Power System Dynamics, Control and Monitoring
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Lecture – 21
Power System stability (Contd.)

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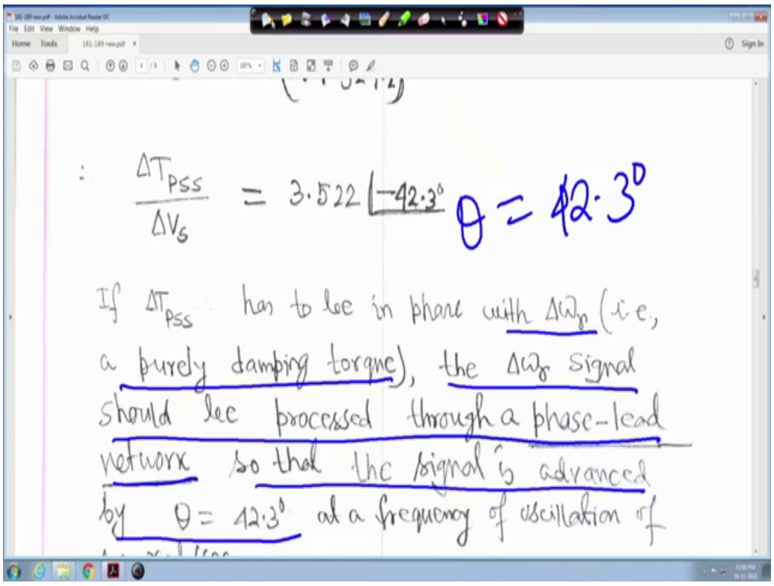

Ok, so in the previous lecture, we have finished here that is delta T PSS upon delta VS is equal to 3.522 angle minus 42.3 degree this is actually phase lag. So, we have to you know design a compensator for your what you call that is, that is why we use PSS such that this can be completely your eliminated that means, it will be pure damping's that is why, you need a lead compensator. We will see little bit in the in this course, because it is basically as for the classroom is what is concerned detail is not possible right, but we will see how things are.

So, if delta T PSS has to be in phase with delta omega r right that is your I mean if you want to be it is in phase with delta omega r that is a purely damping torque, then the delta omega r signal should be processed through a phase-lead network right, so that the signal is advanced by theta is equal to say 42.3 degree, because here theta is equal to 42.3 degree, so theta is equal to at a frequency of oscillation of whatever we have taken right.

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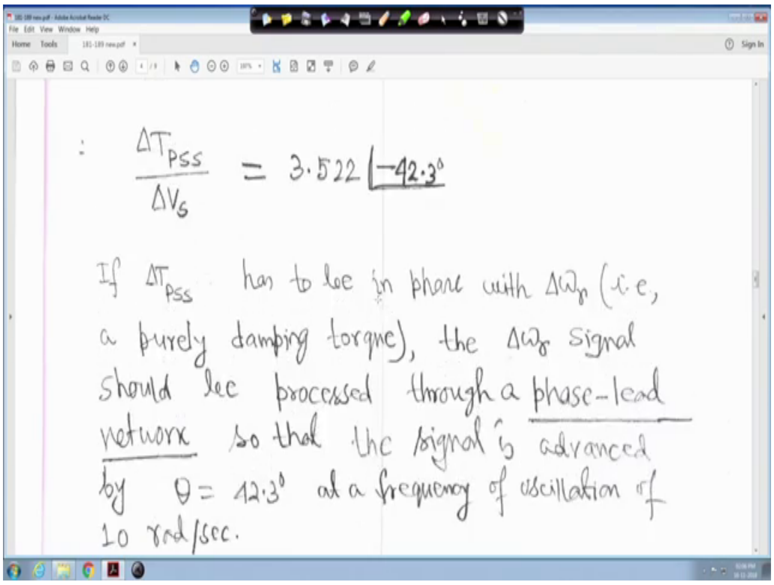

So, that means your in this case we have consider 10 radian per second righ,.

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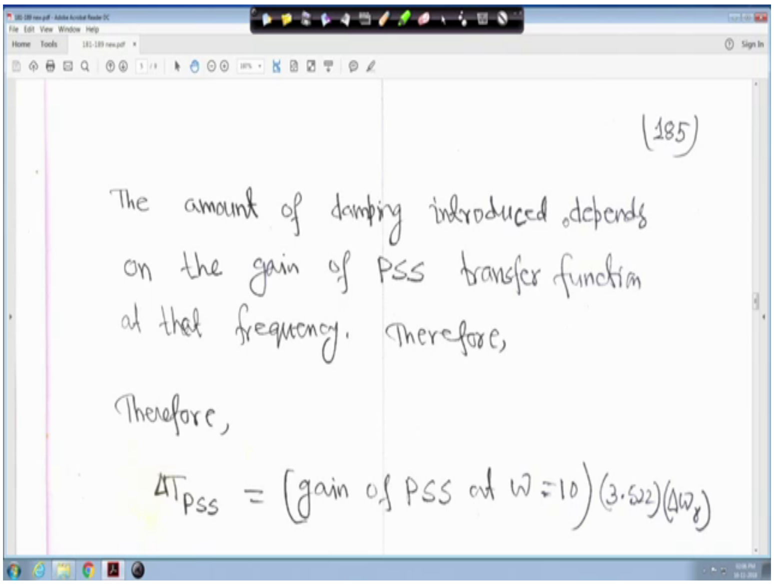

So, that is then what we are supposed to do then the amount of damping introduced depends on the gain of PSS; PSS transfer function at that frequency. Therefore, delta T PSS will be gain of PSS at omega is equal to 10 radian per second into 3.522 delta omega r right. So, here delta T PSS is equal to delta VS 3.522 angle minus 42.3 degree. And here the delta T PSS must be is equal to gain of PSS at omega is equal to 10 radian per second into 3.522 delta omega r right.

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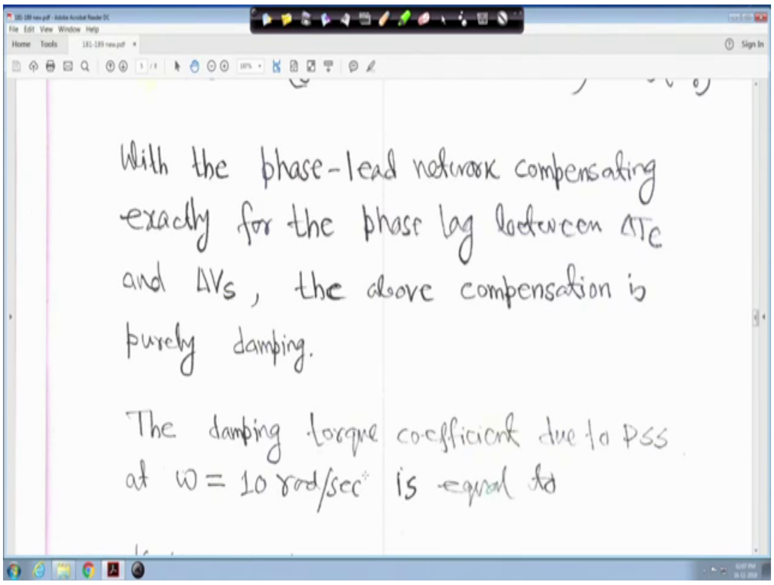

With the phase-lead network compensating exactly for the phase lag between delta T and delta VS, the above compensation is purely damping right.

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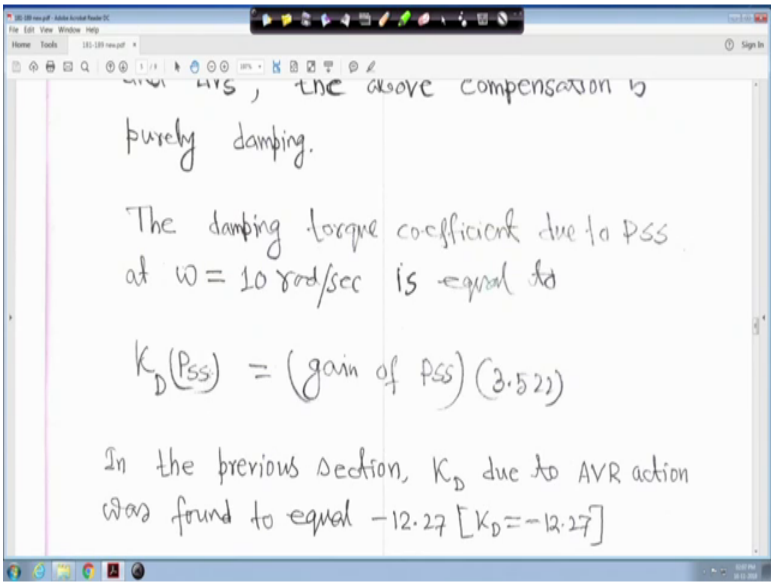

Therefore, the damping torque co-efficient due to PSS at omega is equal to 10 radian per second is equal to that K D P SS that is a due to it is due to PSS is equal to gain of PSS into 3.522 that mean this one that means this one that means, delta V SS sorry delta V S the output of the stabilizer signal, it must be some gain of PSS. And it processed through a lead-network that means, that angle also has to be plus 42.3 degree such that this thing completely eliminate this angle should not be there such that you will get a pure damping coefficient.

So, therefore that gain of PSS at omega is equal to 10 radian per second into that 3.522 delta omega r right. Now, the damping torque coefficient due to PSS at omega is equal to 10 radian per second is equal to the K D PSS is equal to gain of PSS into 3.522. If the in the previous section that K D due to AVR action was found to equal to minus 12.27 that is why, we have seen just before right that K D is equal to minus 12.27 that we have seen in the previous example, whatever data we consider right.

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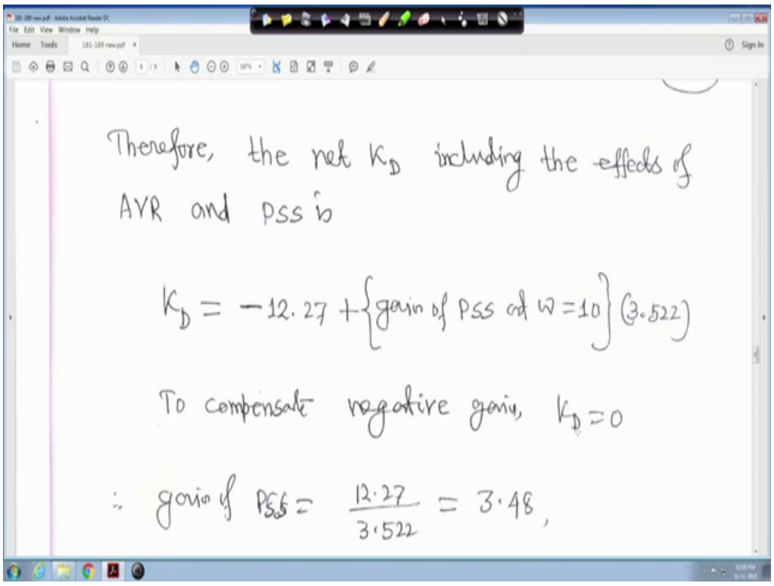

So, therefore the net K D including the effects of AVR and PSS is that minus 12.27 plus the gain of PSS at omega is equal to 10 radian per second into 3.522 right. So, to compensate negative gain that means, this one we can set say K D is equal to 0 right. If you do so, then you will get gain of PSS at omega is equal to 10 radian per second right is equal to 12.27 divided by 3.522. In that case you will get 3.48 right. This is the minimum gain of PSS required right, such that this negative damping thing will be completely neutralized.

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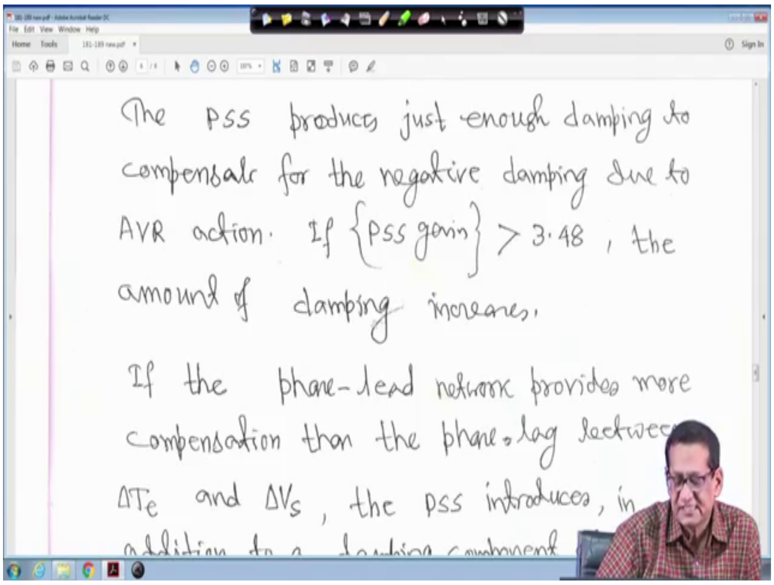

The PSS produces just enough damping to compensate for the negative damping due to AVR action that means if PSS gain greater than 3.48 the amount of damping increases, it will be positive. If that gain of PSS now is more than greater than 3.48, then effective K D gain will increase right it will be positive, so that is the damping increases.

If the phase-lead network, later we will see little bit transfer function of the phase-lead network. If the phase-lead network provides more compensation than the phase lag between delta T e and delta V S that is the output signal of the stabilizer. The PSS introduces, in addition to a damping component of torque a negative, synchronizing torque component also right. So, this is actually things are simple, but little bit of understanding is require.

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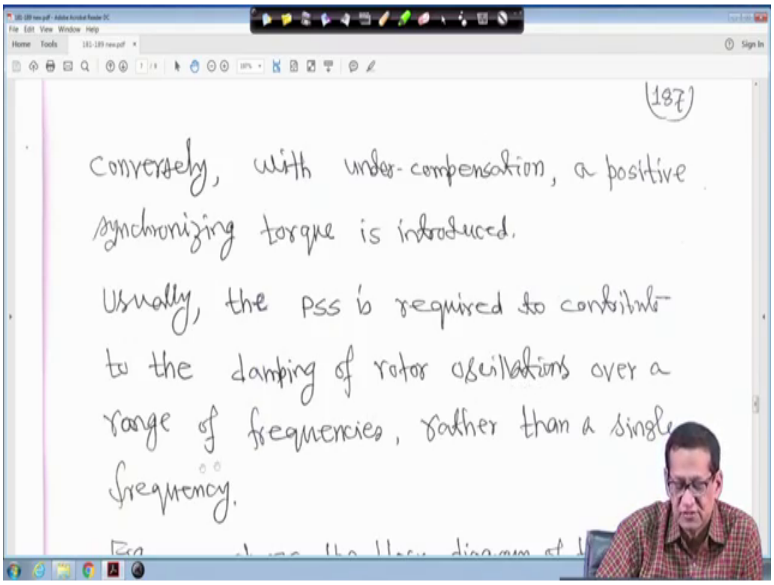

So, conversely with under compensation, a positive synchronizing torque is introduced. Usually, the PSS is required to contribute to the damping of rotor oscillation over a range of frequencies, rather than a single frequency right.

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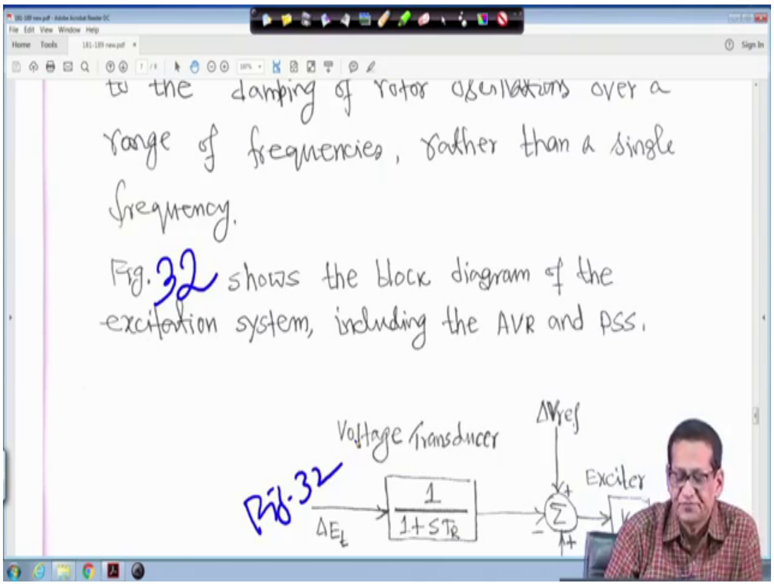

Therefore, this one figure number is not mentioned here, this should be I think figure 32 right. So, these figure actually this figure actually it is figure 32 right, therefore just I am cleaning this, so this is figure 32. So, figure 32 shows the block diagram of the excitation system including the AVR and automatic voltage regulator and PSS.

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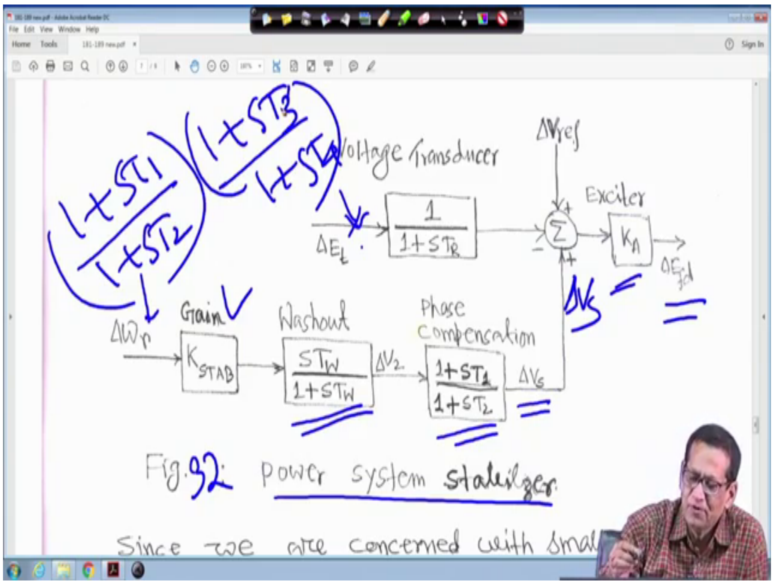

So, this is actually your figure 32 right, and this is power system stabilizer. So, you have input here is delta omega r this is the gain of stabilizer. This is a high fast filter washout, later little bit we will discuss later. And output of this is delta V 2, and this is a phase compensation 1 plus ST 1 upon 1 plus ST 2.

Generally phase-lead compensator. Output is delta V S right, and signal is coming here this delta V S signal is coming here. And this is your delta V reference, and this is coming from voltage transducer input to this is dealt E t, this we have seen that in the block diagram figure 31 also you can have a look right. This block diagram everything is there, and this is exciter gain is K only consider no transfer function consider a, and output is delta E f d right.

So, actually in that your power system application, this is actually your phase compensation only one block is taken T 1 T 2, you have to optimize right it depends on that your what you call that your which system you are applying. And the accordingly you have to you have to design the parameter T 1, T 2 you have to optimize right. So, here it is only phase compensation only single block is there, but it may take some other form.

For example, sometimes you need multiple blocks for example sometimes you need 1 plus ST 1 divided by 1 plus ST 2 say another one say 1 plus ST 3 by 1 plus ST 4 right. So, in this case T 1, T 2, T 3, T 4 such parameters are there, but do not confuse this T 3 with the previous T 3 right. So, do not confuse that with your AVR time constant right, this T 3 mean this thing, if it necessary I can put T 3 dash right.

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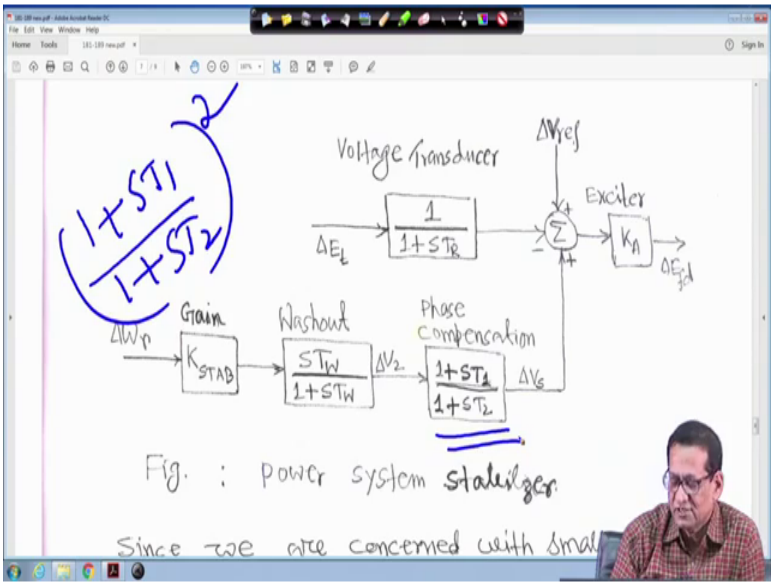

So, in that case four parameters you have to optimize. So, an order of the system also will increase, state variable order will increase. Another form it depends of course, on the system another form sometimes this is also helpful 1 plus S T 1 upon 1 plus S T 2 sometime its square right, so that means, two parameters S T 1, S T 2, but its square right. But, again in this case that dimension of the system will increase. So, this is actually only one block is shown right only one block is shown.

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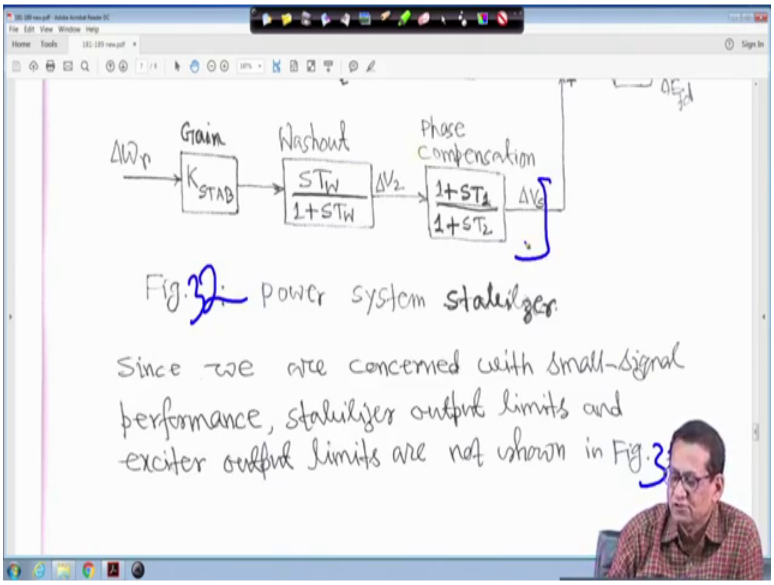

So, each block has its your some your what you call some function later we will see. Since, we are concerned with small-signal performance, because our objective is the small-signal stability right, stabilizer output limits and exciter output limits are not shown in figure-32. Because, this is actually I have forgot to miss I have forgot to wrote this is actually figure 32.

If I recall correctly, because previous figure was 31 right, so that your stabilizer output limits and exciter output limits are not shown in figure. Stabilizer output limits means, here this is also not shown here no, because it is not require right. And another thing is that here exciter output limit is also your not shown here your what you call not shown here right, because no need that is why, it is not shown right. So, we will simply go for linear system analysis right.

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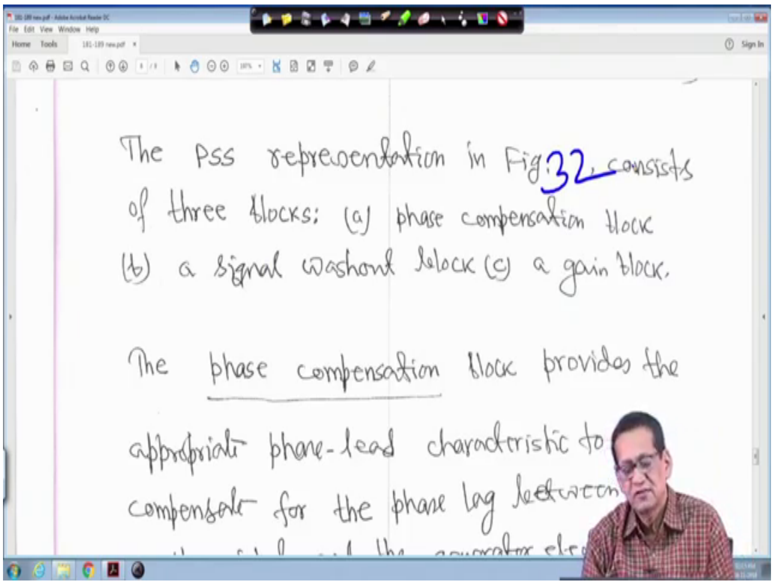

So, the PSS that is the power system stabilizer representation in figure 32 right, this is actually figure 32 that previous figure. Consist of three blocks, so one is that phase compensation block, another is a signal washout block, and a gain block right. So, let me move it up.

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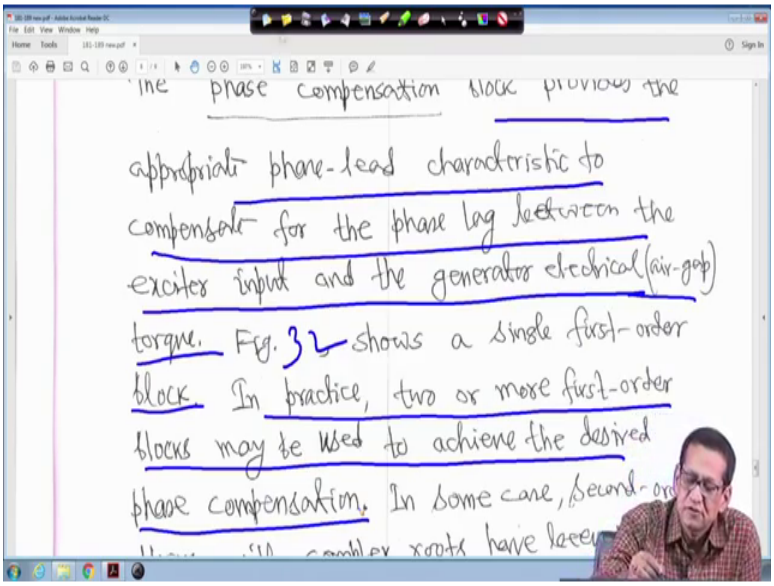

The phase compensation block actually provides the appropriate phase-lead I told you this is actually appropriate phase-lead characteristic to compensate for the phase lag between the exciter input and the generator your electrical torque. We have seen know three point something angle minus 42.3 degree. So, you have to compensate the angle that is why phase lag that that means, phase-lead characteristic to compensate for the phase lag such that we can get a pure gain right, so that is figure 32, it is 32 shows a single first-order block.

We have consider here first-order block, but I told you it may be multiple blocks sometime two or three, sometime its square right, so it depends on the system right. In practice, it is written two or more first-order blocks may be used to achieve the your what you call desired phase compensation right, so that means, we want pure your what you call pure damping that means, you have to compensate that lagging angle right.

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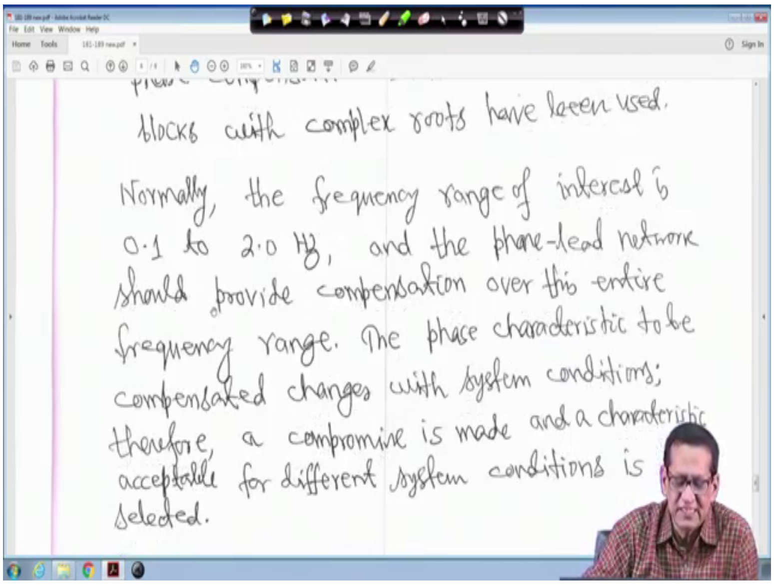

So, in you are what you call in some cases second-order blocks with complex roots have been used. I mean some places also second-order block also has been used, it depends on the system which will your what you call the damp the rotor frequency oscillation. Normally, the frequency range of interest is generally 0.1 to 2.0 hertz right. So, and the phase-lead network should provide compensation over this entire frequency range.

So, whatever phase-lead network you use, actually that it frequency for small signal stability the frequency range is 0.1 to 2 hertz right. And the phase-lead networks must provide the compensation over this entire frequency range. The phase characteristic to be compensated changes with system conditions right. Therefore, a compromise is made and a characteristic acceptable for different system condition is selected right.

So, this is actually that phase details cannot be done on the in the classroom for that you have to do the simulation work right. And T 1, T 2, T 3, T 4 I mean those lead lag compensator, you have to also optimize right. And for that also it is what you call it is little bit of not easy task, little bit of complicated task right some optimization technique you have to follow right.

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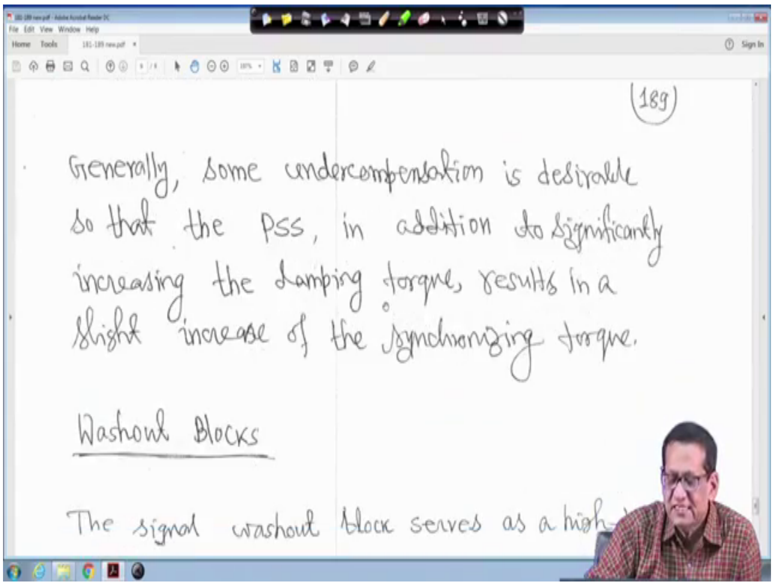

Generally, some under compensation is desirable, so that the PSS in addition to significantly increasing the damping torque, results in a slight increase of the synchronizing torque right.

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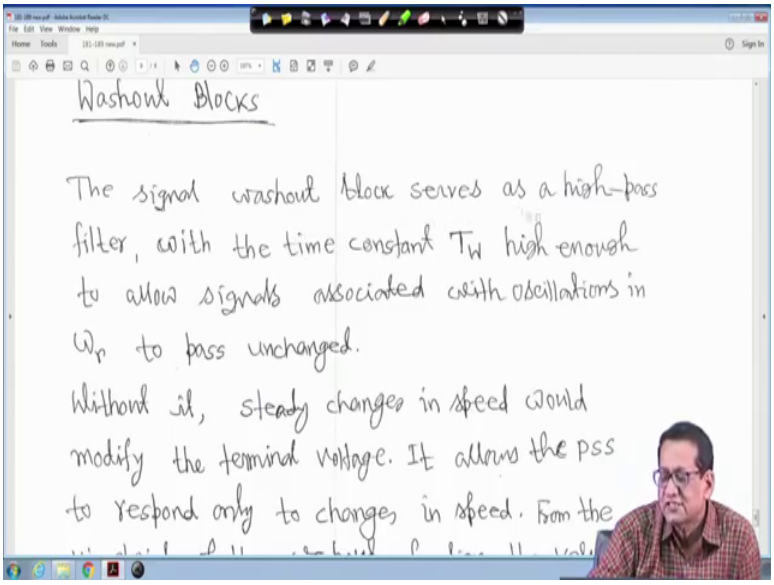

Next is that washout blocks that is S TW upon 1 plus S TW the block is here know that is your washout block this block, this washout block right. So, the signal washout block actually serve as a high-pass filter, with the time constant T W high enough to allow signals associated with oscillations in omega r to pass unchanged.

Actually, the washout time constant T W I mean a little bit of simulation experience I have that generally the T W they keep in between 10 to 20 second. If you keep in between 10 to 20 even little less than that also, it does not affect much on the system performance right. So, it need not optimize there is no need to optimize, but you can select some value in between 10 to 20 second right.

To allow signals associated with oscillations in omega r to pass unchanged right. So, it is S T W upon 1 plus S T W, without it steady changes in speed would modify the terminal voltage right. So, it allows the PSS to respond only to changes in speed, otherwise no. Even steady speed is there, it will not pass right. From the viewpoint of the washout function, the value of T W is not your what you call critical and maybe in the range of 1 to 20 second I told you that even 10 to 20 second you keep any value, I mean below that below 10 also you will not find any this thing not much, it will not much affect the dynamic performances.

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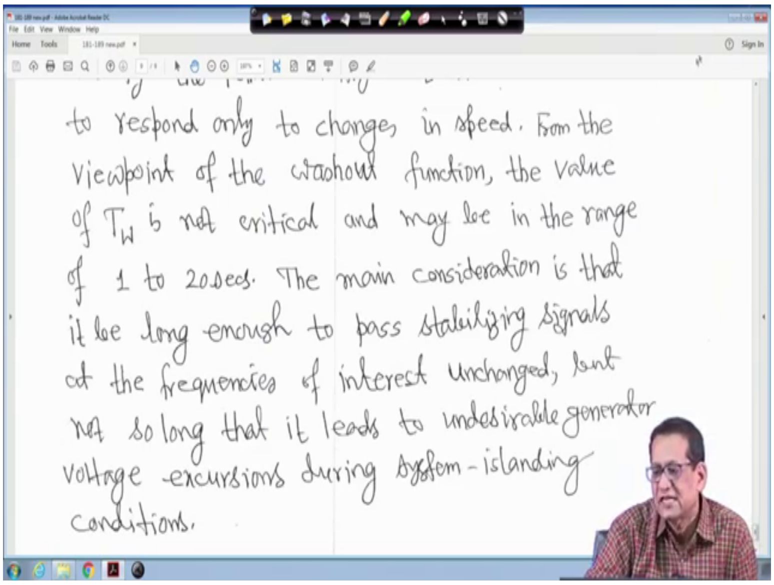

The main consideration is that it will long enough to pass stabilizing signals at the frequencies of interest unchanged, but not so long that it leads the undesirable generator voltage excursion during system-islanding condition right. So, these are the different feature, which will which cannot be covered in the class right, but only those things will be covered which are in this which we can do it in the as a classroom exercise. Next is just hold on next is right so just hold on.

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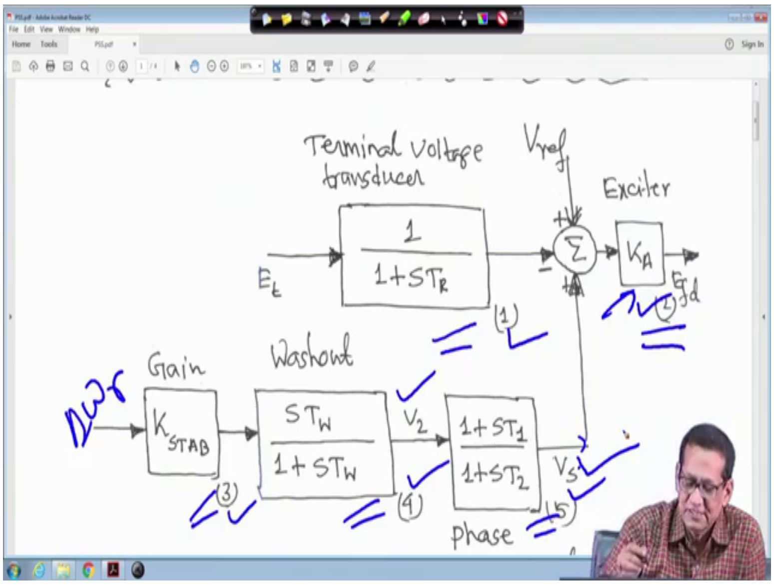

Now, state system state matrix including your PSS right. So, same diagram I have redrawn only one thing I have missed here that input signal to this is delta omega r previous diagram, it was there in figure 32 what I said it was there right. And this is we are marking as a block 1, this is block 2, this is block 3, this is block 4, and this is block 5, it is marked here 1, then 2, then 3, then 4, and this is block 5 right.

And this is your stabilizer gain, this is washout output is V 2, and this output is V S right, and this is your V reference, and this is exciter, and this is E f d, this is the exciter gain right. So, if we write down the your what you call that because of this stabilizer thing that this is one state variable has come, and this is one more state variable right. So, in that case what will happen that, we have to write down the state variable equation.

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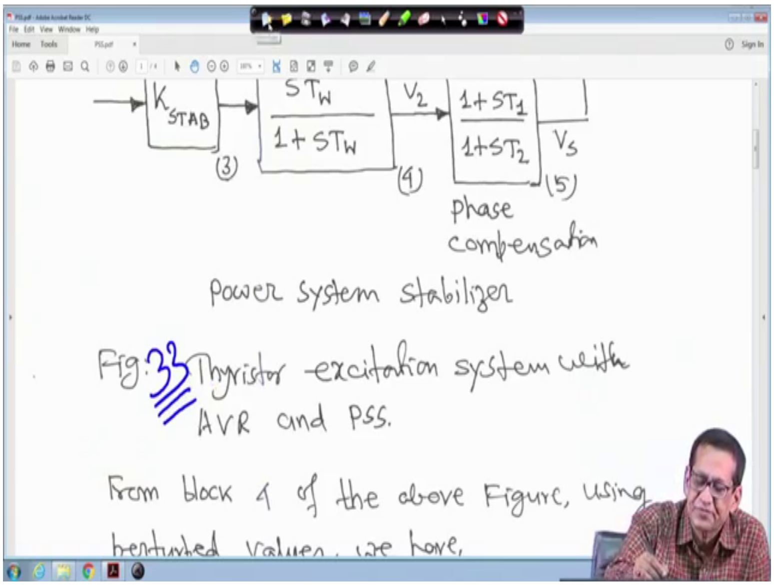

So, now this is this is all this thing and this is delta omega, I told you right. So, this is actually this will be then figure 33 or figure 32 actually right, because it is a repetition same figure right. But, anyway this is figure 33, I did not write it here. So, from this from the block 4 that means that means, from this block from this block if you write right for small your small perturbation if you write from this block right, so it will become I am writing here, then I am going this.

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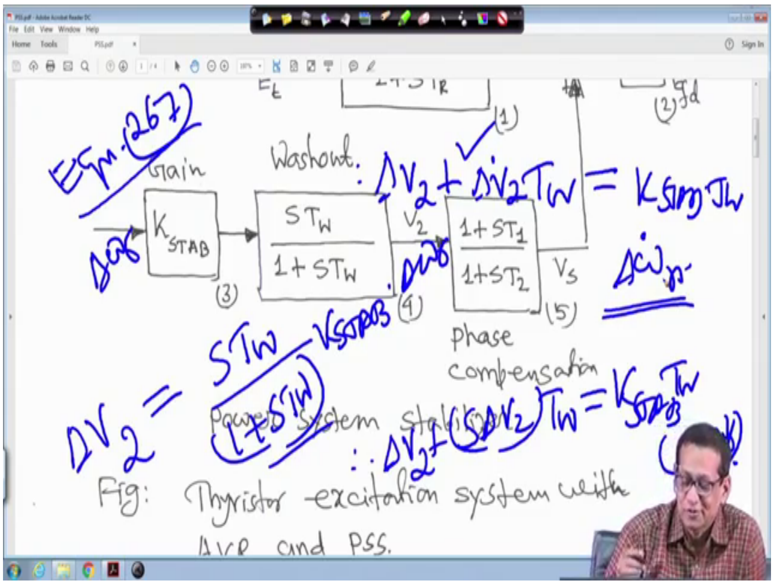

Suppose, was small perturbation I over writing it that delta V 2 will be is equal to that you know from your state variable analysis S T W right into this input signal is delta omega r, I have missed it here into K stabilizer gain into delta omega right, this is your delta V 2 is equal to right that means that means, I am overwriting it that look if you cross multiply if you cross multiply, it will be delta V 2 plus S delta V 2, then T W is equal to K stabilizer, then into T W and into your S delta omega r right.

Now, this I am writing somewhere here look from here, it is delta V 2 plus this S delta V 2 is nothing but your delta V 2 dot right, then multiplied by T W is equal to this is K stabilizer gain into T W, and S delta omega r means, it is delta omega r dot right.

Now, if you want to get the state variable equation for this your delta V 2 dot for this equation, then delta omega r dot you have to substitute. Now, what we will do? You go back to if I recall correctly just check go back to equation your 267 right that equation 267 first equation delta omega r dot is given right, in terms of delta omega r delta delta delta E f d, it is given right that delta omega r you will substitute here, because it is K STAB T W into delta omega r that delta omega r dot you can substitute here such that right hand side dot term will be eliminated right. So, from equation 267 in this equation, you put delta omega r dot is equal to all these things I have not written, then it will take long time right.

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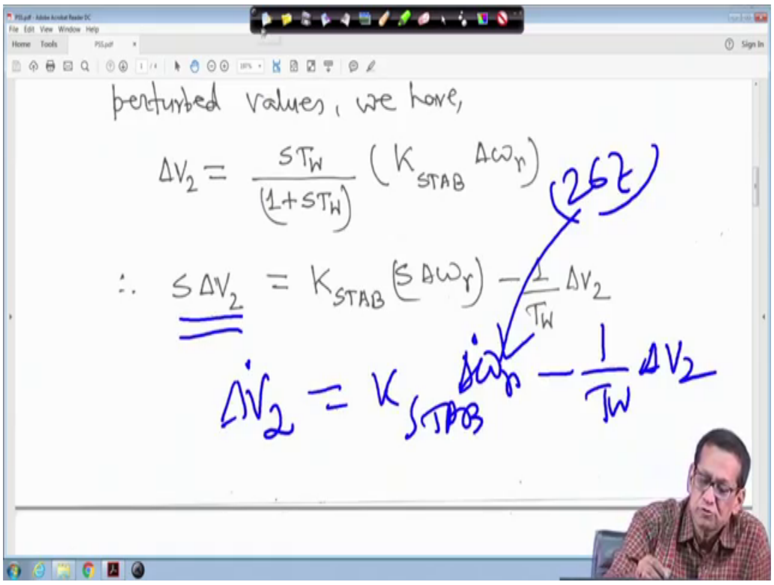

So, just you can put it and you will get it right, so that is why that is why these equation we are writing S delta V 2 is equal to k STAB S after simplification delta omega r minus 1 upon T W delta V 2 that means, this S this S delta V 2 is nothing but delta V 2 dot, because we know that S represent DDT, and all initial conditions such 0 say right.

So, is equal to K stabilizer gain right S delta omega r means it is delta omega r dot minus 1 upon T W delta V 2 right. So, delta V 2 is another state variable. So, this delta omega r dot equation you substitute here that delta omega dot expression here right such that right hand side this derivative term will be (Refer time: 20:21) from two equation 267 the very first equation that that you substitute here right.

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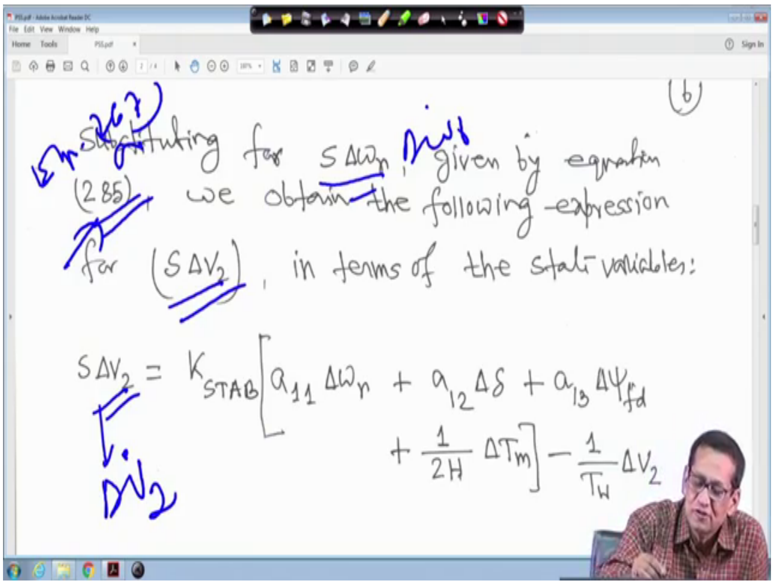

If you do so, if you do so, then it is actually same thing 267 here it is 285 right. I think if you look into that that S delta omega r is nothing but delta omega r dot either 267 or 285, I think from equation 285, I have substituted here right. So, just check right. So, then we obtain the following expression of S delta V 2 you check equation 267 or this here it is written 285 right. So, just you put delta omega r dot equation and that is all right.

So, if you do so if you do so, then this equation S delta V dot delta V 2 is equal to phase stabilizer a 1 1 delta omega r plus a 1 2 delta delta plus a 1 3 delta psi f d plus 1 upon 2 H delta T m minus 1 upon T W delta v 2 right. So, basically S delta V 2 is nothing but your delta V 2 dot, so delta V 2 dot is equal to K stabilizer into all these things right equation number I think I have written later right.

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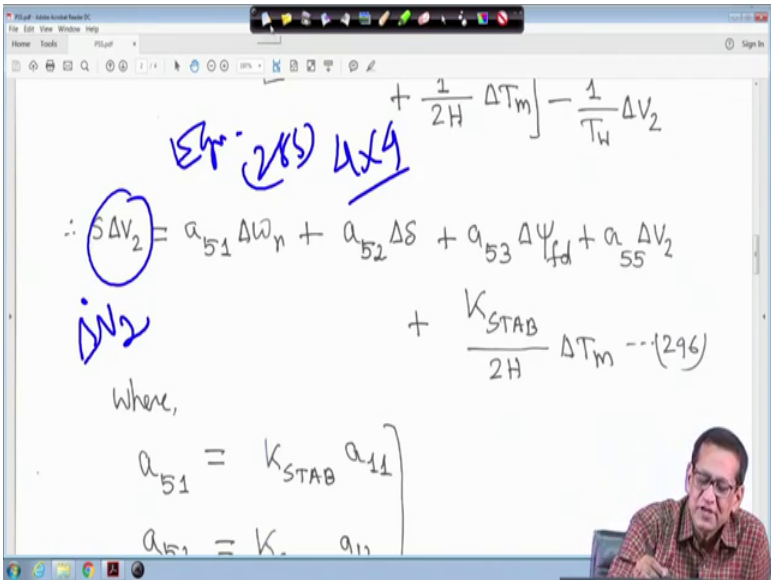

So, that means, this S V, S delta V 2 I have kept it as a S delta V 2 this is nothing but delta V 2 dot. So, delta V 2 dot is equal to basically it is a 5th equation, because two equation 285 is a 4th order that equation 285, it is actually 4 into 4 that a matrix it is a 4th order right.

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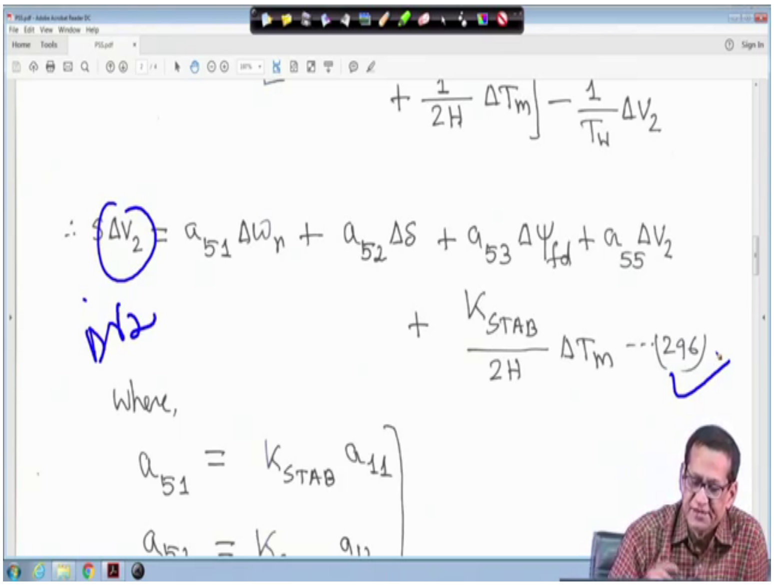

Now, because of these thing the order will increase, so that is why we have this is a your what you call this delta V 2, it is actually your 5th state variable. So, it is a 5 delta omega r, we are writing plus a 5 2 delta, delta plus a 5 3 delta psi f d plus a 5 5 delta V 2 plus K stabilizer upon 2 H into delta T m, this is equation 296 right.

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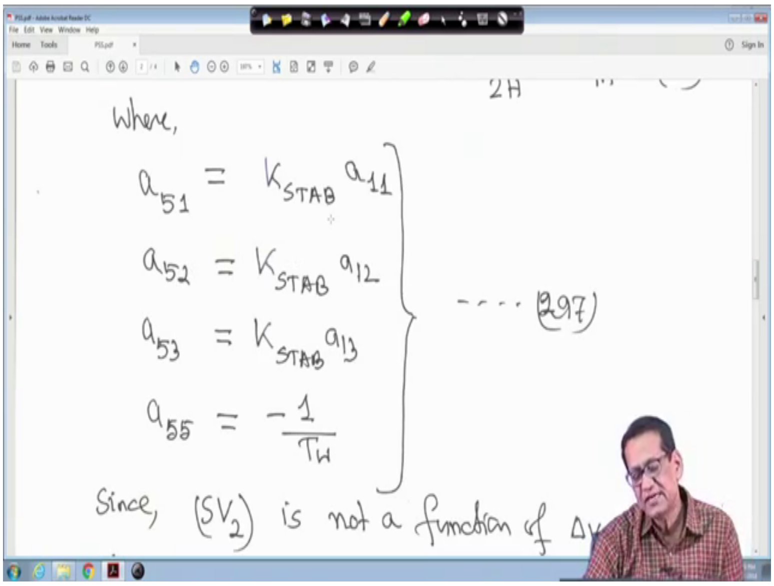

So, this is simple thing just you will put it like this, where a 5 1 is equal to K stabilizer that is stabilizer gain into a 1 1, a 5 2 is equal to K stabilizer into a 1 2, a 5 3 is equal to K stabilizer a 1 3, and a 5 5 is equal to minus 1 by T W, this is equation 297.

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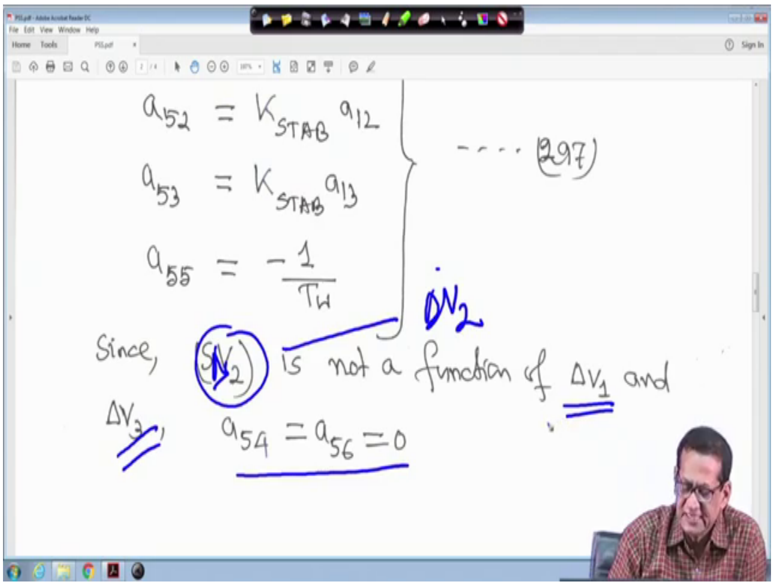

Since, S V 2 is not a function of delta V 1 and delta V 3 that is this S V 2 means, it is delta V 2 S delta V 2 right, it is actually delta V 2 dot, it is not a function of delta V 1 and delta V three. So, a 5 4 and a 5 6 basically 0, because right hand side delta V 1 and delta V 3 are not there.

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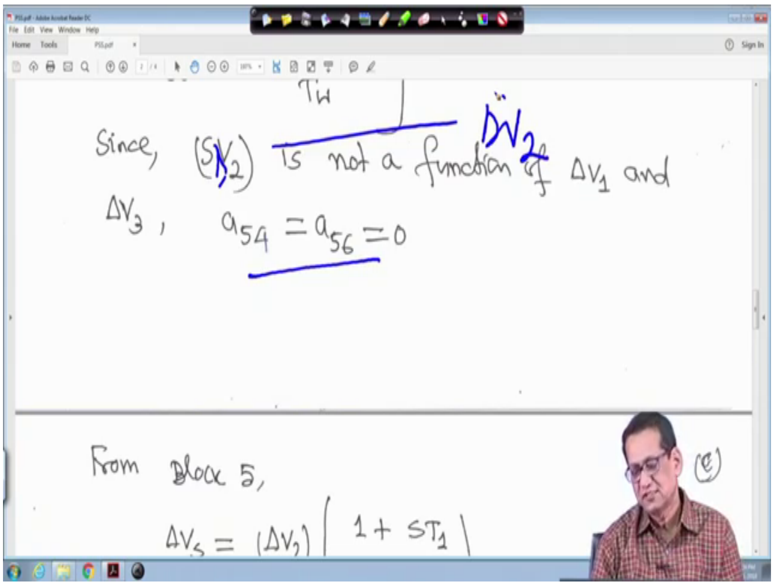

So, right hand side of this equation this is not there right delta V 1 and delta V 3 is not 3 on the right hand side that is why that your what you call that your a 5 4 and a 5 6 is equal to 0, and this is actually S delta V 2 that is your delta V 2 dot right, so this is 5th equation.

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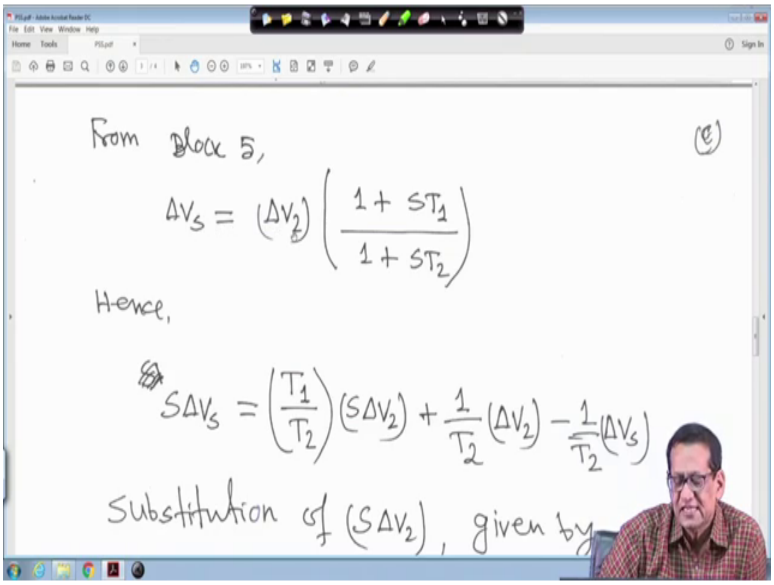

Now, next is that phase compensation block that is block 5. Now, in the block 5 also, you can write for small perturbation delta V S is equal to delta V 2 into 1 plus S T 1 upon 1 plus S T 2 right.

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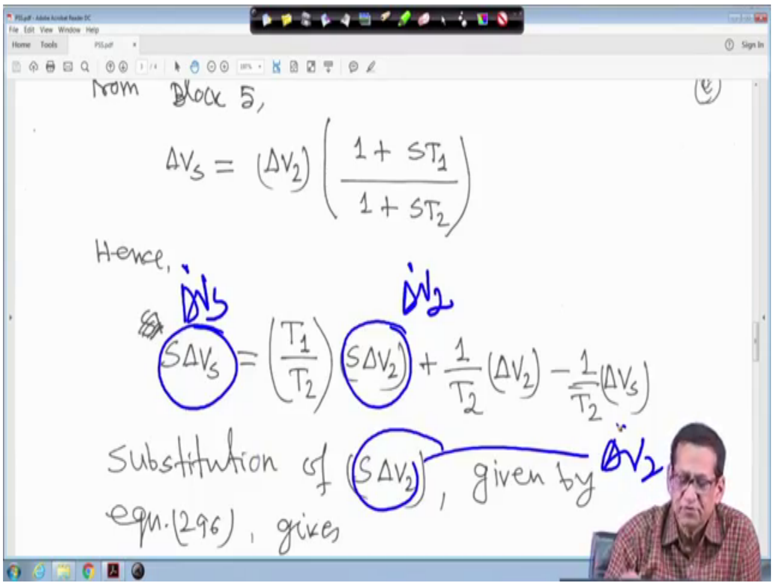

Or if you simplify if you simplify this equation, then your S delta V S will be nothing but delta V S dot right. Similarly, S delta V 2 will nothing but delta V 2 dot right plus 1 upon T 2 delta V 2 minus 1 upon T 2 delta V S right. So, from equation 296 you substitute here delta V 2 dot, because this is delta V 2 dot right. Therefore, from equation 296, here it is, that is your here it is right this equation 296, you substitute here you substitute here.

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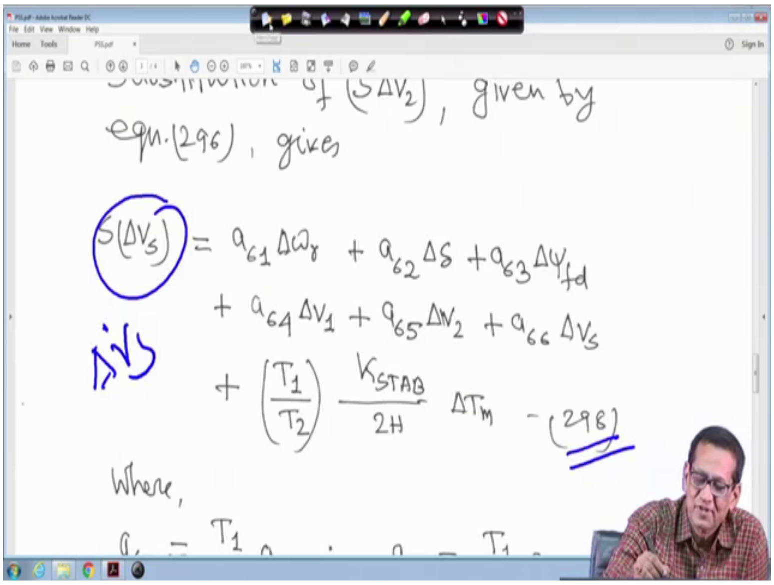

If you do so, you will get that S delta V S that is your nothing but your delta V S dot right is equal to a 6 1 delta omega r plus a 6 2 delta delta plus a 6 3 delta psi f d plus a 6 4 delta V 1 plus a 6 5 delta V 2 plus a 6 6 delta V S plus T 1 upon T 2 into K stabilizer upon 2 H right that stabilizer gain upon 2 H into delta T M, this is equation 298. So, this is the sixth state variable. So, when that your different component you are considering then what is happening that your order of the system is getting increased right.

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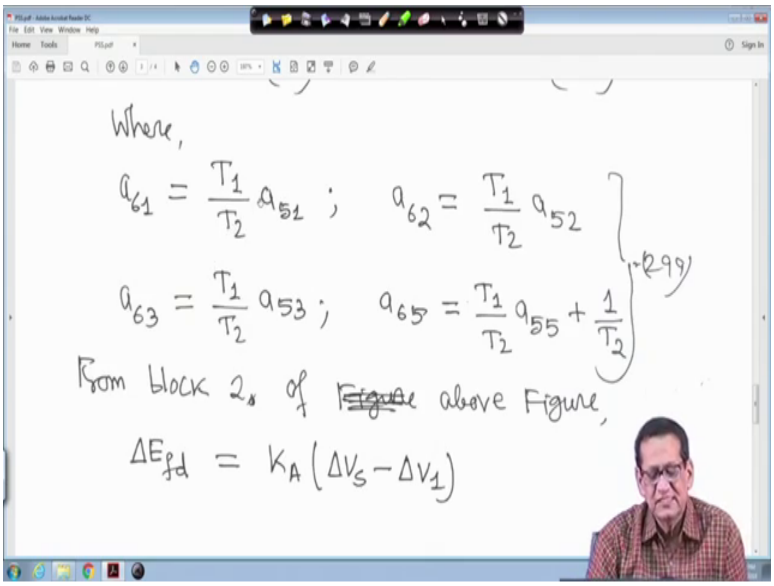

So, where a 6 1 is equal to T 1 upon T 2 into a 5 1, a 6 2 is equal to T 1 upon T 2 into a 5 2, a 6 3 is equal to T 1 upon T 2 into a 5 3, a 6 5 is equal to T 1 upon T 2 a 55 plus 1 upon T 2 right. Similarly, for block 2 of above figure I mean if you go to the that block 2 of this figure right here it is I am going and just earlier also we have discussed, from here if you write small perturbation equation right, so it will be your what you call the delta E f. E f d is equal to delta V reference right minus your delta E t into 1 plus S T R right from this block, I mean from here only including this one including this one right small perturbation one. We take only delta E t delta E f d if you do so, just open the block diagram you yourself can easily do it right.

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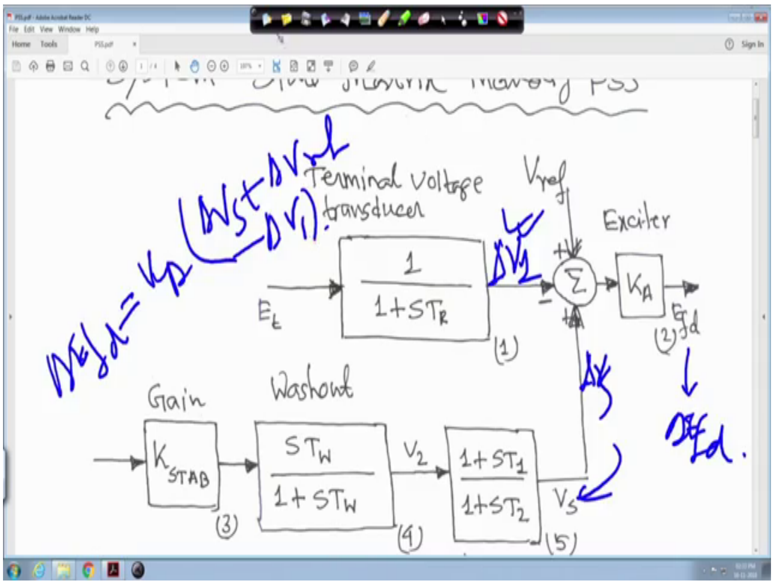

So, from block 2 of above we can write delta E f d is equal to K A into delta V S minus delta V 1 right, so that means that means, this one actually this one previous figure it was there. This is actually delta V 1, and this is delta V S which is here small perturbation V S, small perturbation delta V S, it was V 1 small perturbation delta V 1. So, this is actually delta V 1. In this figure, I have missed it, but previous figure it was there V 1 right.

So, this is delta V 1, so your basically your if you write is small perturbation, this is also delta E f d right. So, in that case delta E f d is equal to your K A right that exciter gain into your, what you call delta V S right plus delta V reference minus delta V 1 right. But, if you say delta V reference is equal to 0, then it will be simply delta V S minus delta V 1. So, here it is right.

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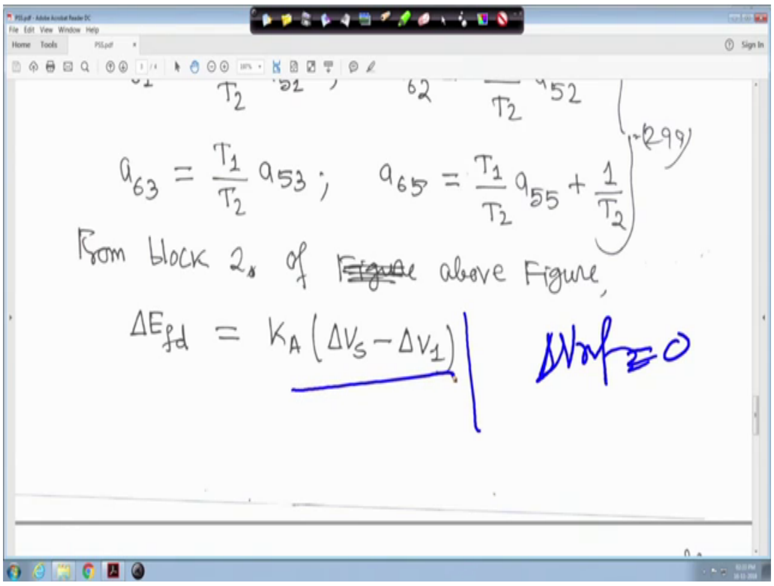

So, delta V reference we have consider that thing is 0, so delta V reference in that case we have consider it as 0, we have consider only delta T m right. So, this is delta E f d is equal to this equation right.

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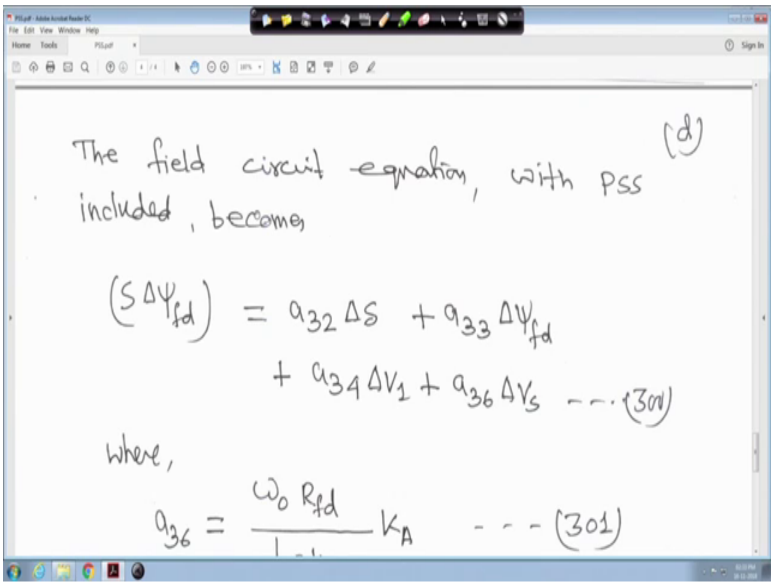

So, now the field circuit equation with PSS includes it become that your S delta psi f d is equal to a 3 2 delta delta plus a 3 3 delta psi f d plus a 3 4 delta V 1 plus a 3 6 delta V S right. And this one again you please go back to the state variable equation right. And then S delta of psi f d means, it is delta psi f d dot right is equal to this expression, this is equation 300 right.

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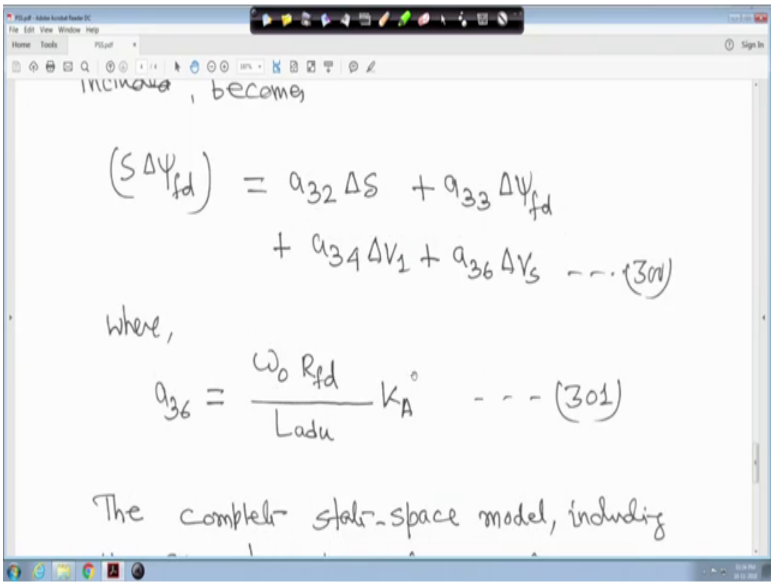

And a 3 6 is equal to omega 0 R f d upon L a d u into K A, just you have to modify those equations because delta E f d is equal to this much right.

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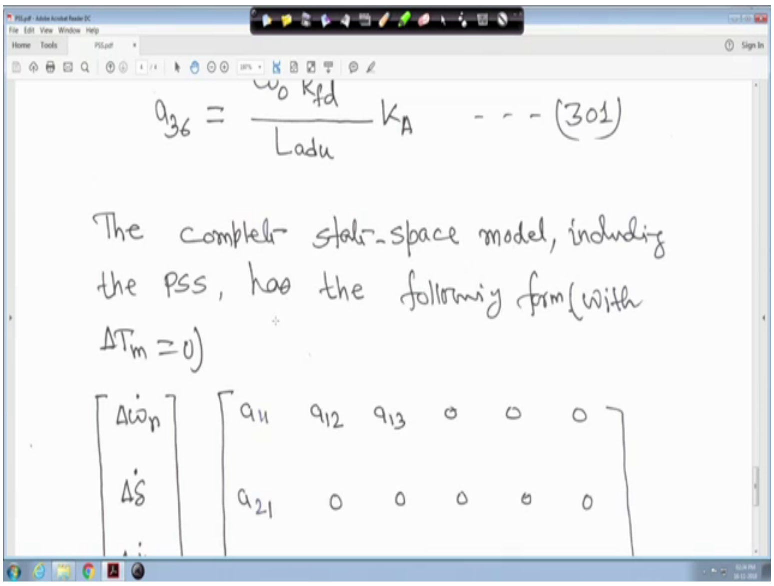

And therefore, the complete state-space model in including your PSS has the following form with delta T m is equal to 0.

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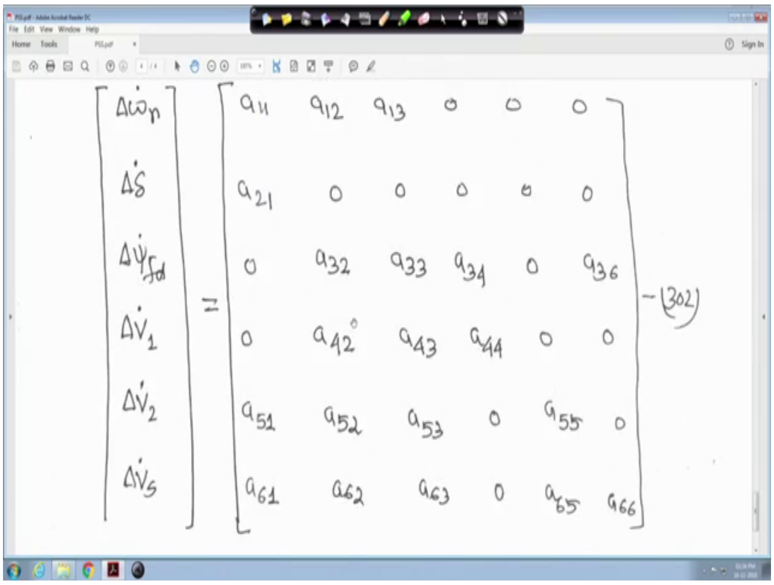

If delta T m is not there, and delta V reference also we have said 0. Say for example, so this is the order, but anyway for the analysis you have to consider the step input for delta T m that is why delta T m second term I have not written. So, this is your equation 302.

So, thank you very much, we will be back again.