**Power System Dynamics, Control and Monitoring**
**Prof. Debapriya Das**
**Department of Electrical Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 19**
**Power System stability (Contd.)**

So, we will come back again.

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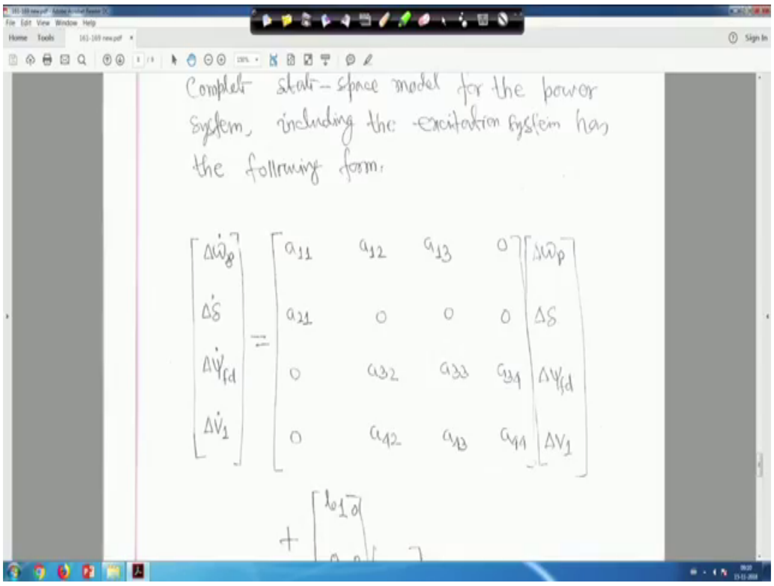


So, in the previous lecture we have finished here that your 4 state variables are there, that delta omega r, delta delta, delta psi f d and delta V 1. So, it is actually x dot is equal to x plus b u form.

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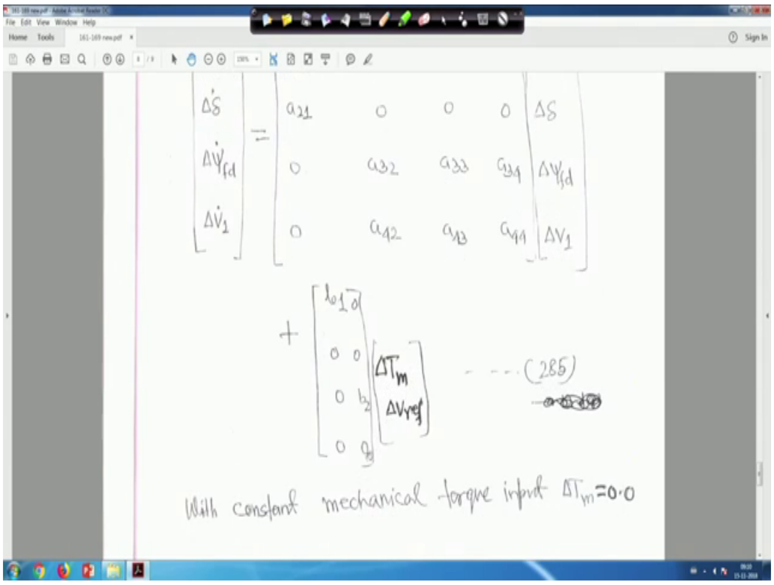


And if you are mechanical torque input is constant then naturally delta t m will be is equal to 0.

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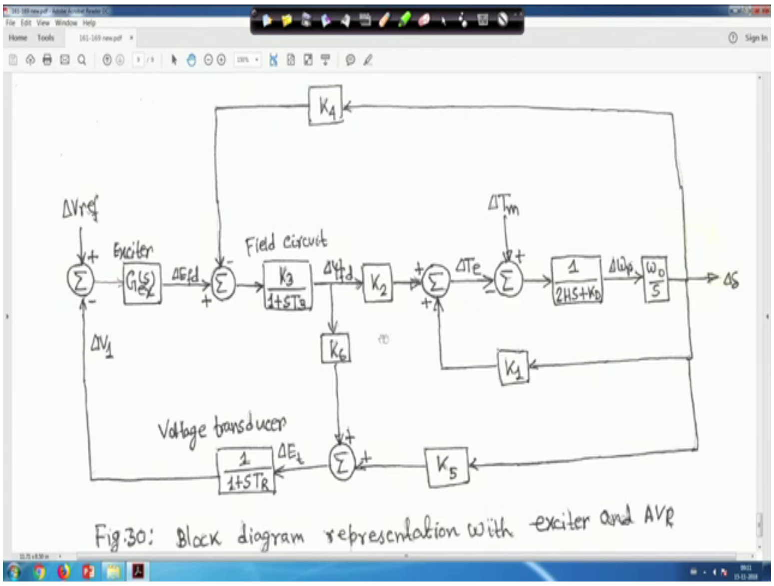


And this is the block diagram we have already shown there, that here we have all the six constant that K 1, K 2, K 3, K 4 and K 5 K 6 right and this is the exciter and will simply represented by gain, but that different type of exciters are available, in that case it can be represented by different type of transfer function, but for the classroom purpose will not considered that will take a simple gain. And similarly for voltage transducer this is one upon 1 plus STR that later we will see that T R actually very small, so we will neglect this T R.

So, simply we will take a your what you call a simply that delta E t delta V 1 will be is equal to actually delta E t. In this sense that if T R is neglected will be back again for these transfer function, but before going to this thing before coming again. So we will go to the next one.

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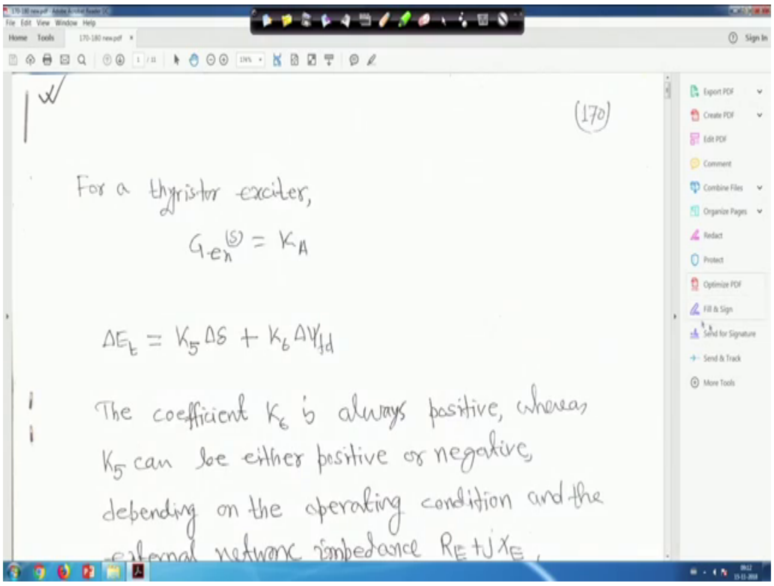


So, for thyristor exciter system that we will simply represented Gex that it is actually Laplace transform, but we will take a simple gain right. And we will not considered the different version of exciters are there then things will become a little bit complicated right.

So, we have seen that delta E t is equal to K 5 delta delta plus K 6 delta psi fd that we have already derived right. Therefore, the coefficient K 6 is always positive. So, earlier I told you k t, K 2, K 3, K 4 always positive and K 6 is also positive and K 5 may be negative may be positive right whereas, K 5 can be either positive or negative depending on the system operating condition right and the external network impedance that is re plus JXE.

Now, next is effect of AVR; that is automatic voltage regulator we call, on synchronizing and damping torque components right.

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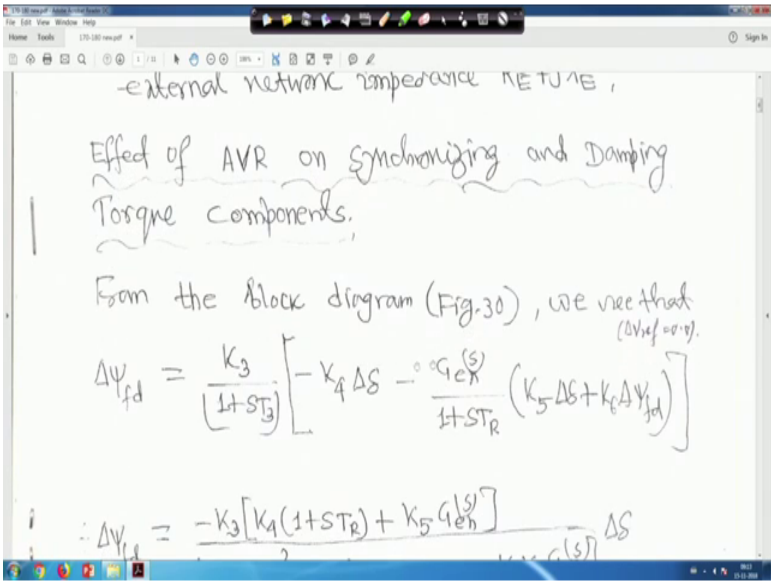


So, from the block diagram that is figure 30, we see that if we make delta V reference is equal to 0. So, I will go back to figure 30 right. So, this is just hold on, let me go down this is figure 30. So, here that we will take say for example, if delta V reference is set is equal to 0. And if we neglect your what you call that T R then what will happen that input to this that input to this here it is K 6 delta psi fd and K 5 delta delta.

So, here already we have seen that this is T R actually is neglected; say it is 0 right. Then it will be input to this delta V 1 will be that we have made it K 5 delta delta plus your K 6 your from here it is coming. So, delta psi f d right and that is equal to delta V 1 is equal to your delta E t, if it is neglected right. And if you assume that delta V reference is equal to 0 then here it will be minus and this gain is actually K A right.

So, it will be minus K into this term right and from here it is coming K A this point it is coming K 4 delta delta right, it is minus. So, it will be basically if you look into that, it will be minus K A right into your K 5 delta delta plus K 6 delta fd bracket close. Then again minus K 4 delta delta into K 3 upon 1 plus st 3 is equal to delta psi fd; I mean I mean this term delta psi fd.

So, if you look into that that delta psi fd for this case, how it will look like? It will be K 3 upon 1 plus ST 3 this thing right, in bracket what it will come that it will be your minus is your minus is here because this delta reference is zero. So, here it will come minus K A then these 2 term right; that is your K K 5 delta delta K 5 delta delta plus K 6 delta psi fd right, because psi fd is coming from here, then again it is your what you call the bracket close, then again minus K 4 your delta delta because, it is coming here right K 4 delta delta then bracket close is equal to your delta psi fd right.

And this is actually this torque this torque delta T e has 2 component; 1 to 1 is 1 is due to delta psi fd then further that K 2 should be multiplied with delta psi fd, that is the whole thing right. And another one is coming from here that is K 1 delta delta right. I hope it is understandable to you because you have all of you have studied that control system in third year and block diagram same thing here right.

So, we will go back to this thing what you call that so that is why you are that is why you are writing the same thing that from the block diagram figure 30. We see that delta psi fd whatever I wrote there that is your K 3 upon 1 plus S T 3 in bracket minus K 4 delta delta minus Gex S means this value actually is equal to K a right divided by 1 plus STR K 5 delta delta plus K 6 delta psi fd, but there whenever I am writing this, I neglected T R.

Later we will see that we neglect TR, but here I have retained it right. So, because T R is very small as compared to other time constant right, but here I have written that KA upon 1 plus STR that is Gex S right. So now, upon simplification if you simplify this, so it will become minus K 3 K 4 in you are in bracket 1 plus STR plus K 5 Gex S and in denominator T 3 T R S square plus T 3 plus TRS plus 1 plus K 3 K 6 Gex S delta right.

So now, T R is not neglected till now right.

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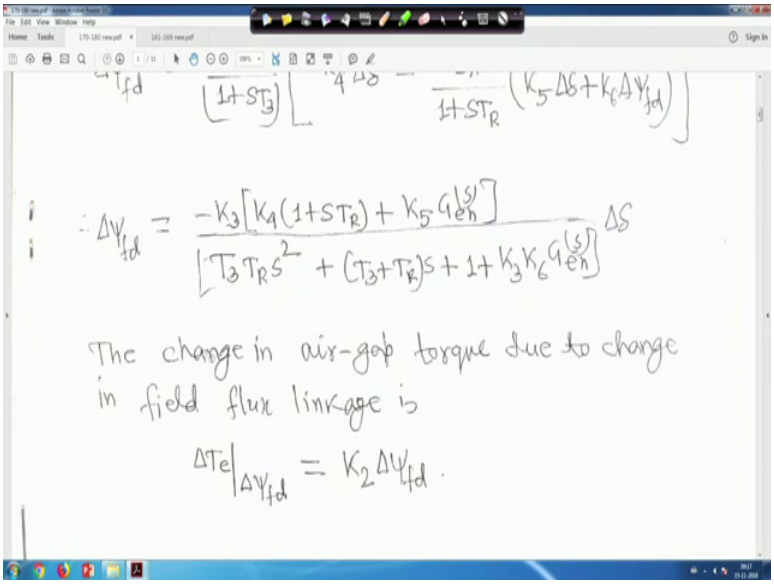


The change in air gap torque due to change in field flux linkage there is delta T e due to delta psi fd will be KT into delta psi fd because, that if you go back to the figure 30 there will see that your delta psi fd K 2 delta psi fd, and this side it is coming K 1 delta delta, that is delta T e. So, delta T e has 2 part; one is K 2 delta psi fd, another is your that is K 1 delta delta right.

So, this is actually your the air gap torque due to change in field flux linkage that is delta T e and when I put in delta psi fd that is your due to delta psi fd is equal to K 2 delta psi fd. So, this term should be multiplied by K 2; I mean this term, this term should be multiplied by K 2. If you multiplied by K 2, it will be minus your K 2 K 3 the whole thing right.

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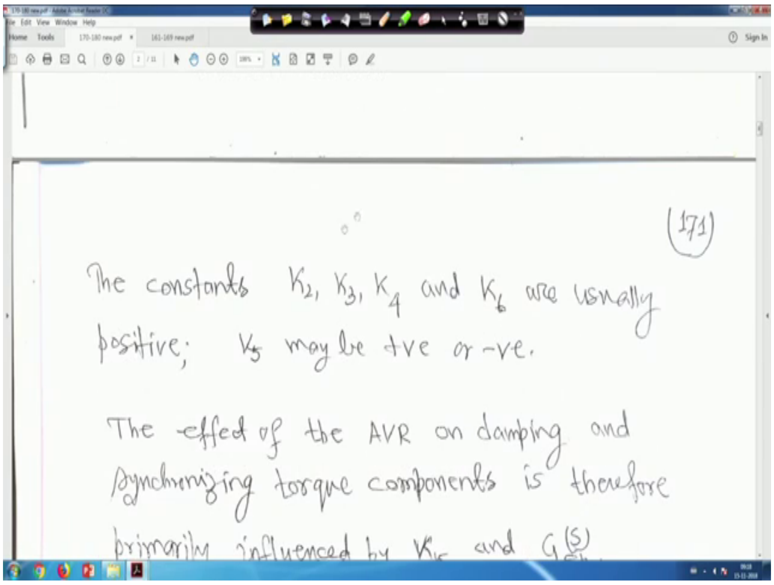


So, therefore, the constant K 2 K 3 K 4 and K 6 are usually positive. Actually K 3 will remain constant for for a system and K 5 may be positive or may be negative right. The effect of the AVR on damping and synchronising torque components is therefore primarily influenced by K K 5 and the Gex S. That is the transfer excitor transfer function, but here we will simply represent it by a gain right for the easy analysis.

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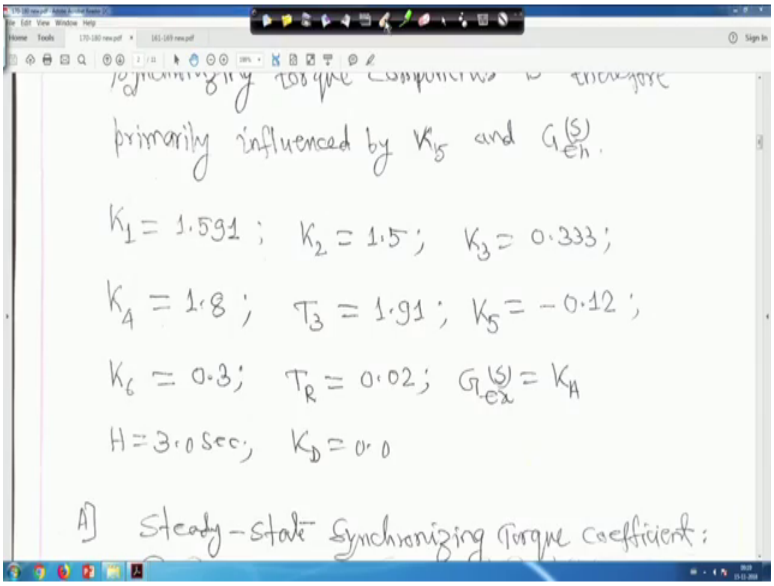


Now, suppose following parameters are given for the system suppose, following parameters are given say K 1 is equal to 1.591, K 2 is 1.5, K 3 is 0.333, K 4 1.8, T 3 1.91

and K 5 minus 0.12 K 6 0.3 and for this case we have we have not neglected T R, for this case we have taken T R is equal to 0.02 second right. Compared to T3, the T R is actually very small we can neglect it, but for the time being we have retained it we not neglected, but later we neglect it right.

And Gex S we have taken again KA. H is equal to we have taken 3 second and damping damping your coefficient KD, we have taken say 0. Suppose these are the parameters are given for some analysis right. So, with this parameter now part A, it is a first part that is your steady state synchronizing torque coefficient.

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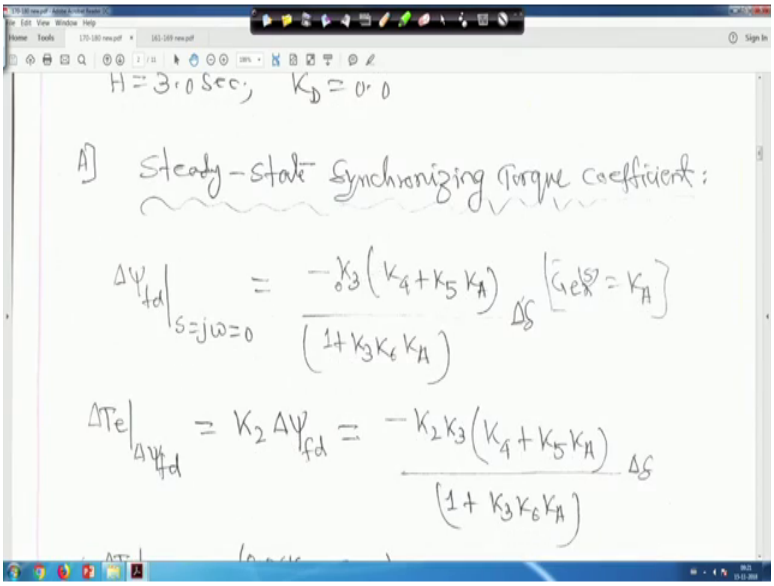


Now, when you make delta psi fd that S j omega, omega tends to 0 then this will become minus K 3 K 4 is minus K 3 into bracket K 4 plus K 5 KA divided by 1 plus K 3 K 6 KA into delta delta when omega is equal to 0. Now in this case, this is what you call delta psi fd. So, in this case here, here delta psi fd if you make your S is equal to j omega and omega tend to 0, then in this case it will become minus when Gex is equal to A, so it will become minus K 3 K 4 minus K 3 K 5 KA right, because Gex is equal to KA; divided by this term will go, this term will go and it will be 1 plus K 3 K 6 KA into that delta delta right.

So, here same thing when we substitute all these will getting minus K 3 in bracket K 4 plus K 5 KA right, and because Gex is equal to KA divided by 1 plus K 3 K 6 KA your delta delta.

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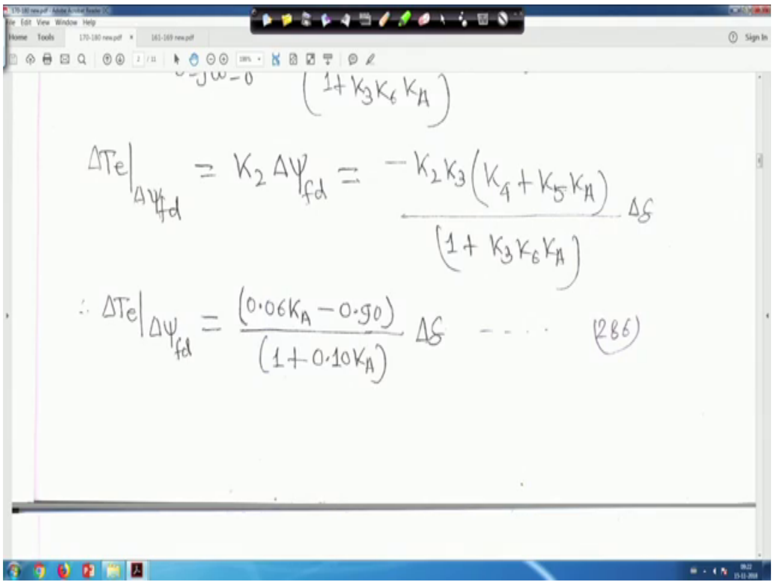

Now therefore Delta T e that component of delta T e due to delta psi fd because in that block 2, 2 terms are there; delta T e is equal to your KA, your what you call that K 2 delta psi fd plus K 1 delta delta. We are considering only that component due to delta psi fd.

So, delta T e due to delta psi fd is equal to K 2 into delta psi fd. So, multiply by K 2 this delta psi fd for omega equal to 0, so it will be minus K 2 K 3 in bracket K 4 k plus K 5 KA divided by 1 plus K 3 K 6 KA into delta delta right. Now all these parameters are given, some parameters we have taken here, some parameters what you do all these available parameters you put in this equation K 2 value, K 3 value, K 4 K 5 and KA we are we do not know right, KA we are not putting, but 1 plus K 3 K 6 KA because here if you look into that KD is equal to given 0 and Gex is equal to KA, we will see the variation of KA right.

So, if you substitute then delta T e due component due to delta delta psi fd, one will get 0.06 six KA minus 0.9 divided by 1 plus 0.10 KA into delta delta. This is equation 286; that means, this function is also in terms of delta delta right. Now and but this is function of KA. So, KA is a variable that is exciter gain Gex say S, we are not considering that transfer function for exciter. So, then things will become little bit complicated and not possible to do anything on the as a classroom exercise, it will create your it will take a long time right.

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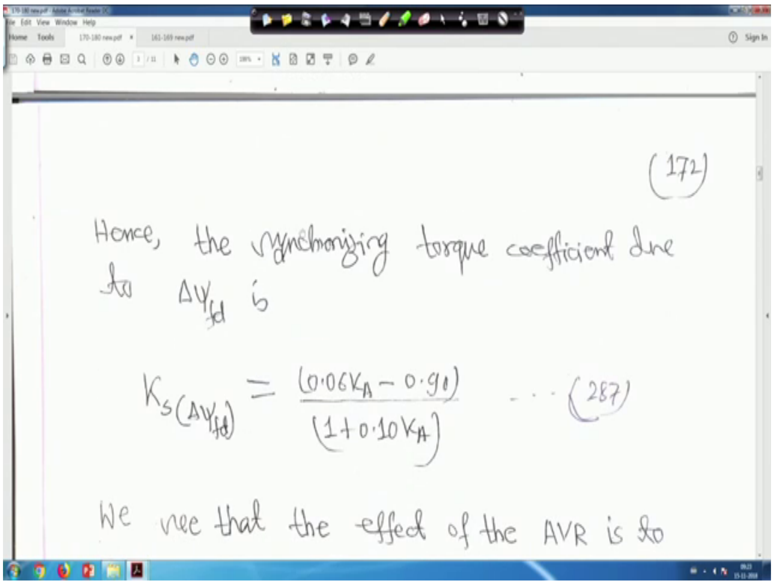


Now, hence the, synchronizing torque coefficient due to delta psi fd is that is K S delta psi fd will be 0.06 KA minus 0.9 upon 1 plus 0.1 0 KA you see. So, this actually this one this is that coefficient of this delta delta this term delta delta. It is basically the synchronizing torque coefficient because this is function of delta delta. So, this is your synchronizing torque coefficient which is function of KA. So, synchronizing torque coefficient value, it depends on the exciter gain KA right.

So, that means, just hold on, so that that means, your this K S we are writing that synchronizing torque coefficient in bracket, we are writing 0.9 upon 1 plus 0.10 KA. This is actually equation 287. So, we see that the effect of the AVR is to increase the synchronizing torque component at steady state right.

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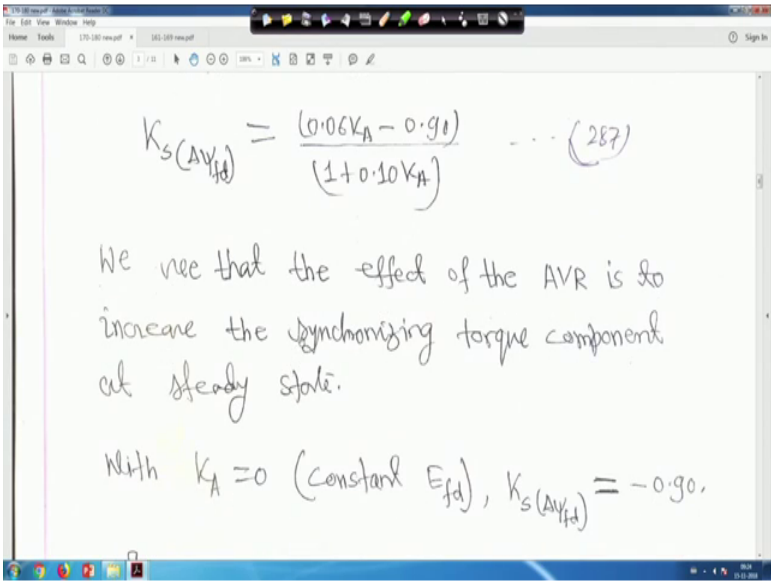


So, this is actually from that you can make it. Now, now you let us see with KA is equal to 0, if KA is equal to 0 means constant E fd right because exciter gain is a 0 that we know nothing is there. So, in that case constant E fd means actually delta E fd is 0. So, there will be no effect for that what you call for your exciter. So, when KA is equal to 0 if you put KA is equal to 0 here, then K Sdelta psi f d you will get simply minus 0.9 right, when KA is equal to 0.

So, this is actually simply you will get minus 0.9. Now if that numerator that.06 KA minus 0.9 if you set it to 0; if 0.06 K minus 0.9 is equal to 0, you will get KA is equal to 15. That means, the AVR compensates exactly for that demagnetizing effect of the armature reaction. So that means, if you set this is equal to 0, that means, K S also will be 0 synchronizing torque component will be 0 because numerator if you set it 0 for which K A is equal to 15.

So, in that case the AVR compensate exactly for that demagnetizing effect of the armature reaction right. Now suppose take some value when KA is equal to 200, in that case if you put KA is equal to 200, say this is another case if you put KA is equal to 200, then you will get it is 0.529 that K S due to delta psi fd 0.529 and the total synchronizing torque coefficient is actually it will be K 1 plus K S delta psi fd which one is 1.591 plus 0.529.

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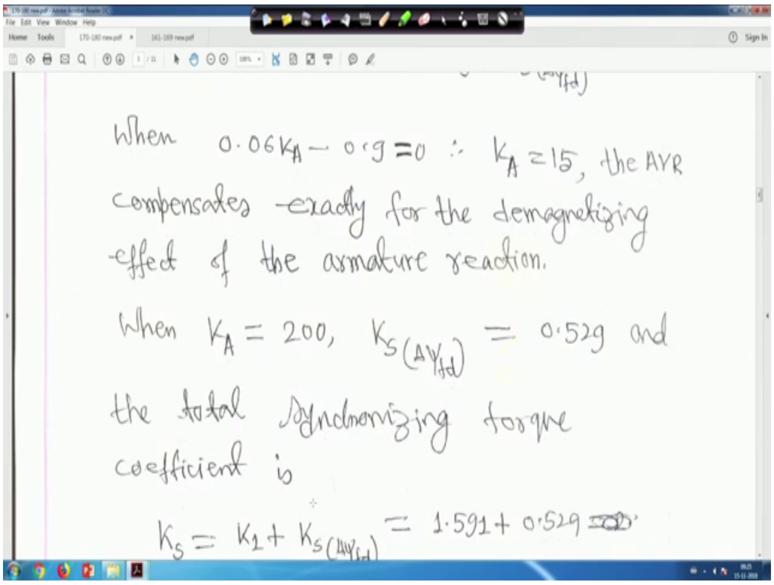


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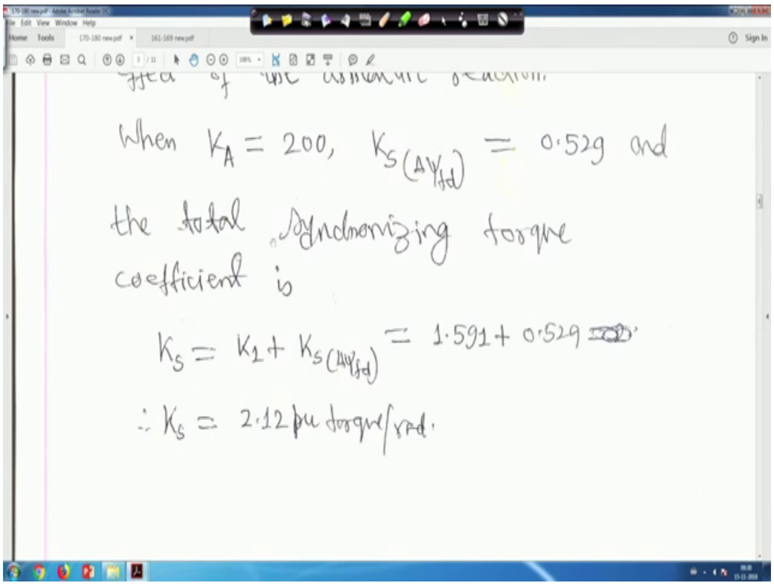


Why it will come that we know no this that look at that I am not going to the block diagram again, you go back to figure 30. Then there you will see that this delta T e is equal to what you call K 2 delta psi fd plus your K 1 delta delta right. So, in this component actually this component is your what you call this delta psi fd due to K 2 delta psi fd and this one we are representing just hold on. This one just hold on, this one we are representing by this component, your what you call that delta T e component due to this function right and whenever we are putting that K 2 is equal to your KA is equal to 200, we are getting KS 0.529.

So, this term if you look into this term, this is due to delta psi fd, just hold on; such that your understanding will be clear. So, this is the function of delta and when you put KA is equal to say 200, you are getting these value actually how much we got 0.529 right.

So, this is actually due to this delta psi fd term plus 1 more term is there, so that is why we are writing that K S right; that is your delta psi fd is equal to 0.529 right. But we know that delta T e has 2 terms; that is one is K 2 delta 2 psi fd this term one is K 2 your delta psi fd and another is K 1 delta delta right. This is figure 30, from figure 30 you know that now K 2 delta psi fd actually basically this is the function and delta delta.

So, we get if you put KA is equal to 2 your 200 then, you will get 0.529. So that means this term actually becoming 0.529 delta delta right. And another term is there K 1 delta delta. So, basically let me clear it, so basically, your delta T e is equal to this term 0.529 delta delta plus K 1 delta delta right.

Now question is that K 1 value is given, that here K 1 value is given, just let me go back to this thing K 1 is given 1.591; that means, I am writing here only. That means, your delta T e is equal to your 0.529 delta delta, this is due to delta psi fd plus this K 1 is there 1.591 delta delta that means, it is 0.529 plus 1.591 delta delta, because K 1 is given right.

So, if you add this up, so basically your synchronizing torque coefficient is increasing right. So, that is why that is why we have written here, that is why we have written here that K S is equal to your K 1 plus K S delta psi fd right and total is we are what you call 2.12 per unit torque per radian. This is per unit value right.

So, basically KS is a dimensionless quantity. So, that is why this K 1 plus K S delta psi fd. I will do hope that meaning of this you might have understood right. So, little bit of what you call little bit of studies required to gain to get into this right. So, that is why easy steps I wrote for you. Such that, there will be no confusion and when you will when you will see this, you just open figure 30 because all notes will be provided to you right.

So, this is actually that case, so here we consider a case now with K 5 negative, upper negative or positive right.

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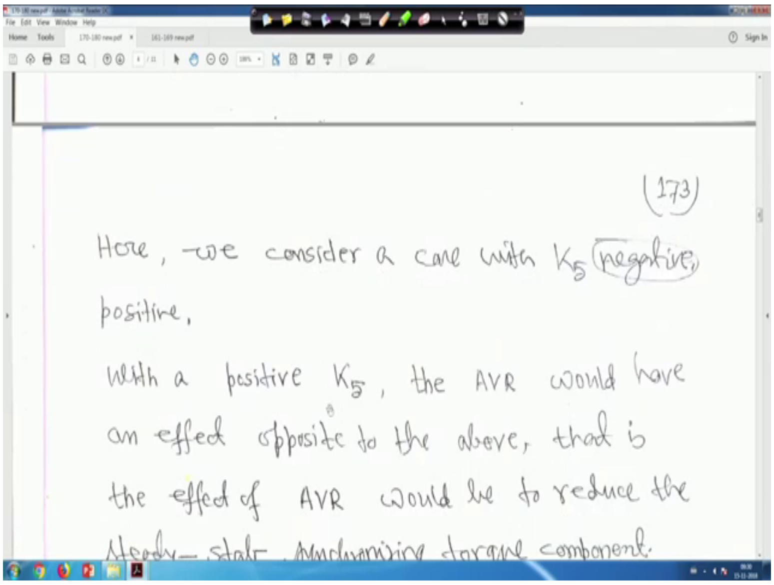


Now, with a positive K 5 it is actually now if it is a K 5 is positive, whatever we have seen there it is K 5 was negative. Now if you see K 5 is a positive the AVR would have an effect opposite to the above. This is an exercise for you, whatever value whatever value is given for K 5 here, I think minus 0.12 I think it is right K whatever is given that K 5 we have taken minus 0.12. This is whatever effect we have seen, I will request to you try for K 5 is equal to 0.12 positive one and just see effect is just opposite or not right.

So, just you have a look, just you have a look this calculation, you will do it as an exercise. So, this thing just hold on, so the AVR would have an effect to the above that is the effect of AVR would be would to reduce the steady state synchronizing torque component.

So, you can see that this value you are what you call these value may become negative. If you take K 5 positive this value may become negative, it may not be the exact value, but or may be exact value it depends on the parameter, but it will be negative not positive. So, if K 5 is negative it actually it actually increases the synchronizing torque coefficient, if K 5 is positive it depends on the system parameters right.

So, if you put K 5 suppose 0.12 this value may become negative. It may not be 0.529, but it may be negative. So, hence if you just make the sum, so it will be what you call it will reduce right. So, this is an exercise for you just a simple thing just you will put it and see it, I did not do it here right.

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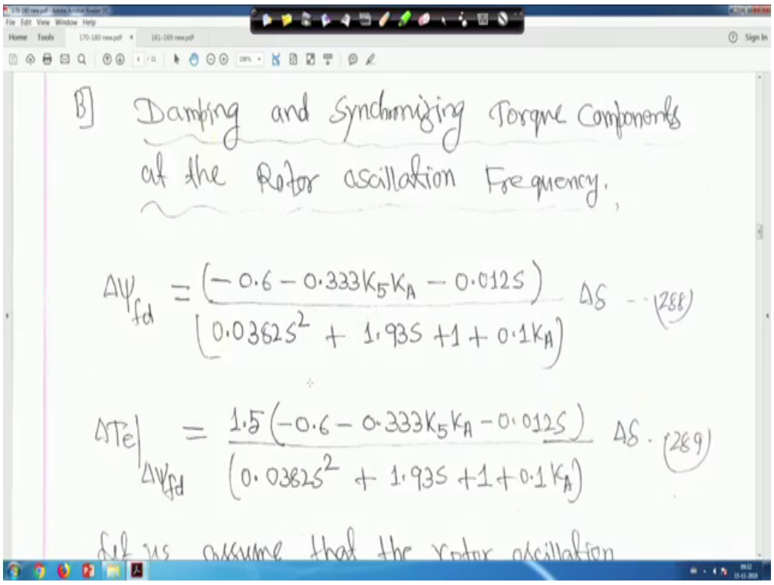


So, next is B, damping and synchronizing torque components at the rotor oscillation frequency. Now suppose when S is equal to j omega, when S is equal to in this equation. In this equation just hold on, in this equation you put S is equal to j omega right and put all the values of K 1 K 2 K 3 K 4 K 5 K 6 all the values you put here and Gex is equal to KA and put S is equal to j omega.

So, if you do so then your function will look like this. So, this delta psi f d will become minus 0.6 minus 0.333 K 5 K A because Gex S is equal to K A minus 0.012 S divided by 0.0382 s square plus 1.93 S plus 1 plus 0.1 K A delta delta. This equation is said 288 right now and delta T e due to delta psi f d means that it will be it is actually K 2 multiplied by K 2.

So, mathematically this one is equal to K 2 I am writing over it, K 2 delta psi f d. So, this expression is this expression is delta psi f d multiplied by K 2 and K 2 parameter K 2, we have taken 1.5, that is why it is multiplied by 1.5 right So, if you multiply this, so delta T e due to delta psi fd right is equal to 1.55 into that delta psi fd; that is the whole term into delta delta. This is equation 289.

Now, let us assume that, the rotor oscillation frequency is a 10 radian per second that is 1.6 hertz right. So, with S is equal to j omega is equal to j 10, if u take omega is equal to 10 radian per second, so omega is equal to 2 pi f. So, from which will get the frequency is 1.6 hertz right. So, our actually interest is generally in between your for this what you call rotor oscillation, our main interest is in between 0.2 to 2 hertz right.

So, if it is 10 radian per second; say that is 1.6 hertz and S is equal to j omega omega is equal to 10, so j 10. So, what you do here, you put S is equal to j 10 and simplify.

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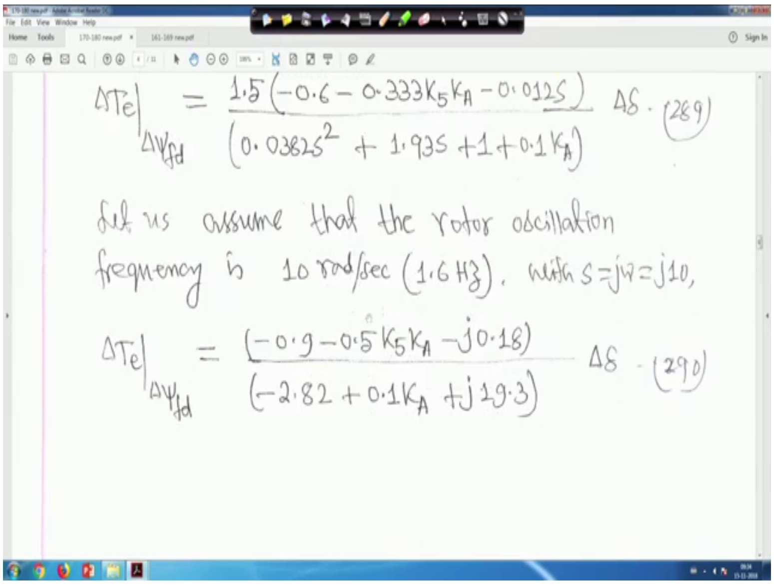


If you do so, it will come that minus 0.9 minus 0.5 K, 5 KA minus 0.1 j, 0.12 minus 2.82 plus 0.1 KA plus j 19.3. So, K 5 value has not been substituted yet, but rest of the values have been your what you call have been substituted here right. So, this is equation 290, this is delta T e, due to delta psi f d, this I have explained before right. Now suppose with K 5 is equal to minus 0.12, whatever value you have taken for K 5 see it is minus 0.12 and KA is equal to say we have taken 200 right.

So, in this case if you put K 5 is equal to minus 0.12 and KA is equal to 200, then you will get delta T e component due to delta psi fd; that is 11.1 1 minus j 0.18 divided by 17.12 plus j 19.3 delta delta right.

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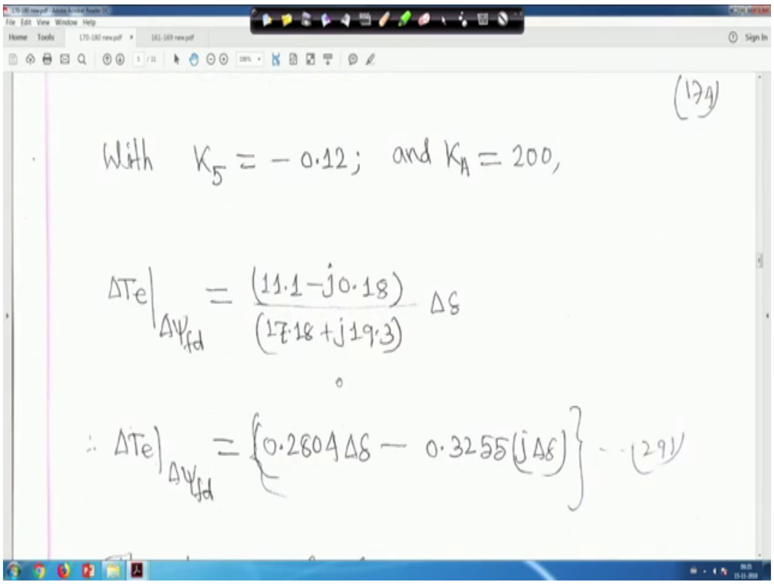


So, if you just numerator and denominator if you multiply by this and simplify it will be like this; I mean this term only this term you can write like this; that is 11.1 minus j 0. 0.18 right E 2 17.18 minus j 19.3 numerator and denominator you multiply by 17.18 minus j 19.3 and if you multiply this one also 17.18 plus j 19.3, then 17.your 18 minus j 19.3 numerator and denominator.

You multiply by this then you will then, this one you multiply and this denominator, this term basically will be 17.18 square plus 19.3 square right. So, then if you simplify that then you will get that your delta T e delta psi fd will be 0.2804 delta delta minus 0.3 255 into j delta delta.

So, this is actually, this part is equal to actually synchronizing torque component and this is the damping part, because j delta delta. Earlier you have seen no something I ask you that it is in phase with delta omega or it is ninety degree out of phase with the delta delta that is you have seen in your Phasor diagram, but this torque component also will define like this, particularly this thing right it is quite interesting.

So, that means, that the effect of the AVR is to increase the synchronizing torque component because, this term is positive because it is point, because it is function of delta delta right. And decrease the damping torque component when K 5 is negative. So, when K 5 is negative, this coefficient actually is a negative, it is minus right, because damping term is a function of j delta delta or in phase with delta omega will see later right, but I put if you have lectures that you put in the forum that is why it is so. And, but just now you will know after this numerical and this is your 0.2804 delta delta, this is your synchronizing torque coefficient, this is positive right.

So, right, when K 5 is negative, we have taken K 5 is negative right.

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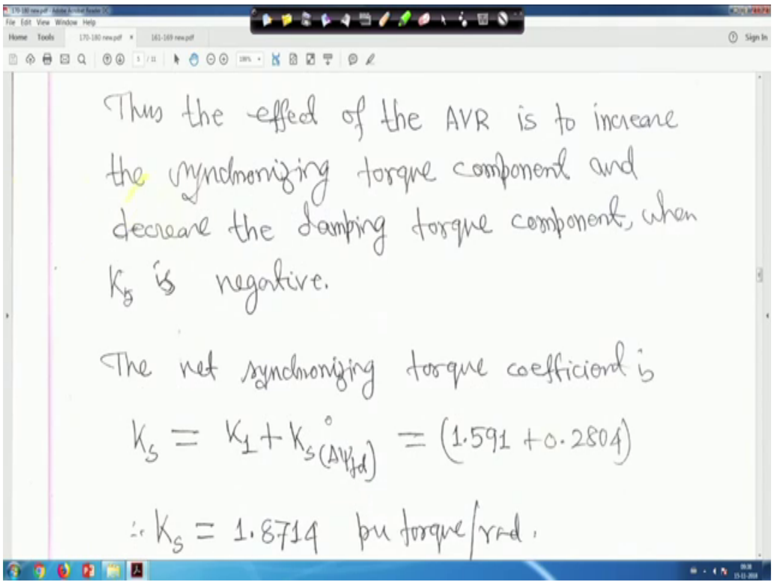


So therefore, net synchronizing torque coefficient is K 1 plus K S delta psi fd; that is 1.59 plus 2.2804, because that if you go back to the figure 30 again, figure thirty again, that you know this that delta T e has 2 component right; that is 1 is coming your K 2 delta psi fd and another is K 1 delta delta right, but due to K, due to your delta psi fd just synchronizing torque component is this one, is this one; that means, this one actually 0.2804 delta delta and K 1 how much we have taken I think, 1. Just let me see that your K 1 data we have taken 1.591.

So, it is actually basically what is happening, that your delta T e actually it is coming 0.2804 delta delta delta because this is due to your delta psi fd K 2 delta psi fd plus 1.591 delta delta. So, basically it is 0.2804 right whatever it is plus 1.591 delta delta. If you add this is the effective synchronizing torque component right.

So, because this torque is in phase with delta delta, so this is actually coming K 1; we are writing K S delta psi fd because, this term, this term will define that K S, the synchronizing torque component due to delta psi fd right. That way that is the meaning is equal to 0.2804. So, that is total its coming 1.871 per par unit torque per radian because, this is a dimensionless quantity, because this is per unit torque means dimensionless radian also dimensionless. So it is a dimensionless quantity.

Thank you very much. We will be back again.