Power System Operations and Control
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Module – 3
Lecture – 8

Welcome to lecture number 8 of module 3. In the previous lecture that is lecture number 7 we modeled exciter as well as amplifier in that modeling. Basically; in this lecture 7 and 8 we are trying to see how we can control the voltage. And already I discussed the various ways to control the voltage, the various elements those are generating and absorbing the reactor power.

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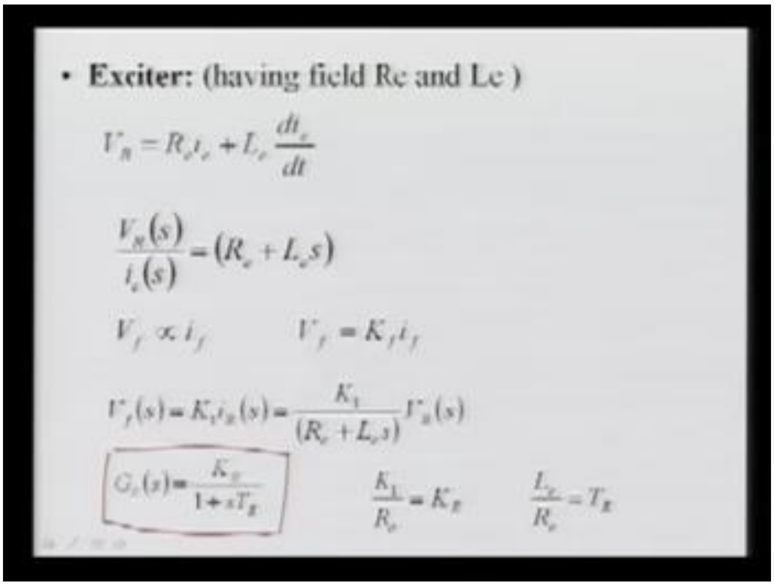

So, in the modeling part already we have seen model of amplifier of the VR loop. We also saw the modeling of your exciter and we from modeling exciter, I said that we can have a transfer function here and that is your transfer function of exciter that is k e upon 1 plus sT. Please note that here there are several other limiting values even though we have not considered this exciters and saturation effect.

So, this is a simple model. So, that we can see in the lecture that we can see the performance of we can say static as well as the dynamic performance of this a VR loop. However, for the detailed modeling if you are using computers etcetera then, you can go for the all the effects that is non-linearities limiters as well as the saturation effect.

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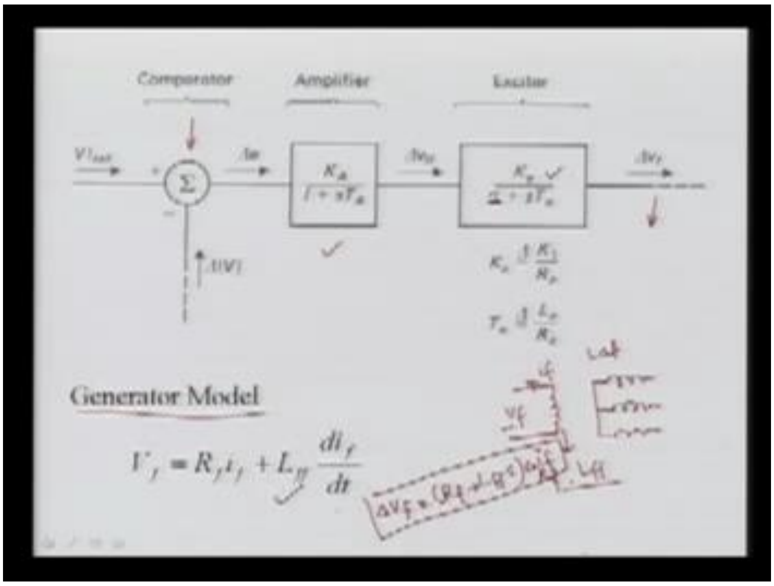

Now, another major component in this area loop is your generator; now, we can see here mainstream model of this amplifier. We had the comparator, we modeled this amplifier as an amplifier gain K upon 1 plus StA; again this Ka depends upon which type of amplifier you are using. We are using the rotatory amplifier, you are using static amplifier. Then gained value is decided accordingly and then we model your this exciter model and we represented K upon 1 plus here, this is 1 plus St and now, this is going to the field voltage of your main alternator and then we have to model that.

So, the generator modeling here as I said in the basic diagram of your complete a VR loop we saw that here your this armature that is 3 phase. Here it is the supplying and the field winding which was coming here it was rotating and this is your basically, your VF which is coming from the exciter. So, here we can write if the current which is flowing in the field winding is IF and if we are having this binding will have let us suppose Rf is the resistance of field winding and this l f is the self inductance of this winding. And if you are having because there’s some usual coupling between the field winding and the armature winding that, I can denote with a LAF means, it is the inductance between the armature and the field that is coupling.

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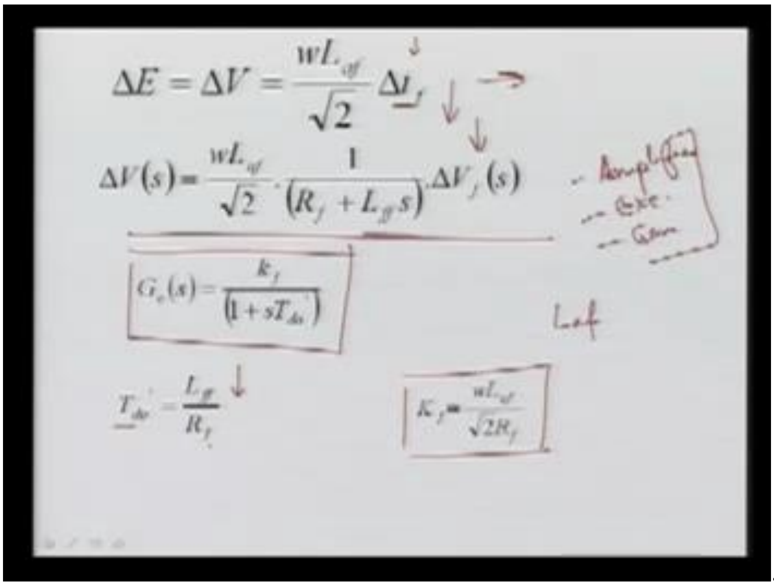

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So, for this circuit we have this Vf and we can relate with the If here with this equation means the voltage here will be equal to your Rfi f plus Lff dif of 1dt. Now, we have 1 relation here this excitation voltage a voltage that is generated in the terminal. Here the internal voltage we are talking this ef is no doubt it is your x.That’s you can say omega here, this omega is this, that is 2pi f. F is the frequency and l is the mutual coupling between a armature and the field winding divided by under a 2 into your change in field current.

So, here we have written in the different form. Now, from our the previous equation here means if you can take the laplace transform and we can write in the difference form, we can write here the change in your Ve f will be equal to your Rf plus your Lfs and here, I can say it is your If. So, this is your equation we can write here and already from this equation we have related that, If is related with the ef. So, from there we can put its value of If from the previous equation we can get this relation here. That relates you’re here, this is you are the voltage of the field and that is coming from the exciter. Exciters the armature that, is rectifier this voltage and that is coming to the d c to your field winding.

So, this is a change in the voltage this is written in the difference form and all we are adding the difference form to see the behavior of the system. Now, whole this we can represent here suppose Rf is multiplied here, Rf we can divided here, then Rf will be going there. So, we can write this complete the transfer functions here. Now, why I have written tdo prim. The tdo prime is your Lff upon Rf means, when your armature is open circuited there is no current or something flowing there. Then this time constant of the field here this Lff upon Rf is called the tdo prime.

If the time constant if you are ignoring this Laf; In fact, then it should be open your armature winding, there will be no induced current there. So, we can write the time constant of the field winding here your Lff upon Rf. So, it is tdo prime. So, we can represent this for you generator model and your Kf. That is gain we can write here omega Laf divided by, under 2r f. Now, we had the 3 modelings that is your amplifier. We have now amplifier. We model exciter and now we model the generator as well; with the help of this basically these are the 3 elements in your a Vr loop.

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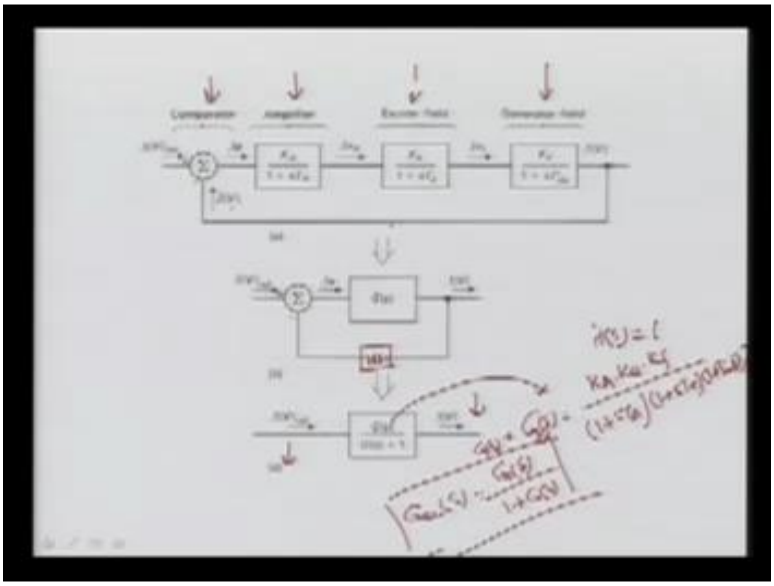

So, here we can now again thus we can add this generator field here in fact, your field exciter modeling amplifier and this is your comparator and then, we have you know this reference is coming from the again this voltage that is measured here and that, is compared with your Vf here, that is your reference value. This terminal voltage is going to be compared. So, this is a closed loop with unity feed very clear h1 is normally, you can say if normally we are having here some function h; that is feedback transfer function and in this case this s h is nothing, but your unity. So, if you can combine completely here and I can write this g s is nothing, but the total open loop. Normally it is called o l open loop transfer function is nothing but, your Ka into Ke into your Kf divided by all these time constant that is 1 plus Sta 1 plus Ste and here, 1 plus tdo prime s.

So, we are having this transfer function here this 1; now, the closed loop transfer function will be nothing but, here I can say this gc Ls will be your gs, it is already we have written as gs. Here 1 plus gh h is1. So, I can write here gs; Now, this is your complete your closed loop transfer function and then here. You're the reference value is now coming here and we are getting your the terminal voltage. The performance that includes your static as well as dynamic performance.

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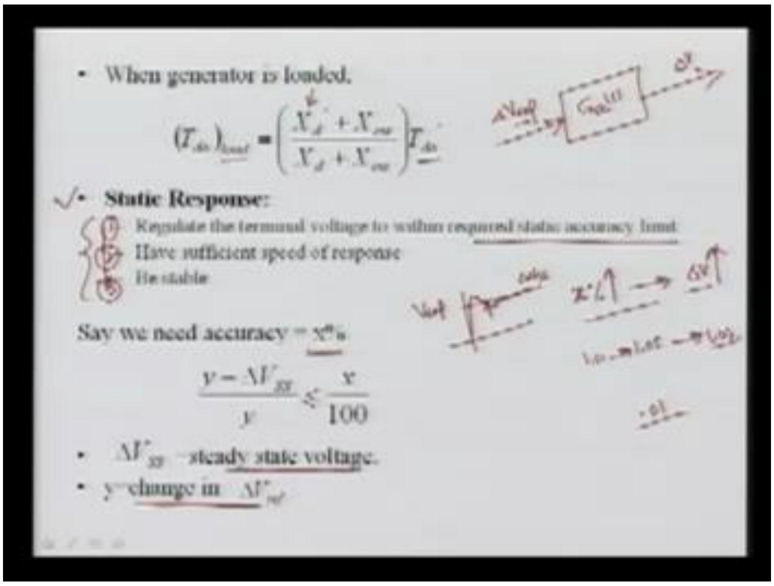

Let us see here, under the normally when your generated is not loaded then the tdo prime which ,we had considered that is tdo prime if it is not loaded, but once it is loaded we are taking current, then that value is normally modified. The tdo at the load here xd is the transient time direct axis reactance and here x external and then, we can from this value we can get the tdo with the load. So, the static performance means we have to go for the 2 performance. 1 is a static, another is a dynamic.

First let us see, the dynamic and then we have to decide the gain because gain is very important, that basically gains gives your information about, the static error and also that gives about your dynamic performance, whether your system is stable or not. So, here again, I can summarize the basic objective of this control loop that, it must regulate the terminal voltage to within required static accuracy limit means how much we want.

Suppose your reference is changed means for example, your reference is changed by x percent. What is you r change in your output voltage means; what is the error between these2 means, if it is we are changing x percent here the reference value this must also change x percent, then you can say a steady state error is 0.

So, we try to minimize that, this if you are changing let us suppose if you are initially it was 1 per unit now you are changing from 1 per unit to a reference 0.1, 0.5; this value here should also change to 1.05 and the difference should be change in that value, then we can say, there's a 0. So, otherwise if there is some error; normally we go for some accuracy. It is not possible that we can go for the 0 percent accuracy.

If accuracy is 1 percent 1 percent means, 0.01 per unit it is sometimes that is desirable. We will see why accuracy if you are going for more accuracy sometimes it is very tough and your system loop may be unstable. So, that is, 1 criteria; second criteria is have sufficient speed of response means, your response should be very fast means your settling time should be less than your settled. If there is some step change here, in the v ref. Here your v ref, you can change then it must your output should be changed here. And it is to be settled very quickly and other criteria that, you hold this a VR loop must be stable. If it is unstable, then it will create chaos and then if you want to do something it will do something; so, these are the basic criteria.

Now, let us see the static response and let us say we need the accuracy of x percent, x may be 0, x may be 1, x may be2 percent. So, here this x now, what is this x; now, we can define here the final that is your change in the v reference y to the change in the steady state voltage of this 1. You should remember here, this we had your change in your v ref. Here this is, coming your change in the voltage of your terminal voltage and here we got the gcl; that is closed loop transfer function.

So, here in your steady state your output means; what is the input change? So, I can say it is your y that is the change in here as I have written that, y is change in the reference value. If you are changing certain y component your what is your change in this value during the steady state condition, because if you are changing suddenly as I said, it will take some different value, but we are concerned about the steady state and this is you r called Vss, V1. So, this Vss input minus your output divided by input here, that should be less than or equal to x percent means x upon 100. If you want that 100, then we can say it is equal to x upon100, but if your accuracy needs we can say x percent means your system here error.

So, always less than that or it will be equal to that value; so, we want x percent accuracy. So, we can decide this accuracy in this way. Here the change in Vss is your steady state voltage. Now, let us see for our case if you are changing the V reference, how the gain is related with this accuracy.

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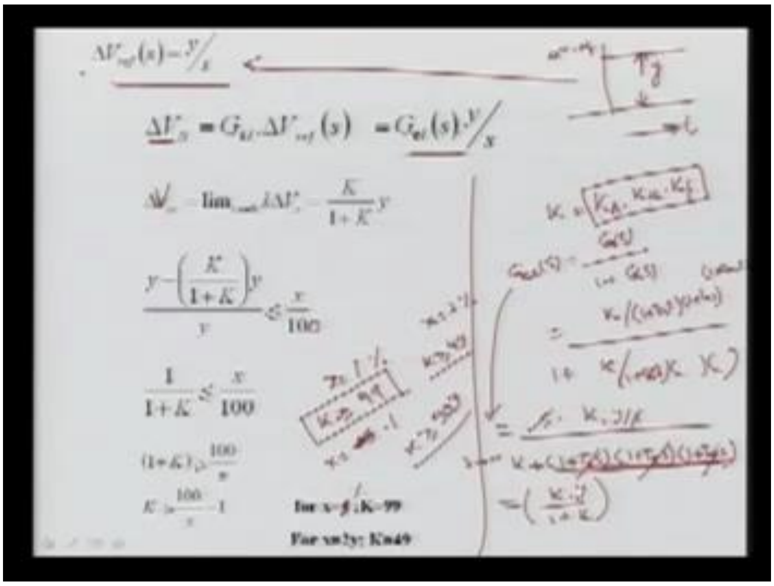

To see this here let us take, there is a step change in your input means your reference you have changed here is your y magnitude means; we have changed suddenly y magnitude and this is your change in V ref. Here this is your time; so, if you are taking this as a unit step input and for that, the laplace transform if you are taking will get this here change in the Vref that is s domain is equal to y upon s. Your output from your equation here this 1 will be equal to this reference, change in the Vref multiplied by your closed transfer function.

So, here I have written this g c l multiplied by your change in Vref. So, here this Gcl is not e l, It is cl multiplied by y into s and we know this our limiting value theorem. That the final steady state value, in this volt is ss will be the limit s tends to 0; s multiplied by change in Vs. Now, we can see now our Ka into Ke into Kf; I have let us go straight as here K value. So, what we are getting; now, the closed loop transfer function will be before coming here how I got it; we require this, Vs in terms of these values.

So, what we are getting; now, you remember this is your Gcl; s is nothing but, your Gs. This is the 1 over Gs. This Gs is the combined that is amplifier exciter as well as your generator model. So, here I can write this K upon various vector; that is, 1 plus Tas 1 plus Tes and here, multiplied by 1 plus Tdos divided by 1 plus here K. Again 1 plus Ts, Tas amplifier. Here your this and we are getting 3; Finally, what we are getting,you can see here, K upon K plus this time constants are coming to picture, means that is Tas into 1 plus Tes plus 1 plus Tdo prime s. So, we are getting this is your Gcr.

Now, what we are doing this ys just we are multiplying here. So, this complete value we are going to write here into y upon s into s and s tends to 0. So, what happens? This is cancelled out and all this we are putting as 0, so, this is 0, this is 0, this is 0 and finally, what we are getting? We are getting plus 1. So, we are getting Ky into 1 plus K. Here it is unity this value is completely. So, we are getting this and now I have written here you can remember here, this K upon 1 plus K into your y value. Now, this is your Vss.

Now, if we are using in our definition which I defined here that, this is your accuracy this is defined as accuracy. So, I can put that value here and then, I can write y minus K upon 1 plus k into y upon y. It should be less than equal to x upon 100 here. Now, you can simplify here. What happens; this y will be cancelled out here y y. So, we are getting 1 upon K plus this and finally, we can simplify here. We are getting this 1upon 1 plus x upon 100. So, we can reverse this means we can send this side here and this side here.

So, we will get this 1 plus K must be greater than, equal to 100 upon x or I can say, K must be greater than or equal to 100 upon x minus 1. Now, let us suppose you are having x is equal to 1; 1 percent. So, how much we are getting for 1 percent the K should be 99. So, you can say this is this x is equal to 1 percent means, x is equal to 1 we are putting and then, we are getting K must be greater than or equal to 99. Now, if you are going for x is equal to 2 percent, what is this is a 200 upon 2 minus 1 is 49; so, must be greater than 49.

This shows that, if you want to more accuracy your gain must be larger. You have to go for the larger gain. For example: if you are using x is equal to 0.5 percent or you can say 0.4 percent; let us what will be this value. This 0.1 here you are putting the thousand minus this. So, K must be greater than your 9999. So, for more accuracy gain must be larger and then, there may be possibility with the larger gain. Gain means; it is a gain for multiplication of these entire 3 components Ka, Ke and Kf, then for the larger gain you can see, for the 0 percent; what happens? Virtually 0 if you are putting 0 here this value is infinite.

So, you should require very large value of a and which is sometimes not possible. It is not possible to realize though infinite gain. So, this normally is we are going up to certain accuracy we can say our system is statically error is 0. Now, let us see our dynamic performance of this and the dynamic performance just we have to go for. We will see now, the various criteria are there to see the dynamic performance of this system.

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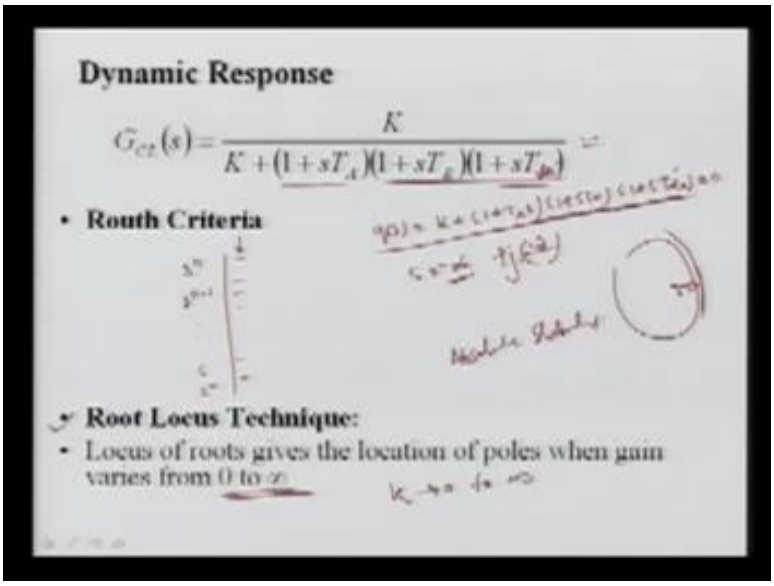

So, let us see our dynamic performance dynamic response here, the closed loop transfer function of this whole a VR loop can be written; again I derived also K upon K plus 1 plus here your amplifier. It is for and it is for your Tf or you can say write Tdo prime. Hardly matters because Tf is the field winding time constant and that is your Tdo prime we have used. To see the dynamic response normally the various criteria are there because the gain, we want to see for what value of K our system will be stable.

So, to see first 1 is that, normally we go for routh criteria and the routh criteria is basically, the necessary condition and it depends upon the characteristic equation of the system. Now, what will be the characteristic equation? Here we can write now this; here this denominator of this closed loop transfer function must be 0. So, we can say the characteristic equation here the qs. Here it is nothing, but your k plus 1 plus Tas; 1 plus sTe. Here 1 plus s Tdo prime.

So, this is your characteristic equation and this if we are equating 0 and then, we are going for the routh criteria and the routh criteria you must know, here we write if this is of order n although this is order 3 only. For the general I can write here, if you are writing for xn, then we write the coefficient corresponding to s n minus 1and so on. So, on and then finally, s and s 0 means that, is a constant and we see here we form this criteria and see the first here the column and that gives you the necessary condition. It is not sufficient. It is giving necessary condition.

So, if there is no change in the sign of the first column no change here in the sign, means if all are negative. If all are positive these coefficients of this first column then, it gives the absolute then it is called absolute stability. Only the problem here it does not provide the relative stability means relatively your system is stable. Let us suppose you are having your is the system of boundary of stability. You are here. How far from your unstable zone.

So, it is not providing the relative stability so, that how much gain we can go for. Then we normally go for another 1 that is root locus technique. Root locus technique is nothing but, it is the locus of roots they location of poles varies from 0 to infinite. Means here, if k changes from 0 to infinite how the roots are varied because, the roots of here the first criteria that here k is varying. Then what happens? The root of this characteristic equation will change.

Normally here the 3 adder system is there; you can say s s s cube will be there. So, third order system in this case, is appearing and what we can do always this s should be here the negative plus minus some miserly part and I can say some coefficient alpha and here you can say omega. So, this must be negative in all the cases, but by varying case there is a possibility that this may go in the positive side and system will be unstable. So, this routh root locus technique gives information if you are changing gain, how the roots are changing, whether they will cross to your left hand plane s plane or they will in the same plane. So, we can decide the gain and it will give the relative stability as well

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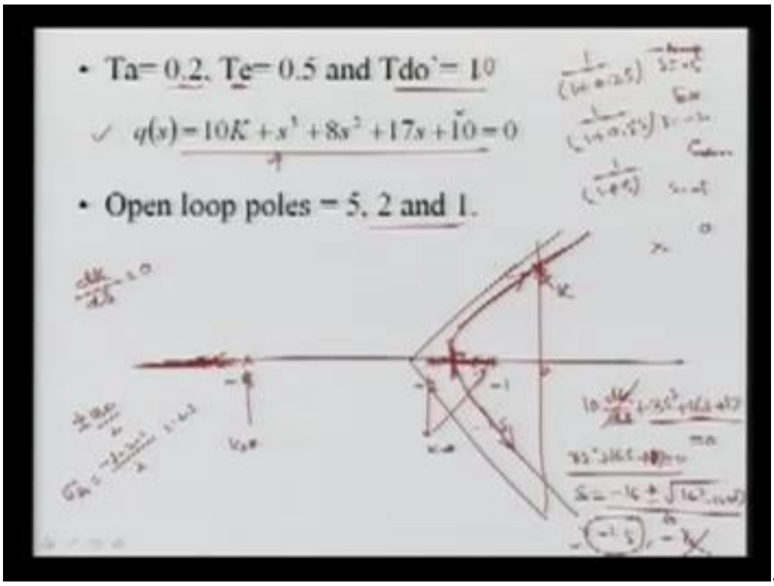

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To see that; let us see 1 example: we can the Ta is equal to time constant of amplifier is very fast because, let us take the static amplifier 0.2; that exciter time constant here 05 and the Tdo prime let us take it is unity. So, if you put these values then our characteristic equation, which was here and we can now we can write with this value putting this we can simply, we can write this characteristic equation in this form . And you can see, we are having the order 3 means we will get 3 roots of this equation.

Now, from here we can now see the open loop poles are this 1 means for example, you can see what we are getting. This 1 upon 1 plus 0.2 s for your for your amplifier for your exciter we are getting 1 plus 0.5 s and your generator, it is 1 over 1 plus s. So, poles are here when you are putting this is equal to 0. So, here s is equal to minus 1. Here if you are putting s is equal to minus2 and here if you are putting 0 then we are getting s is equal to minus 5.

So, we are getting open loop poles 5.2 and 1 corresponding to these 3 and then we have to draw this root locus and we will decide it. So, from here what we do? First criteria are that normally here we go for we draw root locus technique. Here your s plane, here it is your 0 and then, we mark the open loop poles and the poles are denoted by x and the 0s are decided by 0. So, here it will be let us supposing 1; so, I can say 1 will be here. Another is your 2 I can say here the2 and another is here 3, 4, 5; this is you 5.

So, it is minus 5 minus2 and here it is minus 1.So, their 3 open loop poles are there, 0s are the numerator. This upper part of the characteristic closed loop that will be that 1. So, here now know that, there are the various roots means root locus ad the movement of here means from 1s K 0. Let's suppose this K is 0. We are getting this 1 and they are nothing but, if you solve we are getting these are the loops.

So, when K is 0 means we are starting at this point here K is equal to 0. Here also your K is equal to 0 and this value also K is equal to K is 0, but we want to change k means from 0 to infinite then, we will see how they are changing, 1s K of 0 they are lying here and it is your open loop. Now, the movement here always this criteria says that is here, always if you are adding 0 then, your poles and if it is even then odd then it will be going in your left hand side.

So, here it will be moving like this direction; here it will be moving like this direction. So, this will be going in this direction, this will be going in this. Here it will be going in the different direction because they will be emerging and they together. Now, for that we normally decide; now, here there will be some breakeven point that, these2 where they will go even increasing means there will be 1 point, they will go somewhere else and then, what will be their point of here leaving point that they will leave and what will be the angles, at which they will be moving.

So, that angle normally decided that where they will lead it is normally decided by the plus minus 1 aT upon 2. It is your 90 degree, again depends upon here thus the number of 2 there is no 0s. So, they will be leaving at the 90 degree somewhere. So, the poles here they will be moving here. Now, what will be the goes where the angle they will be moving. It is decided by your point where we can draw the axis that will be decided by all these poles divided by 3.

So, minus 5 minus 2 minus 1 divided by 3 and it is nothing but, your minus 2.3. So, that value here we are taking 2.3 and this is and we have to now decide the angle. Angle will be the 60 degree here. So, these 3 axes will be there 2.3 here. Now, this will be leaving at the 90 degree here and then this will be changing. Here it will be the 90 degree. Now, what will be this point of that, where it will lead this real axis. That is basically decided by taking this delta Ks by ds is equal to 0; to know this what we have to do. We have to just differentiate t his characteristic equation here and then, we will get the value of that.

For that, if you are differentiating this here means we are getting 10 del k upon del s plus if you are differentiating with the s here is a 3s square plus here your 16 s plus here 17 and that is equal to 0. Here it is this is a constant, and then differentiation of this will be 0. Now, we know that this value is 0 means, we are getting here this is equation, t hat is a 3 s square plus 16 s plus 17 is equal to 0 and if you are solving here this is a quadratic equation and then, we will get here s is equal to nothing but, your minus 16 plus minus here under root I can do go for 16 square minus 12 into 17 divided by, your 6 and the finally, we will get the value here minus 0.5 and here, we will get the minus something four or something 3this is not possible.

So, only this value is the breakeven point where this breaking is leaving this 1 leaving point. It will be between minus 1 and minus2, because this value is coming here that is not true. So, this is not valid only we are getting. So, they will be leaving here in the intermediate of these points. So, it is the point here it is your 1.5 minus here and they will be leaving at the 90 degree and finally, here the movement will be like this. So, this will be your root locus, while changing the K here. This is your characteristic that is going here means this will be moving by movement of your K and this value is going here.

So, k from 0 if you are increasing this 1 here your loop holes is moving in this direction. other roots 2 roots are going in this 1.Now, you can see once we are increasing this is crossing your imaginary axis here and once it has crossed means, your system will be unstable. So, the value of gain here that is your gain critical means, always your gain must be less than this. Otherwise it will be unstable unless until you are going for some compensation technique.

So, here we have to determine what the value will be for let us suppose for this time constants to obtain this we have to do. We have to find the intersection of the imaginary section and that can be done by going for here, the open loop poles means we have to see when it is changing and that we can use nothing but, your we can go for using your routh criteria, for that and in that criteria what we can do. We can simply we can form this s cube s square s and s naught.

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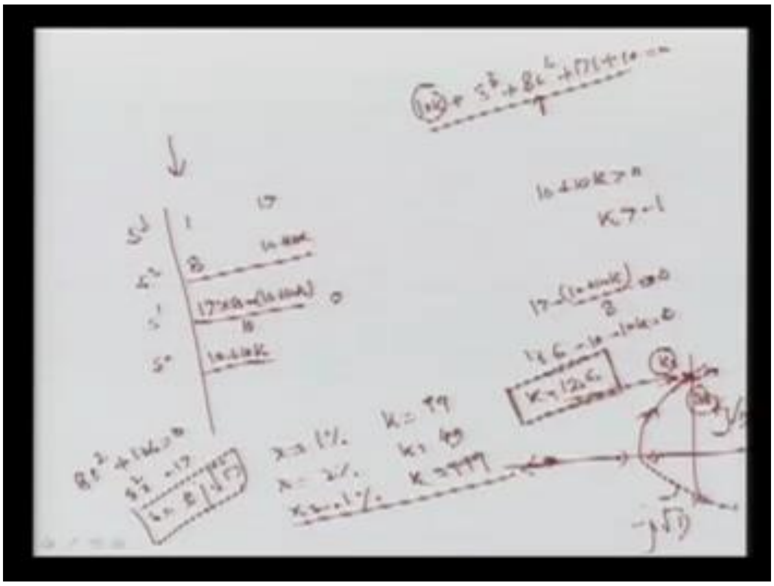

So, to obtain the value of k we have to go for your routh criteria and here we can write the again equation that we obtained that is x3 here plus it was your 10K. If you remember plus x3 here 8x square plus 17 s plus it was 10. That was equal to 0 and for this equation we can just write your routh criteria. So, x cube here is 1; your x now minus 1 the even; now, we are writing here s now it will be 17 for the second column. Here for the second your the second row of first column here it is your right this value square, then we are getting here 10.

Now, this is not only 10 because this is also constant. So, we are getting our 10 plus 10K. Now, s1 is now calculated from here means we have to calculate this and the divided by that value. Then we are getting here 17 here, it is simply s, this value is now we do not have that value. So, that value is calculated and that value is calculated this multiplication of this divided by this value and we can get, that value here is your 10 plus 10K divided by your 8 and here we are getting nothing but, your 10 plus 10K. Now, to obtain that value what we can do, that this value must be greater than 0 no doubt. What we do?

Normally this minus this value is calculated and this value is here what we get 17, we calculate here this multiplied by this minus this multiplied by this we are getting 10K plus divided by 8 and this value will be 0 here we are having 0; so, we are getting. So, what we have to see for the routh criteria the first column here, it should be positive and let us see when, the sign is going to change means here we are first criteria that here we can say 10 plus 10K; So, will be greater than 0; here it should be greater than all the here positive it must be positive.

So, here we are getting K should be greater than minus 1and that is always true. For another condition here, from this 1 you should be also positive. So, I can write the 1788 will be divided minus here 10 plus 10K divided by your 8 must be greater than 0. Let us suppose for the 0 what the value was 0 means, we are at the axis. If it is not 0 means we are just below, this imaginary axis here as I said we are the so, k value is less here. If it is positive then, we are here somewhere, but if it is 0 we are here. If it is more means sign change and system is unstable and we are here.

So, for the 0 we can calculate this is your nothing but, it is multiplied by here 17 into 8. This is your 61 36 minus 10 minus 10K is equal to 0 or you can say is your k is nothing but, 12.6. Now, you can see here the gain value if for this time constant it is more than that, then your system will be unstable. Means here you can see this value K if more this term, will be negative means there will be sign change and it will be crossing your imaginary axis, but in the static we saw for time constant because it was not related with the time constant gain at that time.

So, the K here accuracy 1 percent we saw K we required 99 x is equal to 2 percent. We saw k we require 49 gain and we saw x is equal to 0.1 percent here K was 9900and 99 means, if you are going for more accuracy gain is more, but here it is now may change may cross this. For you can say your gain is equal to for this k we can determine what will the accuracy as well no doubt we can represent.

So, it is for the time constant give you dynamic response and this value decides the stability means, you can if you are increasing the gain more than this. You will be no doubt you will get the more accuracy static accuracy, but your system a VR loop will be unstable. Again now, we can also determine what will be the pole or root where it will be means here I obtain the K value that k is here we calculate it.

Now, I want to know what will be the here s value. What will the root? What will be the magnitude where it is crossing means; we have this characteristic if you remember? This is an 1 is here crossing here it was moving like this and going like this. So, I want to know that, this value of s here and that can be obtained by the function. Function is nothing but, what is the function here that we can form. So, at this point x K we have calculated. So, I can write this a s just below that, above that it is 0.

So, we have to take this function and that will give the system oscillation that, will also get what will be the root at that time k is equal to your 20.6. So, it is your 8 s square plus here if you are putting the value of k is equal to 12.6 here. It is 136 is equal to 0 or you can say s is equal to s square is equal to your minus 17 or you can say s will be plus minus here under root 17.

So, we are getting the values of here s is equal to this top 1 is plus j under root 17 and here it will be minus j under root 17. So, we got the here root also. We got the gain also and then we saw that both are contradictory to each other.

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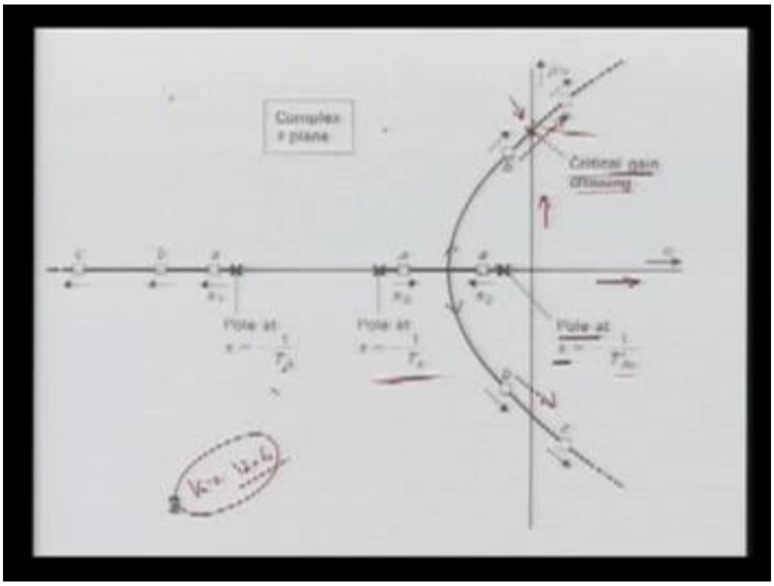

So, let us see now overall that is you’re that root locus plot. This is your complete s plane where this is your real axis. This is your imaginary axis and we saw, that this x relates that the pole at x is equal to minus 1 upon Tdo prime. This was related to your generator here this pole was your exciter 1 upon t pole and this pole was for your Now, once the gain is moving here the d is cross points the gain is equal to 0.That is called open loop gains. Now, if you keep on changing your gain then the movement as I said, it will go at a point they will move here it will move at a.

So, it is an 8 point. If you are again increasing the gain you will reach to b point and this will be here, it is going in this way and it is reaching here and the system is stable, but again if you are increasing the gain let us suppose, c point then your gain from b it can cross the axis here and then, your system will be your a VR will be unstable. So, then we find that crossing here is called your critical gain crossing and the root here that, gives your oscillating system will start oscillating even though I has this point. Although it has not crossed, but your system will start oscillating and then, this factor is small disturbance may lead to your system unstable.

So, we have to decide our gain up to this point even though below that and our system will reach stable. So, this is our without any compensation technique without any weight to improve the stability of this loop and we find that gains was very less to 12.6; it is very less and for this your steady state error will be very high. So, what we have to do because the static gain we require more gain. So, we have to do some compensation and then, we can improve the stability of the loop and that let us see what, the various ways to improve are.

So, we observe that the stability and the accuracy are conflicting, hence for both we use the compensator, means; we can improve the accuracy for going for higher gain at the same time how we can improve the stability of the loop. So, the compensators that are now available.

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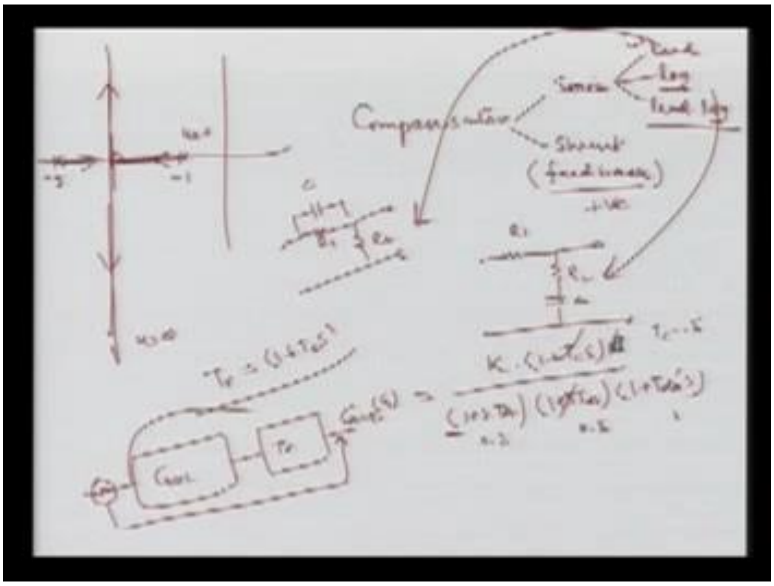

Here I can say compensator; the 2 types of compensators are there. 1 is your series and another is your shunt and no doubt we also have shunt, basically it is nothing but, it is called your feedback, feedback controller's feedback compensation. In series we have the different types. We always you know it; it is your lead compensator. It is your lag compensator; it may be your lead and your lag compensator. Again the lead compensator here is used to improve the stability of the system.

The lags here compensator is used to reduce the steady state error and if you are using lead lag then, it will both your improve your static error as well as it will improve your stability of your system. Normally, the lag compensator here it is nothing but, it is some sort of here it is resistance here your resistance here is, your capacitance and this is your is your compensator for you lag compensator. For your lead compensator it is nothing but, it is your resistance then put the capacitor in parallel with this and here it is your resistor R2 and this will give you means this is your R1, R2; here c here your R1 and R2 and it is c.

So, this is your nothing, but your lead compensator and if you are combining both, then we can get lead lag compensator. Now, the feedback here the feedback compensator is used to improve the robustness or the more stiffness of the load variation and always we use here, we are talking about the positive feedback. So, the feedback controllers are also 1 way. Now, let us see how it can improve the system stability. For example: let us add a series phase lead compensator means, we are using in the series first 1 and the transfer function here, let us suppose Tr is equal to your 1 plus Tcs. Now, you can remember our open loop transfer function that was your Goc open loop s. It was your K plus 1 plus st a. 1 plus your s Te and it was 1 plus your Tdo.

Now, you are using the series then it will be multiplied means we are having this your g open loop and now, we are using some here that, T r that is a compensator and then we are having a this loop. Normally we put this 1here this side because the output here is simply voltage. So, if your will be multiplied here and now we are getting let us suppose 1 plus t c that is the time constant of compensator and here. What we can do? We can set the value of this Tc in such a fashion that, we can cut any of any of our poles here we can cancel here the open loop poles here.

For example: as I said the Te which are having a 0.5 here we had the time constant 1 and here we had the time constant as 0.2. Now, if you are putting the Tc is equal to is 0.5 then what will happen. This and this will be cancelled out and if you will draw here, this root locus here again now what now we are having in this plane. We are having 1 of course. This is for the Tdo prime and then we are having for your amplifier it is your somewhere it is minus 5 here minus 1 here.

Now, what will happen? If we draw this here we will find that the poles here if your gains are increasing here they will leave at the 90 degree and we will find this type of characteristic. So, after changing it will be again starting from K is equal to 0 here and it is moving here K is your infinite. So, now you can say this after doing this compensation this is not crossing at any time. This imaginary axise; so, your system is always stable even you can go for the larger value of your gain and if you are going for your larger value of gain your by static error will be minimum.

So, you can see with this using this type of compensation that is series lead we have used and our system is improved and stability is very much improved here. Another is your let us see the feedback. In the feedback it has also some great advantage that, it is very robust and also it provides more stiffness to the load variation. If load are changing also there will be less effect.

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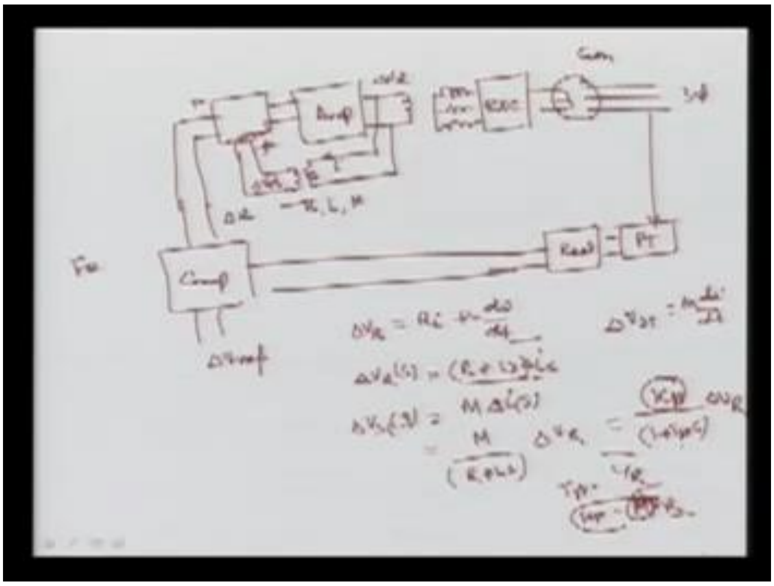

What here normally we do? If again I can model this is your generator this we are having here the 3 phase power that, is your taking here and this is your field winding and this field winding is basically through your exciter. Here exciter and this exciter is nothing but, your 3 phase power generation again is another alternator and the field to this we are giving from your is field and this field current is coming through your amplifier. If you remember, this was nothing but, your change in VR here and this field it is your generator or alternator there 3 phase power supply is going.

Now, here we have another basically we have the comparator means we measured, again you could remember this suing the pt. This is a potential transformer means voltage we are measuring and this is now, given to your rectifier circuit means we are getting some Dc voltage and this Dc voltage again is compared with the comparator and then, we are here getting v reference value and this is coming your change in e.That’s error.

Now, here we are using some let us suppose the series here we are using some series sort of compensator and this is value is coming here and this here we are having another winding. Let us suppose here and then we are this is related with the feedback I can say. So, here we are giving a feedback that is here some editor here. We are adding the positive feedback here means, we are adding this is a from this block. This is adder f of x.

Now, here we are having your change in the Vst; that is some voltage is generated is thus we are taking here and let us suppose, this is the winding is in r l and m that is mutual coupling. So, I can write the change in the VR will be equal to your Ri plus your l d I upon dt. Here this voltage here in this circuit here your I is coming and you can write this and finally, we can write in laplace form. Your r plus your l s here I s again, it is change in the I s and now this change in the Vs t it is nothing but, I can write this m d I by d t. The mutual coupling between these2 though this Vst is generated and then we are adding together here.

So, again I can write this Vst laplace domain it will your m here and then we can replace this value from here taking laplace means we can take m into your change in I s and this value is here we can write. So, we are getting m over R plus ls or this is your Vr or we can say here, simply we are getting the Ks t the gain plus 1 upon Ts and we are getting here change in Vr. So, this is your time constant and this is nothing, but the Tst, It is your l upon R and your Ks t it is your m upon R.

So, these are the gains and the time constant of this feedback and then with this we can if you are putting there because t s t is very small and if you are putting then, we can also improve the stability of the system. So, in total you can say this is your feedback means we can improve the stability either using the series or with the shunt or that is called the feedback and we are using here the positive feedback and it will improve. You can now out this 1 in this feedback and then you can analyze you will find again, we can by changing this value of m and n or we can change the feedback because you can say this gain is directly related with your m upon r.

So, m the mutual coupling we can change we can have the winding in such a way R is the resistance always the resistance is very less because if you are putting more resistance there will be huge loss. So, this is your feedback controller; now, let us comeback to this whole your a VR loop where, we previously ignored certain things and we ignored your basically, your excitation compensation techniques and now I will explain that.

So, just I discussed that we can go for series compensation. That’s lead compensator because we have to improve the stability stability is the major concern for us. So, we can use the series compensation also we can go for the feedback controllers always we saw the feedback how it can be done.

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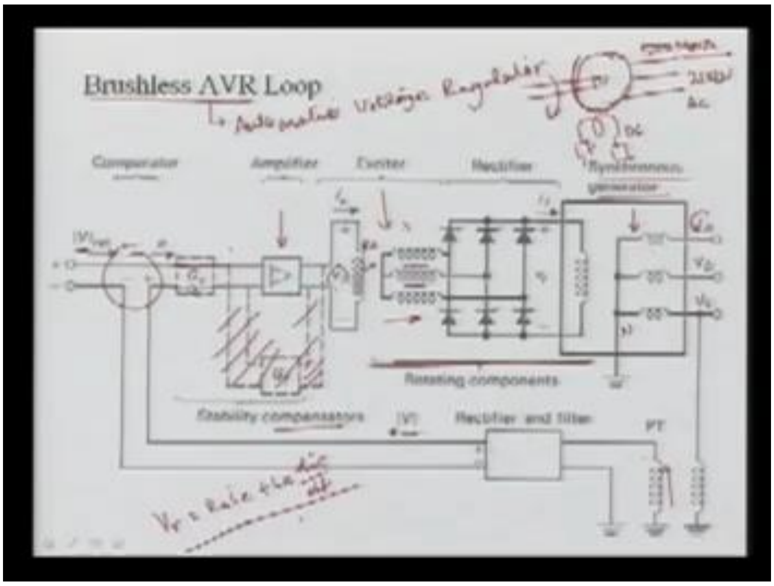

So, if you remember in our lecture number 7 we had this brushless a Vr loop and I cut the2 transfers functions here g s and your g f. Now, this g s is coming from there. So, this Gs is nothing but, it is your series compensation. If you are adding any series compensator that is a lead compensator then, this block will be added in the series of your this transfer function means series transfer function your amplifier, transfer function exciter transfer function and of course, the generator field constants. So, these four will be added.

If you are using feedback and you are not using this then you can see again I explained this feedback that is Gf and Gf already we modeled that Gf in that fashion. So, this is your feedback and if you are going for your feedback as well as Gs then, all these two components will be varying. As I said the feedback is required to provide the robustness and more stiffness to the load disturbance and always we use the positive feedback. So, we can use this 1 along with the series because that improves the stability upgrade.

We saw the even for our larger even though infinite value of gain very high value of gain it is not crossing the imaginary axis and the loop a VR loop will be stable. So, to recap here what we did in our for the a Vr loop in the our first and that is lecture number 7; I model this your amplifier means we solve and reactive power generators means voltage control. Here then we find various components then we saw the Vr loop. Then again we model our amplifier with this 1 and I did not consider much only I just take the first order the transfer function that is amplifier gain 1 plus St a. The time constant and gain are basically, depends upon which type of amplifier you are using.

You are using amplifier, you were using static amplifier. The gains are changed accordingly if you are using static then gain can be very higher, but for others it may be not so the time constant also if you are using static gain amplifier then the time constant is very less. Now, so, another just we went for exciter modeling and then we saw the exciter that's we can have our transfer function like this. This Ke upon 1 plus s t and then, in this whole exciters and model we ignore the limiters because this value is also having some limiters in the Vr means, your Vr cannot have all the values.

So, we can have limiters and then we can of course, we model this and we ignore the saturation because again it is a rotating type of excitation means it is machine saturation effect because saturation effect will also take into the picture. So, this was your transfer function here and now what I can see; we can now, we compared now amplifier then exciter we model and then, that is v f which now went for your generator modeling and this is your Vf and we came here. Normally we did not consider here the value of the limiter as I said. We can have the limiters here and also we can, with this limiters we can regulate the value of Vr and also we can take the saturation effect. That will be another loop in the here excitation, that's feedback loop will be coming.

Next then we model we modeled our this generator and the generator transfer function we write here the Kf upon s t and we had the complete loop and then we derived the closed loop transfer function. What we did we static performance static performance we saw in terms of accuracy how much accuracy you want. And then you found that accuracy for higher accuracy the gain must be larger. For lower accuracy gain must be less, then we saw the dynamic response. In that dynamic response we analyzed this closed loop transfer function and the routh criteria is 1 way that, will give you necessary condition, but it is not sufficient it is does not provide the relative stability information.

So, we normally we went for the root locus technique which gives the plot of the root from varying gain from 0 to infinite and then, we take 1 example here with this 1 by taking the your amplifier time constant 0.2 exciter 0.5 Tdo is 1 and then, we analyze this complete and we found that our whole this root locus is varying like this and finally, at certain value it is certain critical gain it will crossing and then your system will be unstable. So, we have to use some stability improvement techniques means some compensations are there is 2 types of compensation whether it is series or feedback.

In series there's various 1; it is lead lag or lead lag together, then feedback and the lead is used because it used to improve the stability of the system and we also saw, if 1 of the pole here we can cancel this, it will be here. Simply it will be vertical axis and it will not cross the imaginary axis.So, the system will be purely stable.

We also just went for feedback loop and then, if you are using feedback that will provide you robustness and more stiffness to your load variation and then we can go for the combination of both type of controllers and then, here this includes your complete your a v r loop. Now, in this next lecture we also discuss the various types of other facts. Basically, the reactive power controllers apart from which we discuss in lecture number 7 and8 that we will be using some sort of devices and using the power electronic devices we can use the static compensators.

So, that is we are changing the reactance value whenever it is required; that's s Vc it is called static compensators. There are other devices like stat com static synchronous compensators and others like, controllers we will discuss in next our next lectures. How they can improve the performance of the system in terms of voltage control. For the voltage control and also for, you power flow control or improving the stability of the system these devices are very much useful and that we will see in lecture number 9.

Thank you.