Power System Dynamics, Control and Monitoring
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Lecture – 18
Power System stability (Contd.)

So from here, we finished from here right in the previous lecture.

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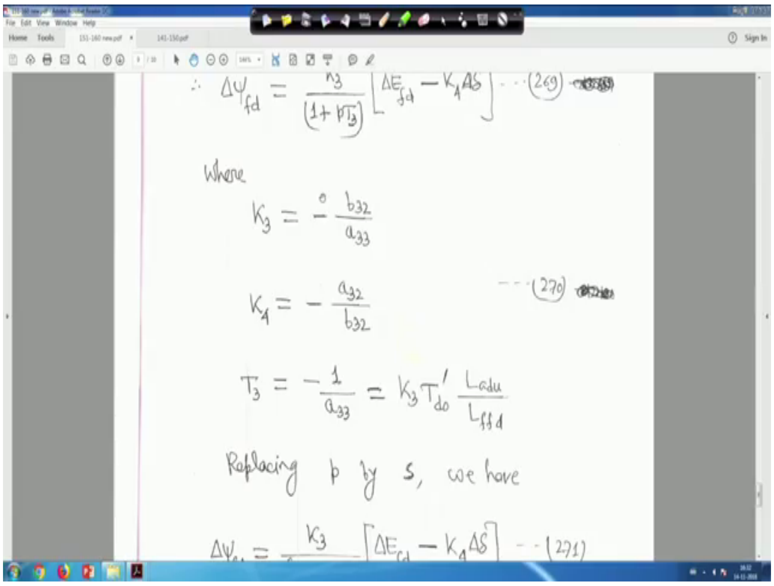

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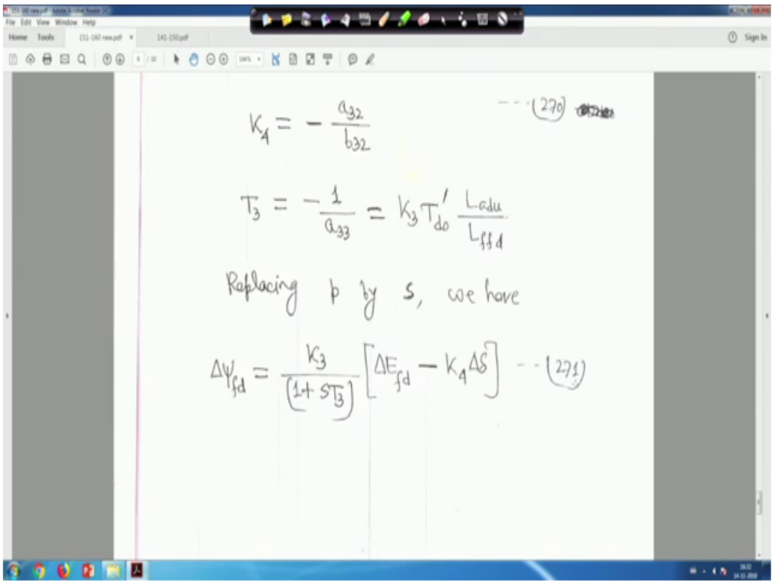

So, now, replace p by S, we have delta psi f d will be K 3 upon 1 plus S T 3 in bracket delta E fd minus K 4 delta delta. This is equation 271.

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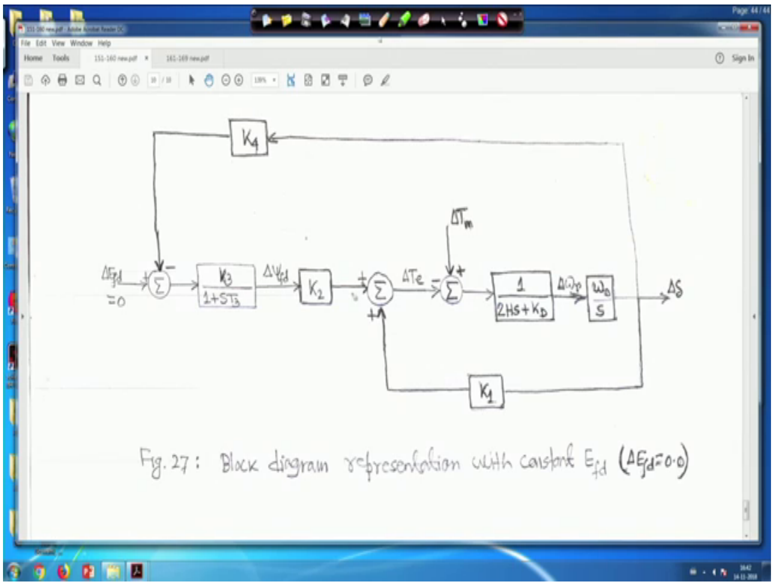

Next after this is block diagram is drawn, now here if you see that, delta psi f d that delta psi f d right is equal to just; now we have given no K 3 upon 1 plus S T 3 into your what you call K 4 delta delta, your delta E fd minus K 4 delta delta. Here the delta E fd field volt to the E fd is a constant right, then your delta E fd will be 0. That is why I have just made it delta E fd 0. You forget about this one for the time being right, it is basically delta E fd minus here the here the entry point it is K 4 delta delta right K 4 delta delta.

So, E fd minus K 4 delta delta into K 3 upon 1 plus S T 3 right and that is equal to delta psi f d. And delta T whatever it is, it has two components; one component due to this delta psi f d right and another component which coming from here this is nothing, but K 1 delta delta.

So, this is actually 4 constants, so far so we have to make 2 more constants, well later we will see and this is a your delta delta right. So, this is that your complete block diagram for all this equation in terms of K 1 K 2 K 3 K 4, I think this is understandable to you. This is 271, so this is a block diagram representation. For a with constant E fd, constant E fd means delta E fd is equal to say here it is 0 that is why it is written right.

So, now we will go to the next page right.

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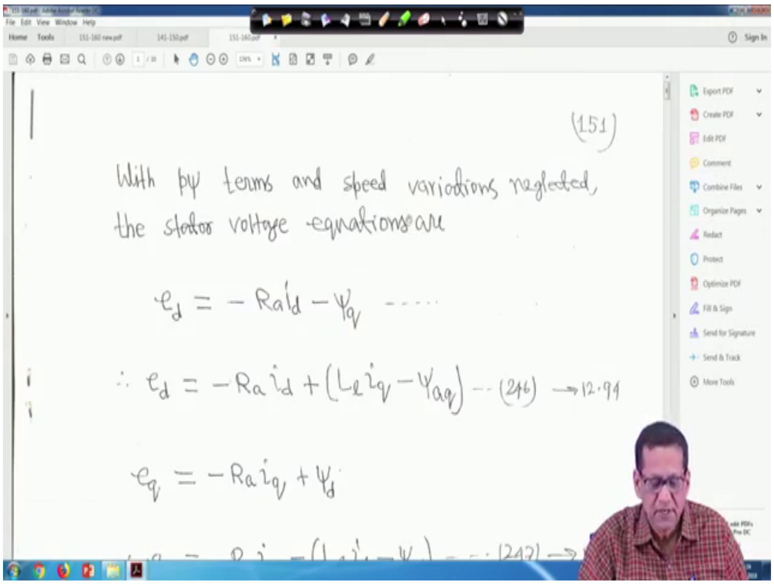

Now with p psi terms and speed variation neglected the stator equations are right. So, now, if you go to the your what you call the stator voltage equations right because, we have to find out 2 more constants K 5 and K 6. So, with p psi terms and speed variation neglected the stator voltage equations are it will become actually, if you go back to the stator voltage equations and there you just make this small exercise you will get e d.

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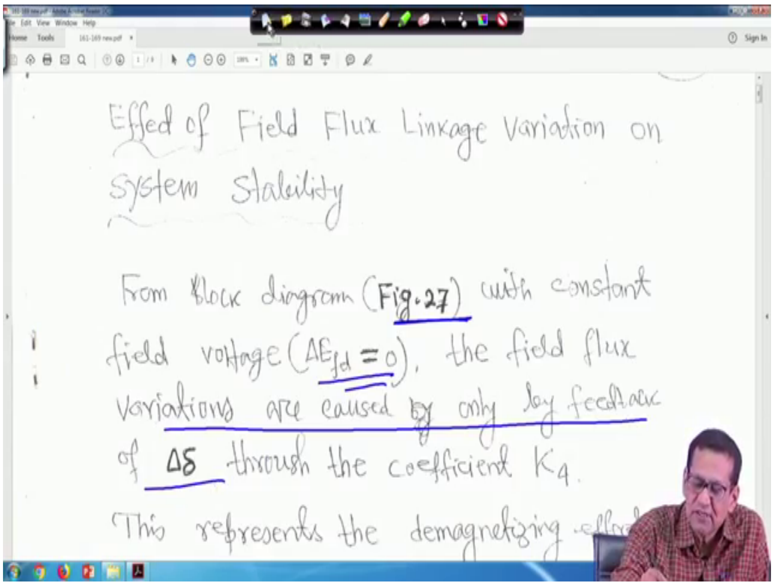

So, effect of field flux linkage variation on system stability. Now from the block diagram that is figure 27, we your constant field voltage that is delta E fd is equal to 0, the field flux variations are caused by your caused only by feedback of delta delta right to the coefficient K 4, just hold on right.

So, this represents the demagnetizing effect of the armature reaction. This is another question to you that why it represent the demagnetizing effect of the armature reaction, this is a question to you.

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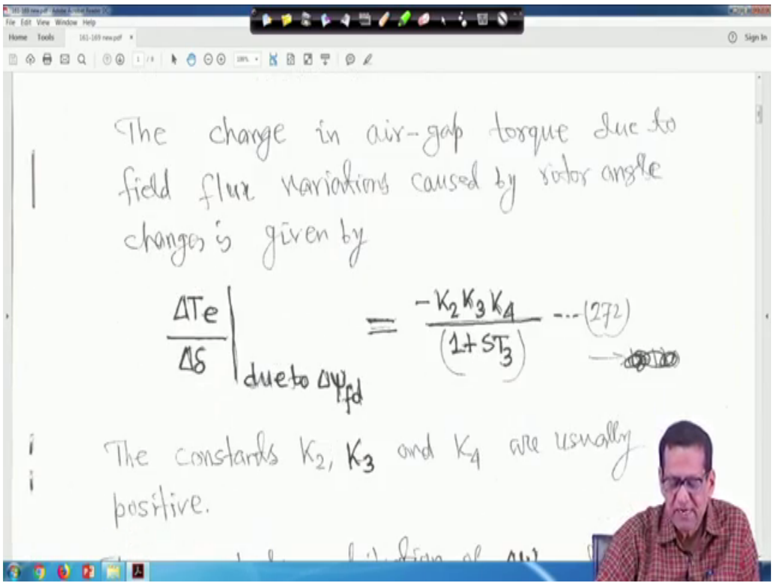

You will put in that answer you put it in the forum right. The change in the air gap torque due to field flux variation caused by rotor angle changes is given by delta T e upon delta delta due to delta psi f d is equal to minus K 2 K 3 K 4 divided by 1 plus S T3 right delta delta delta T e upon delta delta due to delta psi f d. So, let us go to the block diagram.

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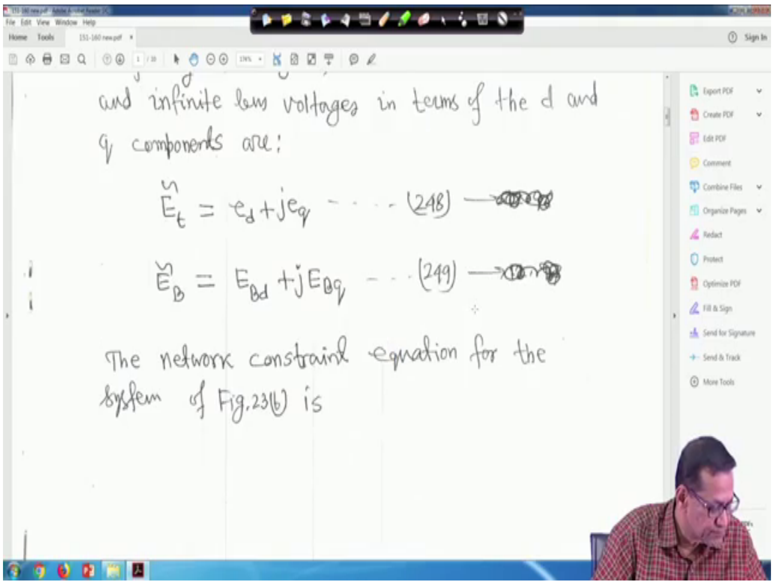

So if you look into that that change in your what you call that your just hold just hold on yes, so change in your delta T e term right, only because of this delta psi f d, how what will be it is basically it will become this delta E fd is 0, delta E fd is 0 because it is constant your this is your constant E fd.

So, delta E fd is 0, so, it will be your minus K 4 delta delta, then K 2 K 3 this is due to your delta psi fd. So, basically it will become whatever we are writing that change in this thing right, it will basically minus K 2 K 3 K 4 right K 2 K 3 K 4 and delta delta because, delta E fd is 0 right divided by 1 plus S T 3, this is the thing it is input to this to this point right.

So, that is why, what and this side if you think, this side it is coming, so K 1 delta delta. So, that is why due to delta psi fd this is minus K 2 K 3 K 4 upon 1 plus S T 3 delta delta is here. So, if it is, so just let me clear it right. So, that is why the delta T e delta delta due to delta psi fd, because there it was given know that particular term was minus K 2 K 3 K 4 delta delta upon 1 plus S T 3.

Therefore, delta T e by delta delta due to delta psi f d only the left hand side of that block it is minus K 2 K 3 K 4 upon 1 plus S T 3, this is equation 272. In general the constant K 2 K 3 K 4 are usually positive. K 2 K 3 K 4 for what you call for realistic values, they are all positive. So, if K 2 K 3 K 4 all are positive means, this term is what you call numerator term will be always negative, right.

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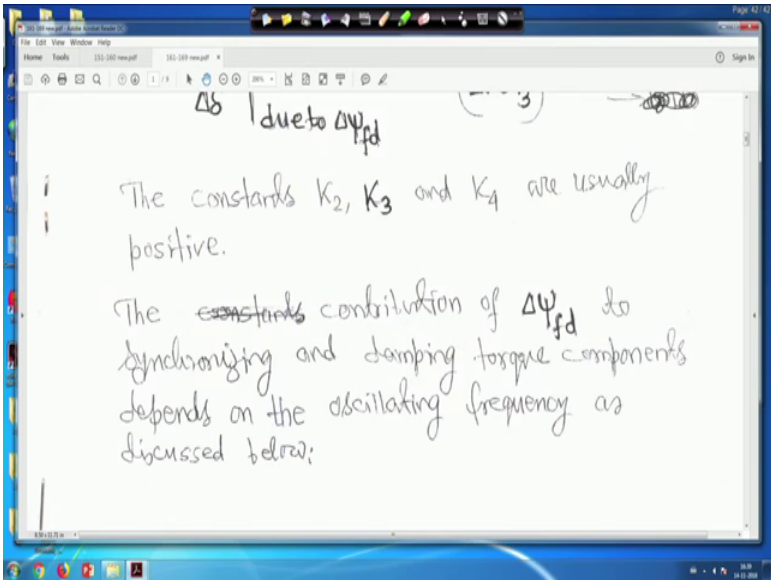

So, the contribution of delta psi fd to synchronizing and damping torque component depends on the oscillating frequencies as discussed below right. It depends you will see for S is equal to j omega then we analyze certain thing.

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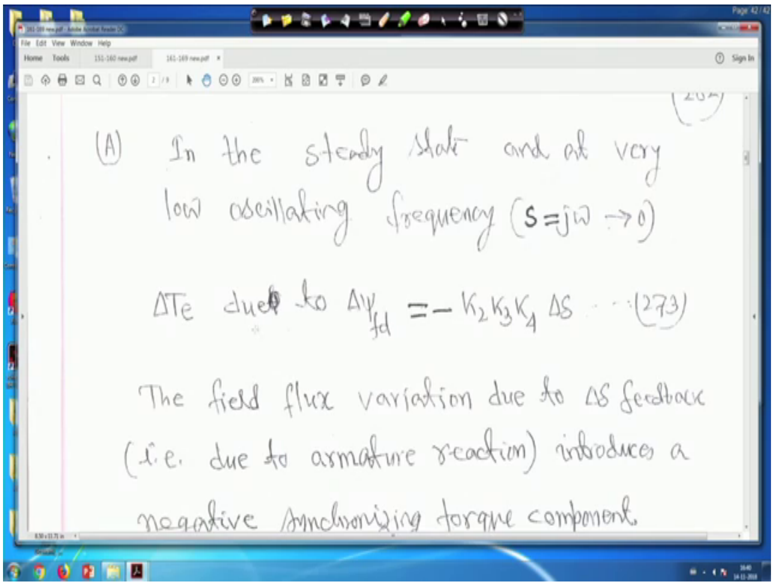

Now, the A first part, in the steady state and at very low oscillation frequency say when omega tends to 0 right, delta T e due to delta psi fd will be minus K 2 K 3 K 4 delta delta, because if omega at a it put here S is equal to j omega and omega tends to 0. So, 1 plus S T 3 term will become one. So, it will be basically minus K 2 K 3 K 4 delta delta right. Therefore, delta T e due to delta psi fd actually just I am making for you it is something like this, that you are we are writing delta over writing on it delta T e by your delta delta due to delta psi fd say is equal to minus K 2 K 3 K 4 divided by 1 plus S T 3 right.

Now S is equal to your j omega and omega for very low frequency omega tends to 0, so this term will become basically minus K 2 K 3 K 4 right. Therefore, we can write delta T e due to delta psi fd will be minus K 2 K 3 K 4 into delta delta; that is why we are writing that delta T e due to delta psi fd is equal to minus K 2 K 3 K 4 delta delta, this is equation 273 right.

Now, next is the field flux variation. Due to delta delta feedback that is due to armature reaction I told you that why it is called. Introduces a negative synchronizing torque component right. So, field flux variation due to delta, because K 2 K 3 K 4 these all the constant that are positive.

So, therefore that coefficient of delta delta is negative right. Therefore, you introduce a negative synchronizing torque component. Now the system becomes monotonically unstable when this exceeds K 1 delta delta the steady state stability limit is reached when K 2 K 3 K 4 is equal to K 1.

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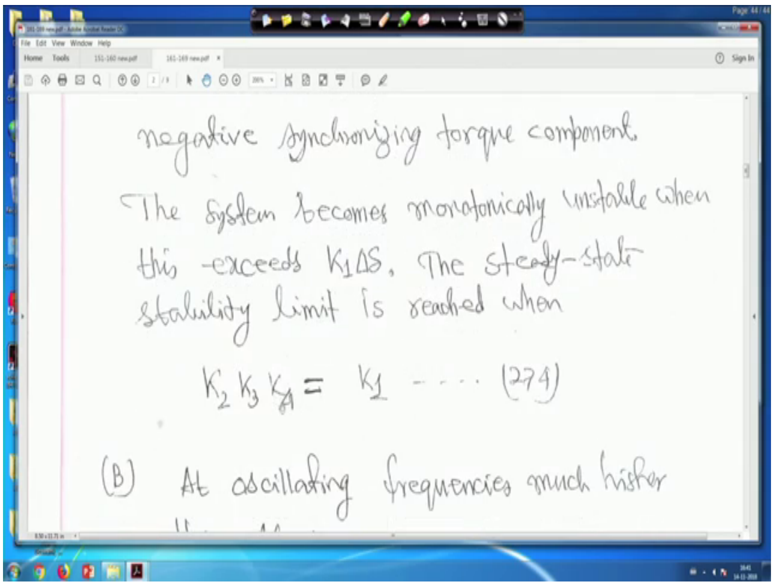

Now again, I have to go back to that your block diagram. Now this is our block diagram. So, in this case at low frequency right when omega tends to 0, that term here whatever it is going that is your minus K 2 just mathematically K 3 K 4 delta delta and from this side it is coming your K 1 delta delta right.

Now, then delta T e will be what it will be basically K 1 minus K 2 K 3 K 4 delta delta right. Therefore, if these term is equal to 0 this term K 1 minus K 2 K 3 K 4 if is equal to 0. Then your K 2 K 3 K 4 is equal to K 1 that is what we are telling when we are taking, S is equal to j omega and when omega tends to 0 right.

So, that is why just; hold on that is why we are making this one that system become monotonically unstable when this exceeds K 1 delta delta. The steady state stability limit is reached if we make K 2 K 3 K 4 is equal to K 1 right. Now part B, at oscillatory frequencies much higher than 1 upon T 3 right.

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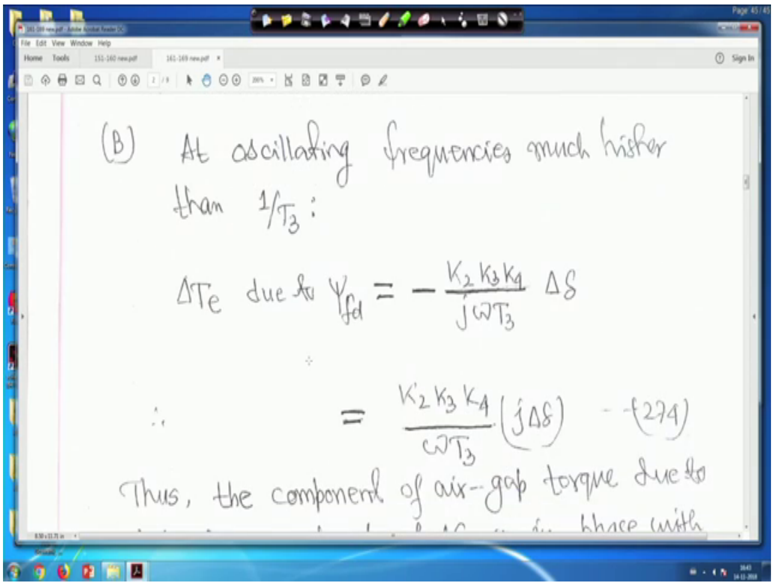

When you take your S is equal to j omega right and omega is much much higher than one upon T 3. That means 1 plus what you call j omega 3 is approximately j omega t 3 right.

So that means, in that time at the time delta T e due to delta psi fd will be minus K 2 K 3 delta delta divided by j omega T3. At that time that oscillating frequency is much higher than one upon T3; that is your omega is much much higher than one upon T3 and S is equal to j omega right. That means, 1 plus S is equal to j omega So, j omega T3 right if approximately equal to your j omega T3 that is what we are written here right.

So, in the and that one can be written as you numerator and denominator you multiply by j. So, it will become j square, so minus minus minus plus. So, basically we are writing K 2 K 3 K 4 upon omega at T3 j and j delta delta right now here, just hold on.

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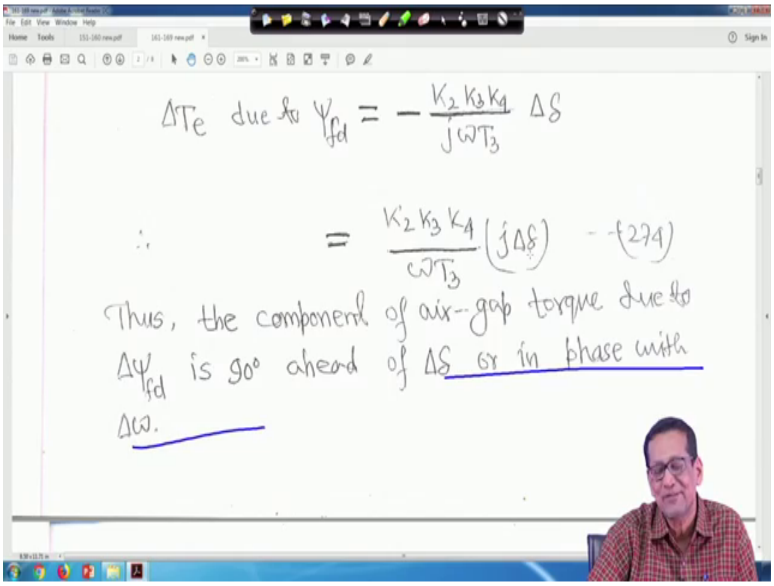

So, here the delta T e due to delta psi fd actually K 2 K 3 K 4 upon omega at T3 j delta thus the component of air gap torque due to delta psi fd is 90 degree ahead of delta delta or in phase with delta omega. This one again I am putting a question to you that it is given j delta delta. So, you just a just a hint I am giving that bring j delta delta in term. So, if you look into that that K 2 K 3 K 4 j delta delta, but torque is a function of your delta delta, but 1 j term is there.

So, thus the component of air gap torque due to delta psi fd is 90 degree ahead of delta delta or in phase with delta omega. So, this is a question to you, you have to bring it j delta delta terms in terms of delta omega. How to do this? Everything is there in block diagram, just you do this. That is why I call or in phase with delta omega; that means, j delta delta term will become in terms of delta omega also and that time we call it is in phase; otherwise we call 90 degree out of phase. So, this is a small question to you. And just give the reason when you listen to the lecture in the forum right.

So, actually this one is small derivation is there 3 4 lines at not 3 4 lines when two lines you can make it right.

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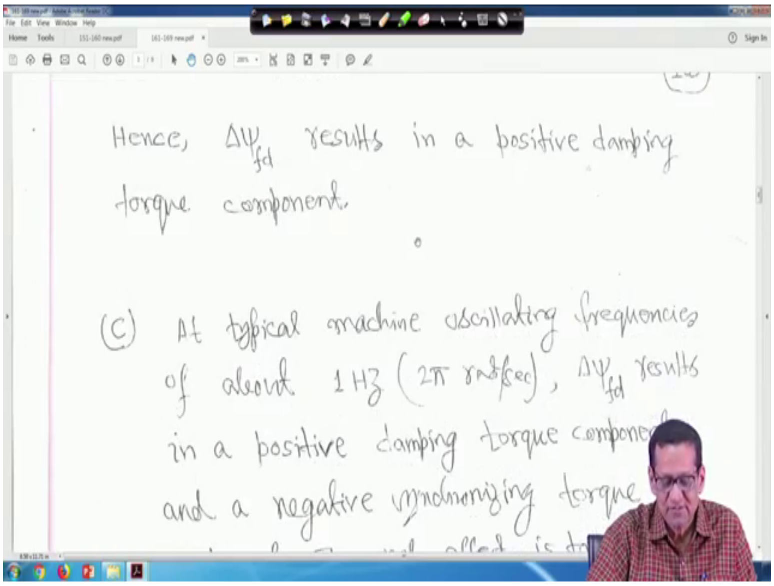

Hence, delta psi fd result in a what you call in a positive damping torque component. Just I will go there. So, therefore because K 2 K 3 K 4 all are these positive omega is positive T3 it is positive. So, it is producing basically giving a positive damping torque right. So, now at third point the C, at typical machine oscillating frequencies of about say: 1 hertz that is 2 pi radian per second delta psi fd results in a positive damping torque component and a negative synchronizing torque component right.

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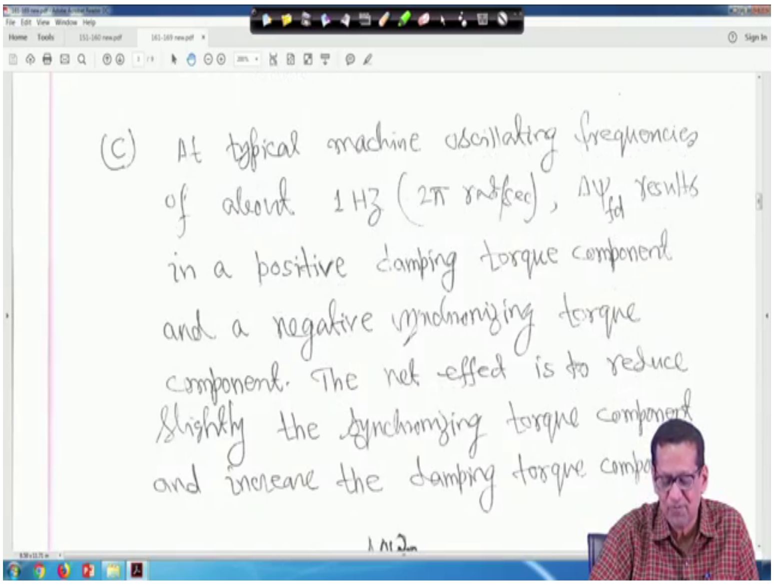

So, the net effect is to reduce slightly the synchronising torque component and increase the damping torque component.

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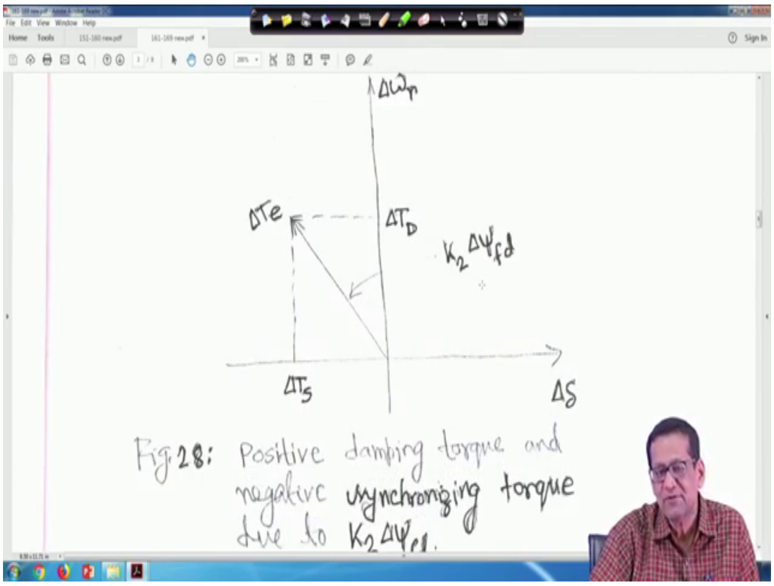

Now if we make like this, this is my delta delta and x axis y axis is delta omega r and this is delta T e right.

So, this is delta T e is the synchronising torque component it is, so negative and delta this is actually K 2 delta psi fd that delta psi fd right. That is your due to the your what you call that K 2 your delta psi f d that field flux changes right. So, this is your delta T D. So, this is actually positive damping torque delta T D and negative synchronizing torque due to K 2 delta psi fd right and this is your what you call the representation.

So, next stage I hope this is understandable, but 1 or 2 questions I have put right, that one is that your torque is in phase with a delta T e that due to delta psi fd is in phase with your delta omega or 90 leading 90 degree that delta delta that is j delta delta right.

So, effect of now excitation system. So, far we have seen your how many constant we have seen that your K K 2 K 3 K 4 right.

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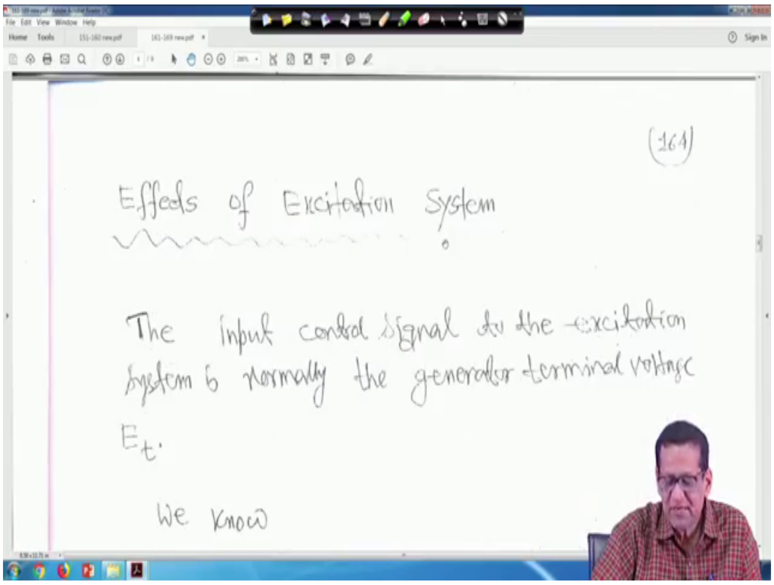

So, next we will see that, effect of excitation system. The input control signal to the excitation system is normal if the general terminal voltage E t. And we know that E t tilde is equal to e d plus j e q, this we have seen again and again. Therefore, magnitude if you take magnitude also E t square is equal to e d square plus e q square.

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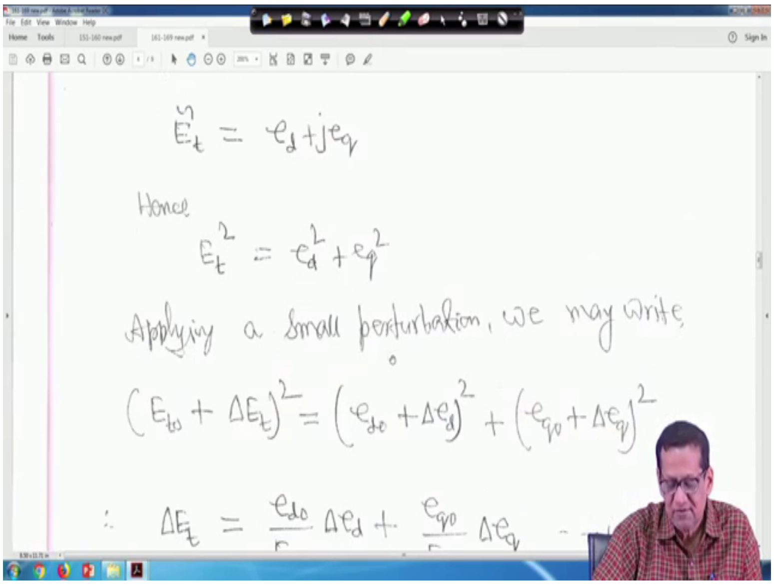

Now, analysis of small perturbation we may write this equation that I mean I mean it is something like this, I mean when you take small perturbation say initial value was there, so, E t is equal to say E t 0 plus delta E t right.

Similarly your e d is equal to e d 0 plus delta ed; similarly eq is equal to eq 0 plus delta eq, that is here and here we have substituted it. Now what you do you square it and simplify, but as your small perturbations term square neglected. That means, these terms have been neglected, delta E t square, it is very small neglected, then delta E t square also neglected and delta eq square also neglected right, these terms have been neglected.

And you simplify then you will get this thing, you will get delta E t is equal to e d 0 upon E t 0 delta e d plus e q 0 upon E t 0 delta e q. This is equation 275.

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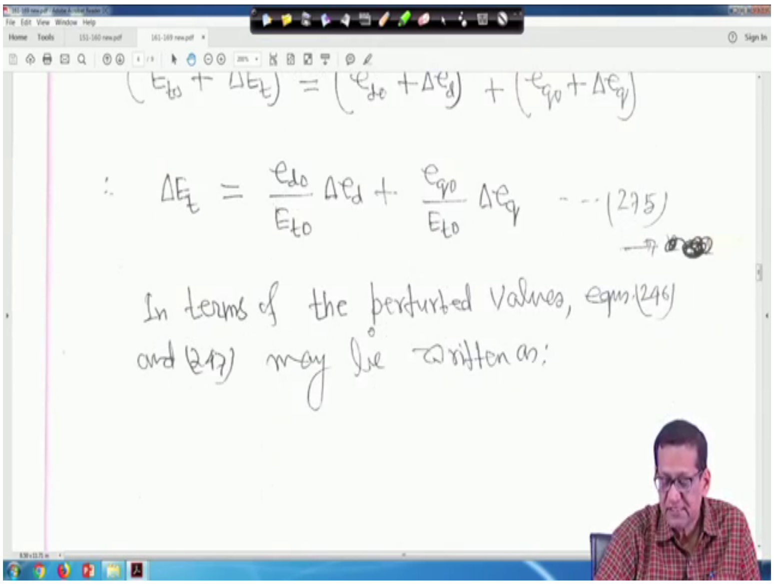

Where, in terms of perturbed value equation 246 and 247 may be written as.

So, I suggest you go to equation 246 and 247 and just take the small perturbation values look. Now it is 275. And again I am not going back, but this notes will be available just you open this equation and take the small perturbation, I am writing the final one.

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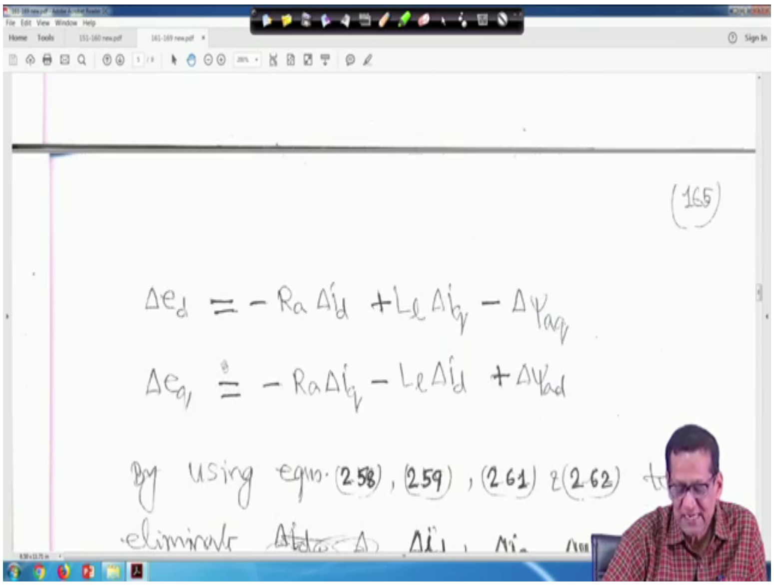

Therefore delta ed will become minus Ra delta id plus Ll delta iq minus delta psi aq right. Similarly delta eq will become minus Ra delta iq minus Ll delta id plus delta psi ad right.

So, by using equation 258, 259, 261 and 262 to eliminate delta id, delta iq, delta psi ad and delta psi aq from the above equations in terms of the state variables and substitution of the resulting expression for delta ed and delta eq in equation 275 here right.

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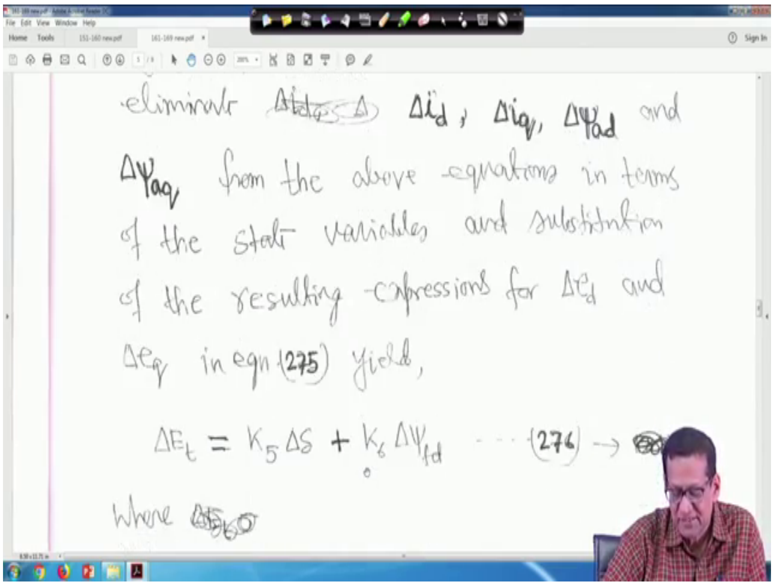

So, basically you will get delta E t you will get in K 5 delta delta plus K 6 delta psi fd. That means, this delta E t expression is there right, but we are trying to find out the delta E t term into K 5 into delta delta and delta psi fd. So, 2 more constants have been introduced K 5 and K 6. So, but here to I suggest you do it ones, the why it has been say it has been means given here right.

So, delta E t you have to by in terms of delta delta and you are what you call delta ed right psi fd right. So, what you have to do? Use equation 250 8 258 to 262 to eliminate delta psi id delta psi iq delta psi ad and delta psi aq and from the above equation in terms of the state variables and substitution of the result of expression for delta ed and delta eq in equation 275. This we will give you K 5 delta delta plus K 6 delta psi fd.

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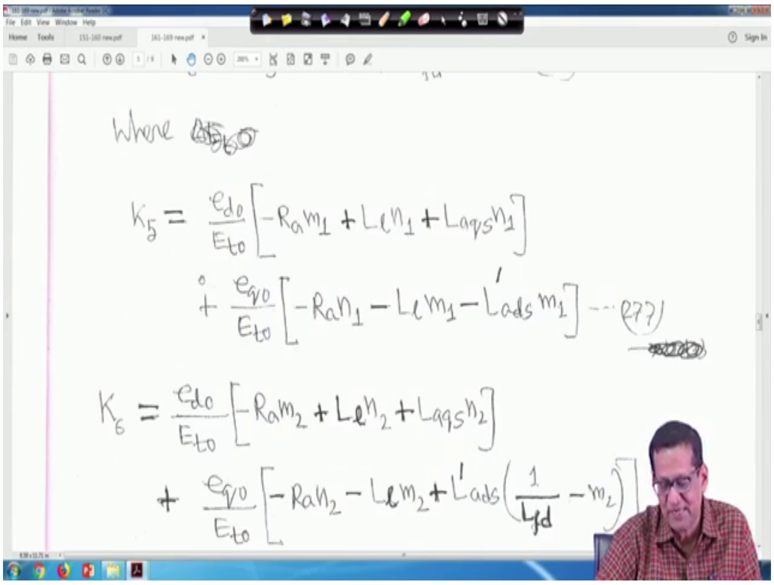

You know expression for K5 is given here. So, it is ed 0 upon E t 0 minus Ra m 1 plus Ll n 1 plus laqs n 1 bracket close plus eq 0 upon E t 0 in bracket minus Ra n 1 minus L l m 1 minus L a d s same the L a d s m dash L a d s dash m 1. This is equation 277, if we simplify and do this you will get this is the expression for K 5. Similarly for K 6 you will get is equal to ed 0 upon E t 0 in bracket into minus Ra m 2 plus L l n 2 plus L a q s n 2 right plus eq 0 upon E t 0 in bracket minus Ra n 2 minus L l m 2 plus L a d s dash in bracket, again one upon L f d minus m 2 bracket close and bracket close, this is equation 278.

This expressions you need not remember you need not remember, K 1 for K 6 if anything is there all data will be supplied but I suggest you just derive once right just you derive once.

So, this is actually equation 278.

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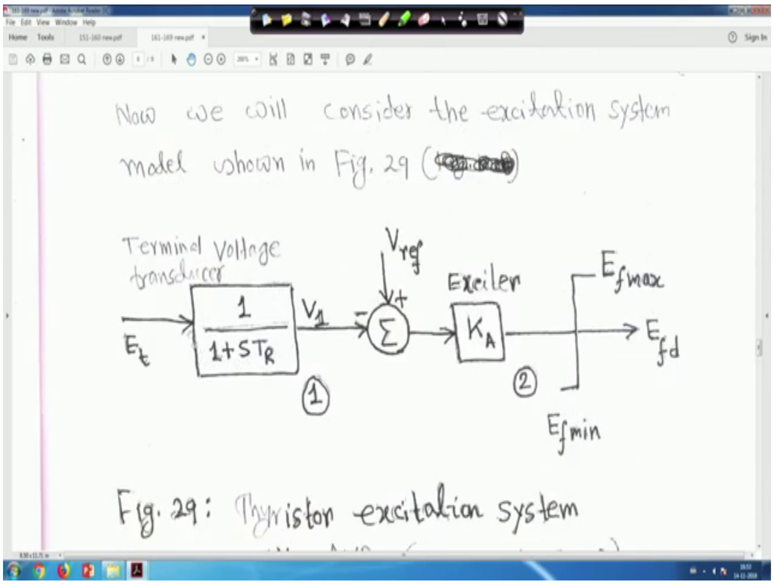

Now, we will consider the excitation system model shown in figure this thing. This is K 5 K 6 we have made delta E t, but that will be added in the block diagram, but before that after that we will take a excitation system. Now we will consider that excitations you have model shown in figure 26 right, here you have at a terminal voltage transducer is that input to these is E t and its time constant is the T suffix capital R; that is 1 upon 1 plus STR output is say V1 and this is a reference set point reference voltage and this is V1 and exciter is there, we are taking just gain only right, you are what you call you have taken IEEE type ST1 A exciter and just represented by gain different type of exciters are there, if time permits then I will cover right.

And then output in field voltage efd, but it has a limiting value of Ef max, but Ef min, but for this course those limiting thing and simulation we have no time to do that right, we have to only think about the classroom exercise. So, this is exciter and this that; that means, you are in general efd will be actually is equal to V1, sorry V reference minus V1 into K A is equal to e fd and V1 is equal to your E t upon 1 plus STR right and TR is the time constant of the terminal voltage transducer, which basically TR is very small right.

So, this is thyristor excitation system with automatic voltage regulator right and this is IEEE type ST1A excitation system only we have consider the gain KA of the exciter right. Now parameter TR represent the terminal voltage transducer time constant.

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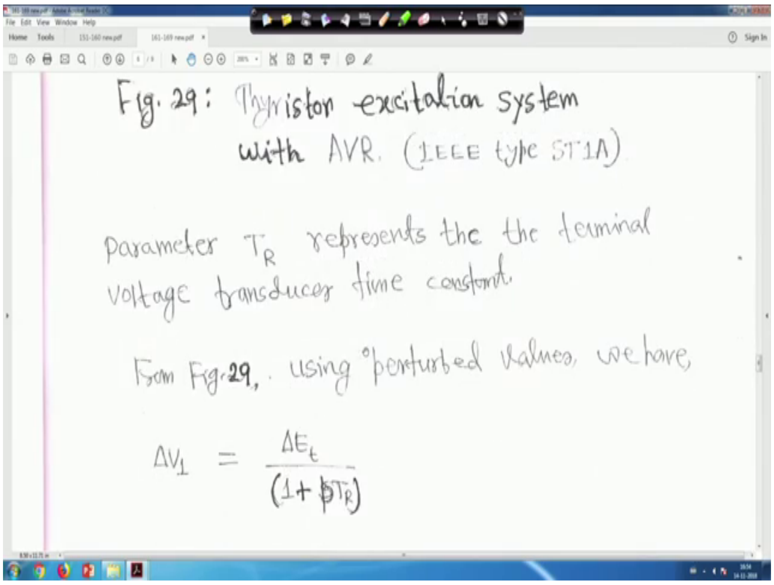

Now from figure29: from this figure, you can write the delta V1 is equal to delta E t upon 1 plus STR because, V1 is equal to E t upon 1 plus STR we are making it p, p and S same actually right; that is p is equal to your d by dt is equal to S.

So, there is no confusion at all right. So, delta V1 is equal to delta E t upon your 1 plus pTR right. So, using this perturbed value because V1 is equal to E t upon 1 plus STR, so delta V1 is equal to delta E t upon 1 plus STR or you can write that p delta V1 is equal to 1 upon tr delta E t minus delta V1 right.

Now, question is that we got the expression of delta E t that is K 5 delta delta plus K 6 delta psi fd.

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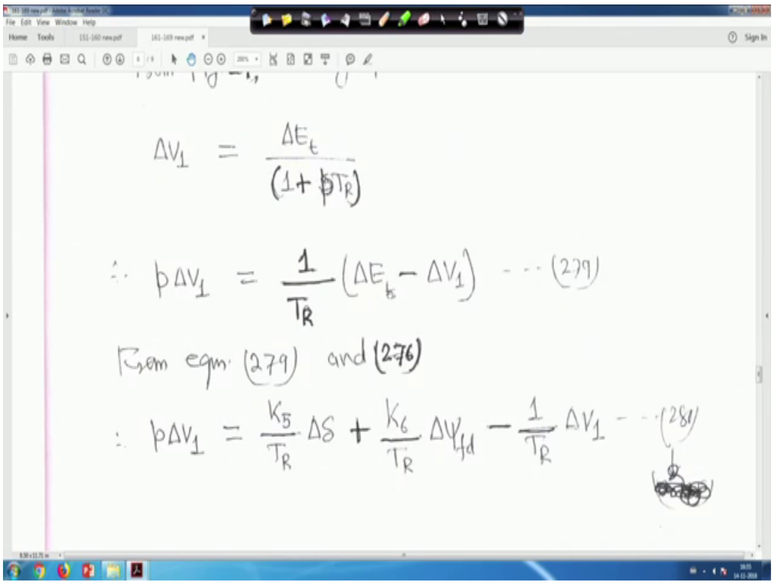

So, you substitute that expression that is from equation 279 and 276 at 276 delta E t is given; that is your K 5 delta delta plus K 6 delta psi fd and you just simplify it will be p delta V1 will become K 5 upon TR delta delta plus K 6 upon Tr delta psi fd minus 1 upon TR delta V1. This is equation 280.

Now, next is you come to come back to this equation right. Now efd I mean if you make it like this that from the; forget about that min max limiting value. In general if you write that your efd is equal to your V reference minus V1 right, minus V1 into that KA. Now if you take the small perturbation thing then it will become delta efd is equal to K A, then delta V reference minus delta V1 right.

So, this is delta efd. Therefore, this thing will use in the next your equation right.

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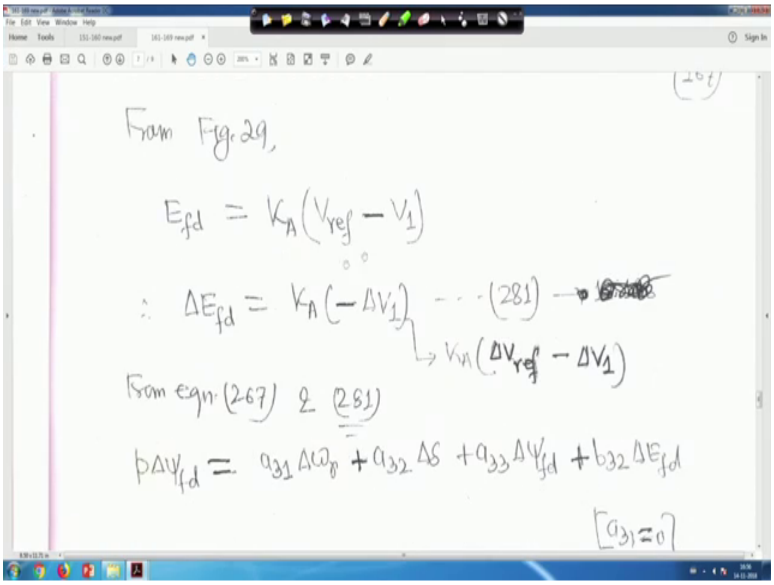

So therefore, from figure 29, I wrote this one delta V reference is not 0, so this 1 you should not consider. Delta efd is equal to your K A into delta V reference minus delta V1; whatever write this is actually equation 281 right because we are not setting delta V reference 0, if delta V reference 0 then this is true. But this is not require, it is actually K A delta V reference minus delta V1 right.

Therefore, from equation 267 and this equation is 281 use what you do? You substitute in that right 267; that is the third equation for your delta psi delta psi fd. This is a third equation and go back to the matrix of 267, these are third equation at there you will I have written a 31, but actually a 31 is equal to 0 right. So, see that matrix actually you will see a 31 is equal to 0, where here also I have written a 31 is equal to 0 right.

And if you substitute this thing, you will get in this form; that is your p delta psi fd is equal to a3 delta omega r plus a 32 delta delta plus a 33 delta psi fd plus b 3 2 delta efd, but a 31 is 0 right or if you write that a 31 delta omega r plus a 32 delta delta plus a 33 delta psi fd plus a 34 V1 plus b 2 V reference right, because from here delta efd is equal to K A into V reference minus delta V1. So, you replace delta efd, this delta efd right, and you will get in this form this is equation 282, where a 34 is equal to minus b32 into K A is equal to minus omega 0 Rfd upon L a d u into K A. This is equation 283.

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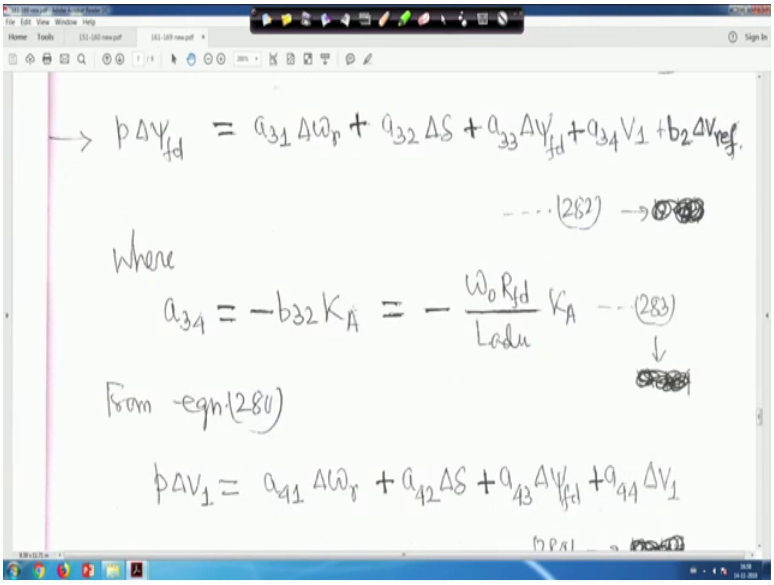

And from equation your 280 right, you will get that you are I mean from this equation from these equation p delta V1 equation from equation 280 right, you will get that p delta V1 is equal to a 41 delta omega r plus a 42 delta delta plus a 43 delta psi fd plus a 44 delta V1 but there is no omega r term in that. That is why a 41 is 0.

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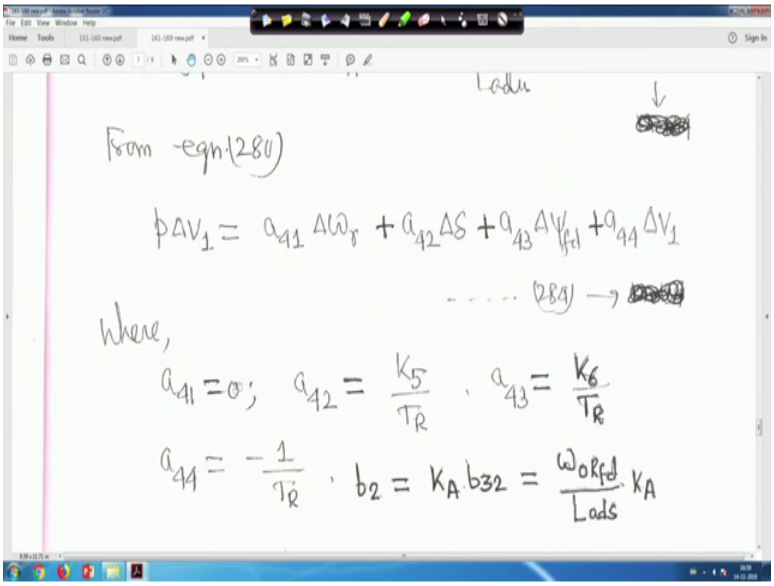

That is why here it is written a 41is 0, a 42 is K 5 upon TR a 43 is equal to K 6 upon TR right, A4 is equal to minus 1 upon TR, b2 is equal to K A into b32 is equal to omega 0

Rfd upon L a d S and into K A. Just you put all these things, because each and every thing if I write and all these things it will consume more time.

So, little bit you make it right, there is no need to remember all these things, but you make it what you call yourself you do it, I am giving you the final one right; otherwise it will consume lot of time right. So now, complete steady state space model for the power system including the excitation system has the following form.

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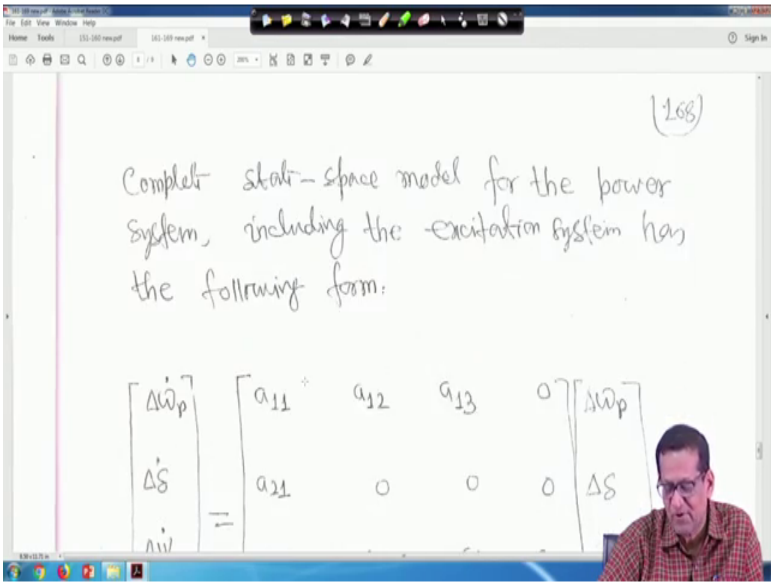

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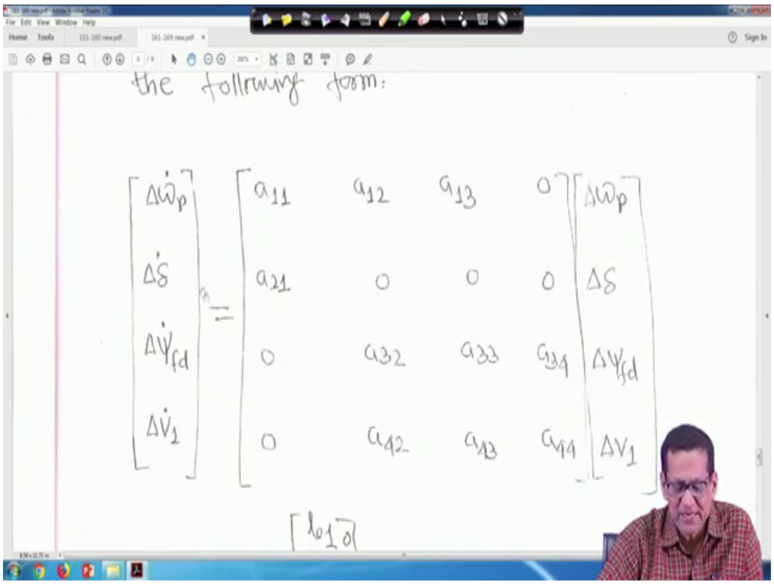

So, if you write it is now 4 into 4. We will come here only 4 into 4, not more than that.

So, one is delta omega dot, for steady variable delta delta dot, delta psi fd dot, delta beyond dot, this is your a matrix, all elements are given, delta omega r into delta delta delta psi fd delta V1 plus your b 1 0 0 0 0 b 2 0 0 delta tm delta V reference.

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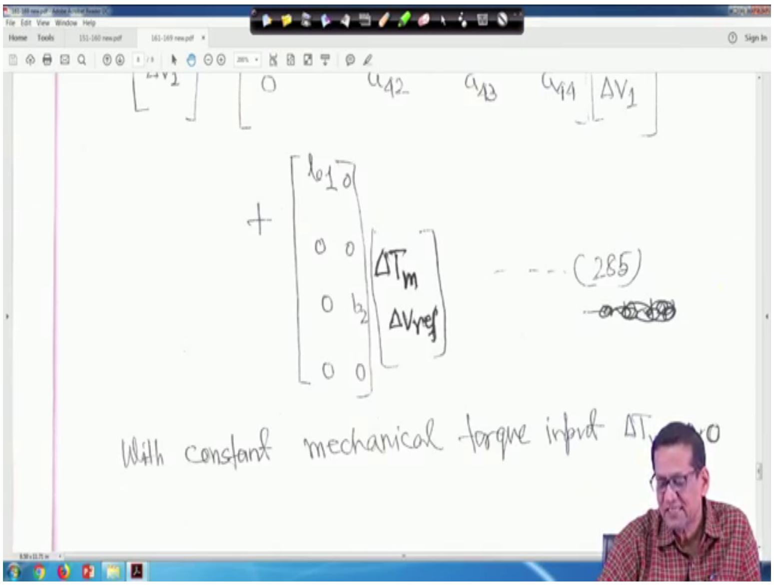

This is equation 285. Now with constant mechanical torque input delta tm actually will become 0.

With this, thank you very much we will be back again.