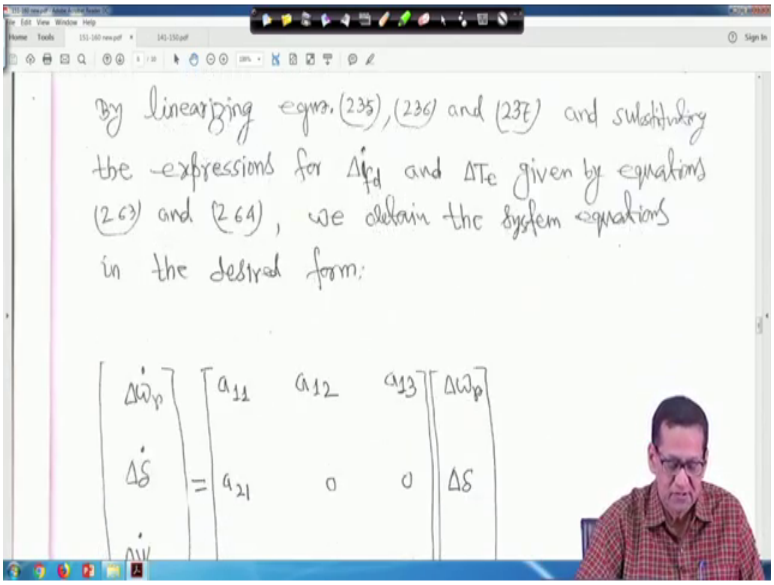

So, now by linearizing equation 235 236 and 237 and substituting the expression for delta ifd and delta T e given by equation 263 and 264 we obtain the system equations in the desired form right. So, you have to linearize equation 235 236 and 237. So, I will go to that 235 2 once again 235 236 and 237 right.

So, this is your what to call just hold on this is equation 235 already we have linearize it and I have shown it right and 236 also has been linearize and shown because that previous block diagram in terms of H right. And your what to call omega 0 other thing this all these things has been linearize p delta omega are I told you how to linearize this 1 p delta omega r will be 1 upon 2 H is delta T m minus delta T e minus KD into delta omega r and why it will derive I have shown you already similarly p delta delta omega 0 delta omega.

So, p delta delta also will be is equal to omega 0 delta omega r because delta omega r is equal to omega r minus omega 0 this already we have discussed and 237 right and 237 you have to linearize this is 237also you have to linearize here. So, this is basically p delta psi fd is equal to this one delta E f d minus omega 0 R f d delta i f d. So, all these things expression for your what to call all these things you have to put together in that differential form right.

So, those things little bit I suggest I am giving the final expression because it takes long time to this, but you try once right. So, if you do so, that is a linearizing equation 235 236 and 237 and you substitute the expressions for delta i dash show you delta T e given by the equations 263 and 264 we obtain the system equation in the desired form right.

That means, in that your differential form the derivative form. So, this will be consider delta omega dot delta delta dot and delta psi fd dot because, it is p delta omega r so, p is d d t. So, it is delta omega dot similarly for delta delta dot.

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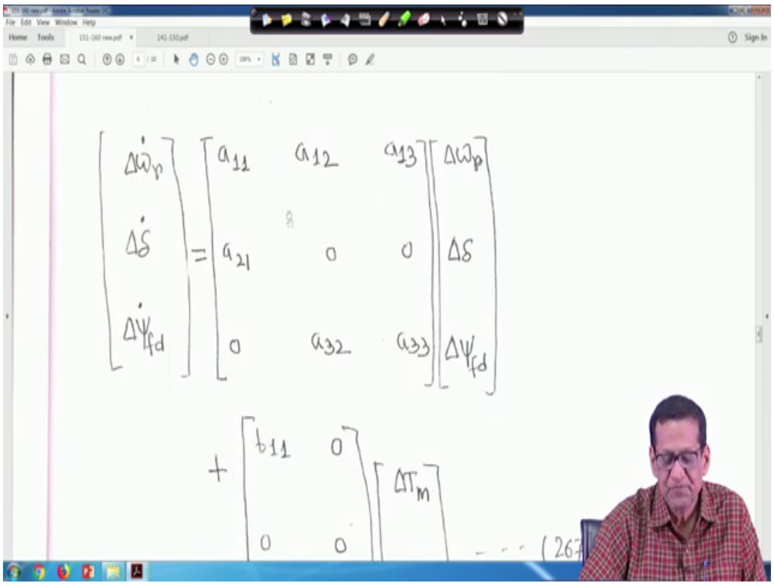

Similarly for this one you put in this form that a 1 1 a 1 2 a 1 3 a 2 1 0 0 0 a 3 2 a 3 3 and delta omega delta delta is state variable form a variable form you are put in delta psi fd plus b form that b 1 1 0 0 0 and 0 b three 2 delta T m delta Efd this is equation 267 right.

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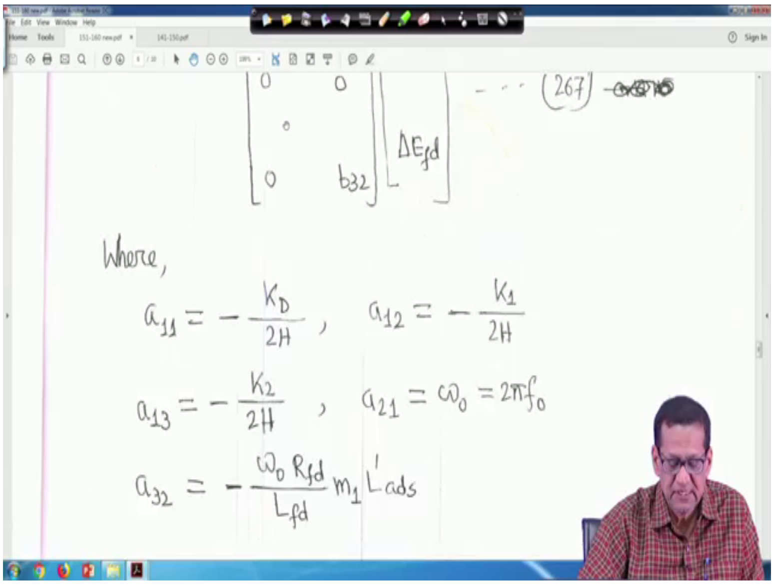

So, later you will see sometimes I have use this is a 3 1 right a 3 1 actually is equal to 0 sometimes for generalizing the expression I have written a 3 1 delta omega r, but unless and until state it you have to see that a 3 1 actually is equal to 0 right. So, where now when you when you make all these your a 1 1 will become minus KD upon 2 H, a 1 2 will become minus K 1 upon 2 H. A 1 3 will become minus K 2 upon 2 H a 2 1 will become omega 0 is equal to 2 pi f 0. And a 3 2 will become minus omega 0 Rfd upon Lfd m 1 into L a d s dash when you do all these things and putting in this form. So, ultimately this is non 0 elements of a matrix right and similarly for non 0 element of b matrix that is b 1 1 and b 3 2.

So, a 33 is also there minus omega 0 R fd upon L fd this is your here a 33 is there. So, this is your minus omega 0 R fd upon L fd in bracket 1 minus L a d s dash upon Lfd plus m 2 L a d s dash right.

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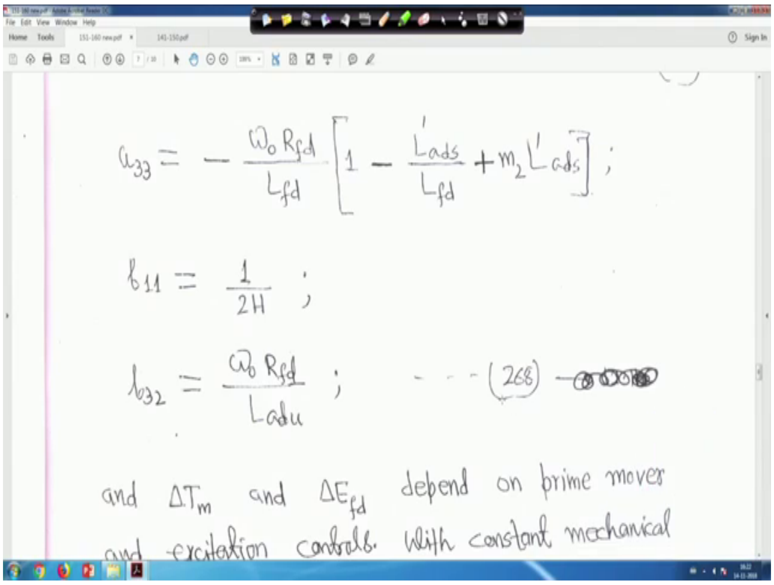

And b 1 1 will become 1 upon 2 H and b 3 2 will become omega 0 R fd upon L a d u this is equation 268 all this things right. So, this is basically, if you look into that this is basically a now 3 into 3 matrix right at present it is 3 into 3 matrix and state variables are delta omega r delta delta and delta psi fd right.

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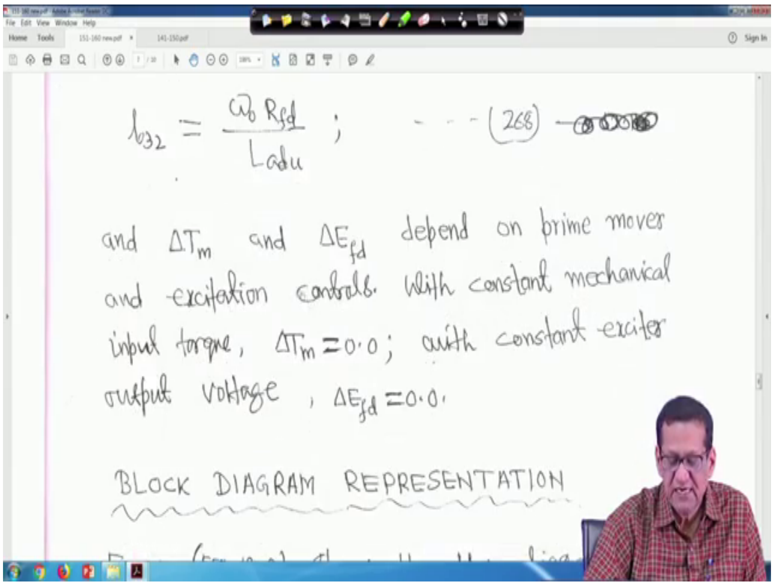

Now and delta T m and delta E fd depend on prime mover and excitation controls with constant mechanical input torque if it is constant then delta T m will become 0. Similarly, when constant exciter voltage delta E fd will become 0 right if T m is constant then delta

T m will become 0 and if E fd is constant that exciter output voltage then delta E fd will be 0 right.

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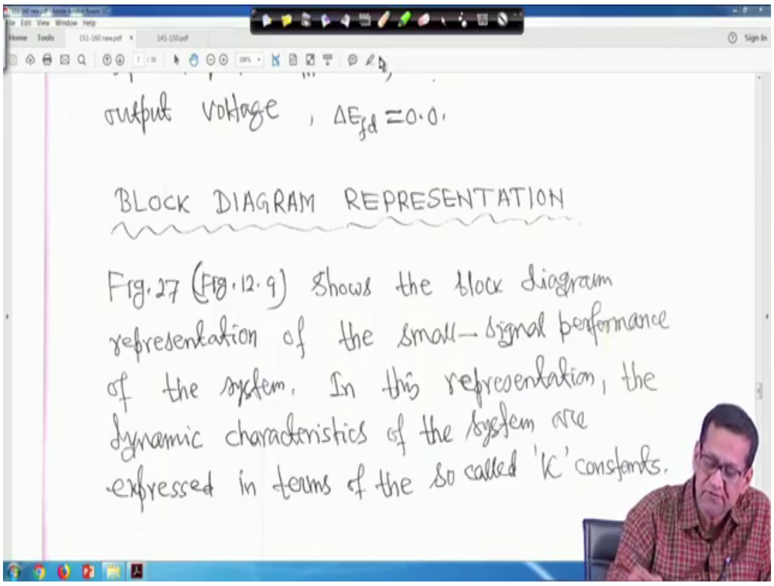

Now, block diagram representation; so, now once we have developed these equation this is not required this is from my reference the figure 27; I will show you that shows the block diagram representation of the small signal performance of the system. In this representation the dynamic characteristics of the system are expressed in terms of called the K constant. I told you so, will find out there are 6 K constant K 1 K 2 K 3 K 4 K 5 K 6 till now we have made a K 1 and K 2 slowly and slowly we will develop right.

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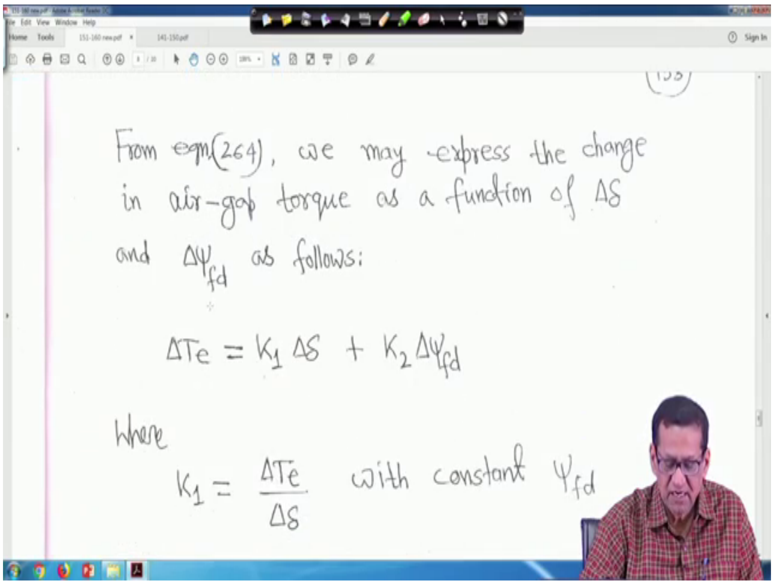

So, with this constant K 1 figure 27 will go right and this your I will show you figure 27, but from equation 264; that is we may express the change in air gap torque as a function of delta delta and delta fd as follows. This is we have developed delta T e is equal to K 1 delta delta plus K 2 delta psi fd right.

Now, where if where K 1 can be written as delta T e upon delta delta with constant psi fd psi fd is constant then delta psi fd will be 0. So, in that case K 1 will be delta T e upon delta delta. Similarly, K 2 will become delta T e upon delta psi fd with constant rotor angle delta, if rotor angle delta is constant then delta delta will be 0 therefore, K 2 will be delta T e upon delta psi fd this is the meaning of this 2 term K 1 and K 2 right.

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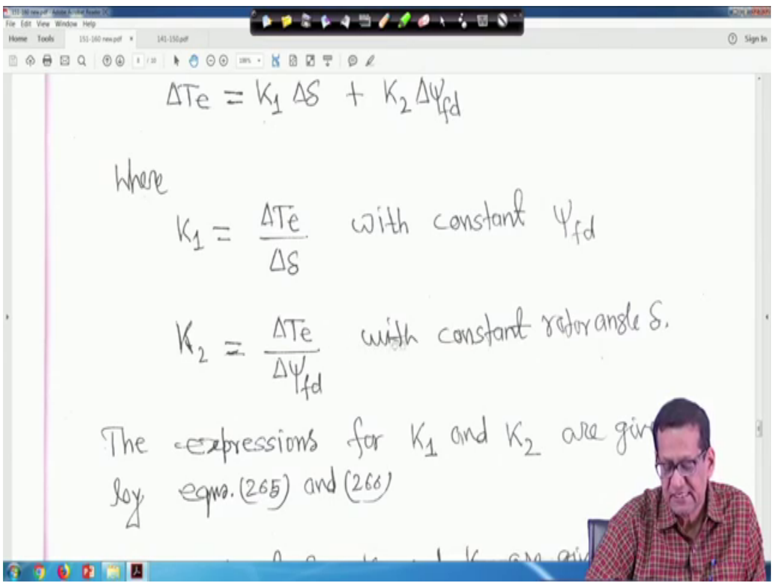

Now, the expression for K 1 and K 2 are given already given in equation 265 and 266 right, but this is another way of determining your K 1 and K 2. Now, the component of torque given by K 1 delta delta is in phase with delta delta. This meaning will see later the component of torque given by K 1 delta delta is in phase with delta delta and hence represents a synchronizing torque component.

So, why it is in phase next we will come after some time and that is there also I will put a question to you will that question you should given answer first let me show it right. So, component given by K 1 delta delta is in phase with delta delta and hence represent a synchronizing torque component right.

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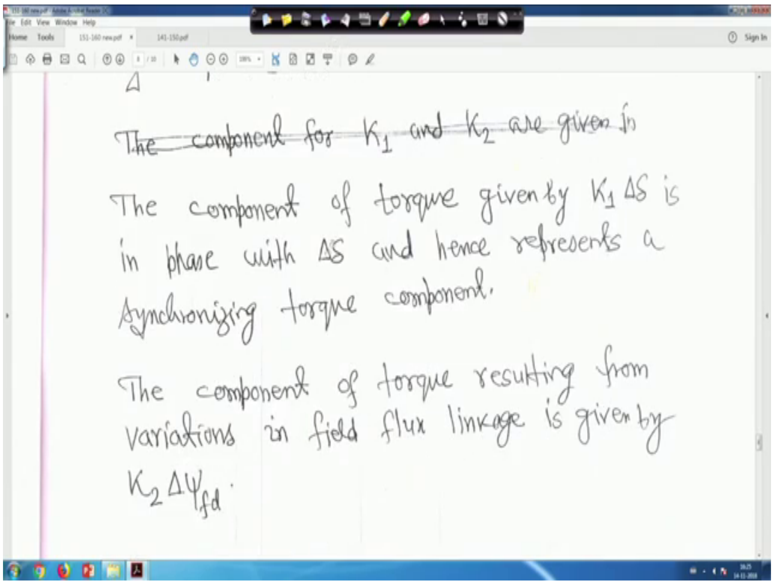

So, we will come to that and the component of torque resulting from various in field flux linkage in given by K 2 delta psi fd; that means, when we will come to the block diagram right that figure 27 we have not come. So, I will go back again this is my figure say 27 in terms of K 1 and K 2. So, earlier we have seen that your this block diagram you bring that your KD delta omega term to the left hand side and simplify you will find this is delta T m positive this is minus delta T e and it is 1 upon 2 HS plus KD.

Then I here it is output is delta omega r and delta delta will be delta omega r omega 0 upon this already shown. And from delta delta that that you are what you call that 2 terms are there for delta T e one is K 2 delta psi fd another is your K 1 delta delta. So, if you look into the block diagram block you make the block diagram right when you make the block diagram that there you see the delta T e is nothing but your K K 1 rather fast I am writing this one delta delta plus K 2 delta psi fd right.

And delta psi fd also related to your what you call that your this is a K 4 K K 4 term right and K 3 and one sorry and another K 3 term that will see later right, but this is your figure 27. So, we will go back again.

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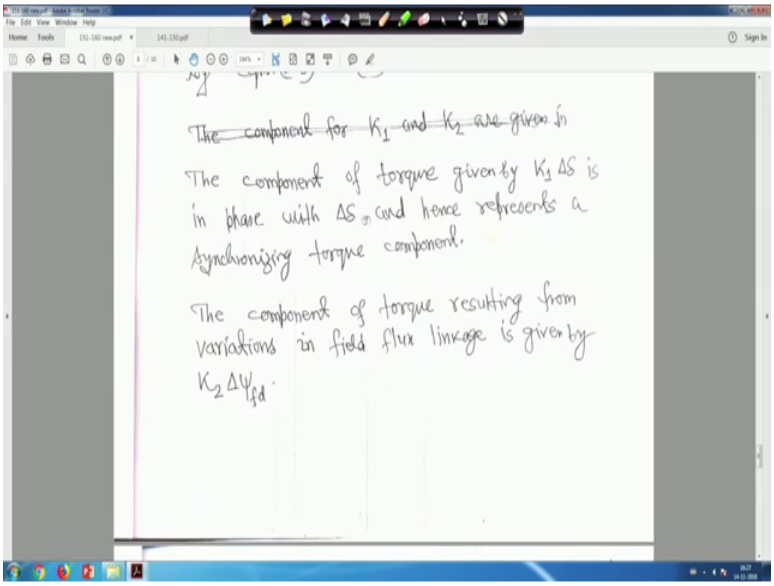

The component of torque given by K 1 delta delta I told you is in phase with delta. We will come to that later and hence represent a synchronizing torque component. The component of torque resulting from variation in field field flux linkage is given by K 2 delta psi fd right. The variations of delta psi psi fd is determined by the field circuit dynamic that is 3rd equation of 2 equation 267 right.

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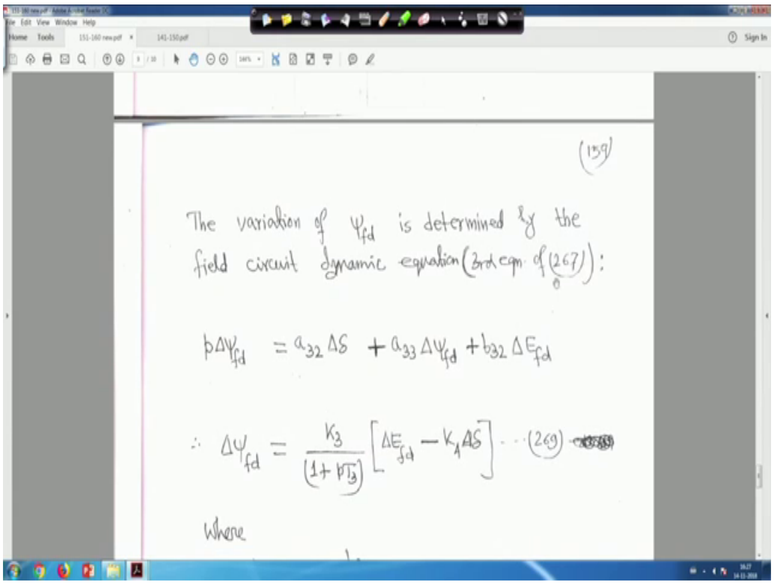

That is a 3rd equation of 267 the state variable equation you have written and this is actually third that is p delta psi fd. That if you write a 3 2 delta delta plus a 33 delta psi fd plus b 32 delta E fd; that means, this equation; that means, this equation right. You when you come to this thing matrix 1 right this equation that delta psi fd dot is equal to your a 3 2 delta delta plus a 3 its a 33 delta psi fd plus b 32 delta a fd from this equation 267 right.

So, same thing we are making it here the 3rd equation we are writing that your ps delta psi fd is equal to a 3 2 delta delta plus a 3 delta psi fd plus b 3 2 delta efd right. Now delta psi fd can be put in this form what you do is this; this term this, this term this term you bring it to the left hand side and simplify the way it has been made here the way it has been made here bring this term. And here you here you make it you are what you call that your b delta E fd term is there right and a 3 2 delta delta you so, you what you call that you bring this term and simplify this one I will bring in this form all that definitely K 3 K 4 are given.

You please bring it in this form right that is why I mean just you have to simplify this and you simply it will become delta E fd minus K 4 delta delta. So, now, question is that you are that K 3 and K 4 K 3 and K 4 are given like this K 3 is equal to minus b 3 2 upon a 3 three K 4 will become minus a 3 2 upon b 3 2 you just represent in this form and p is nothing but deferential operator in its domain we will put yes that is all you right.

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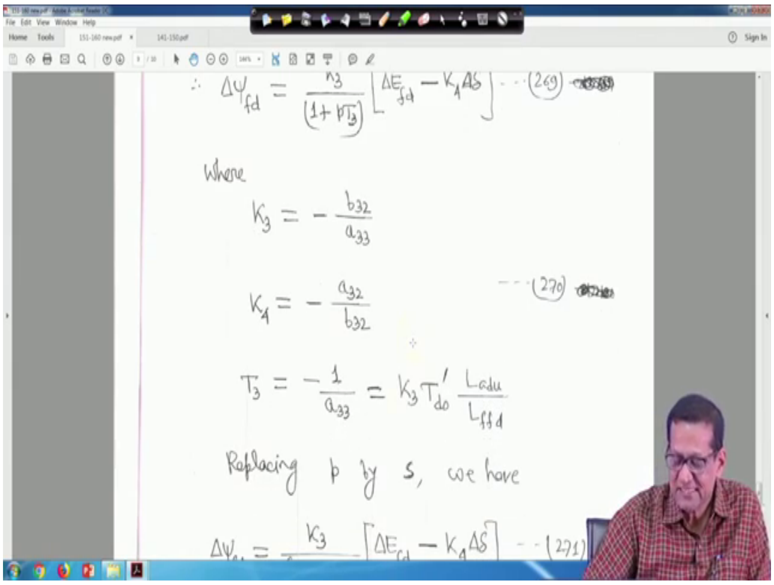

And T 3 is minus 1 upon a 3 3 is equal to it can be shown that it is K 3 T do dash into L adu upon L ffd this is this is for your this is a small exercise for you that how T 3 is coming this is a small exercise for you just see the book right and just find it out. So, this is a small exercise for and p is nothing but a differential operator that will take always s right that is actually ten replacing p by s right.

Thank you very much. We will be back again.