Power System Engineering
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Lecture - 51
Load frequency control (Contd.)

So, with this we have seen that with integral controller; actually your frequency deviation that delta FSS is zero. So, whatever we have seen with integral controller. Now, next will come to the, your what you call that steady state value for that, your generation.

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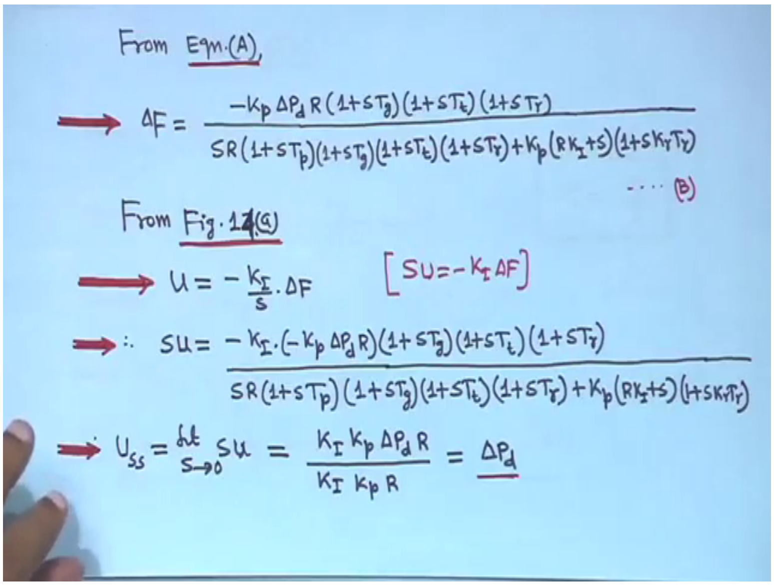

So now, from equation A, I have given some number equation – A, B. From equation A, I mean this equation.

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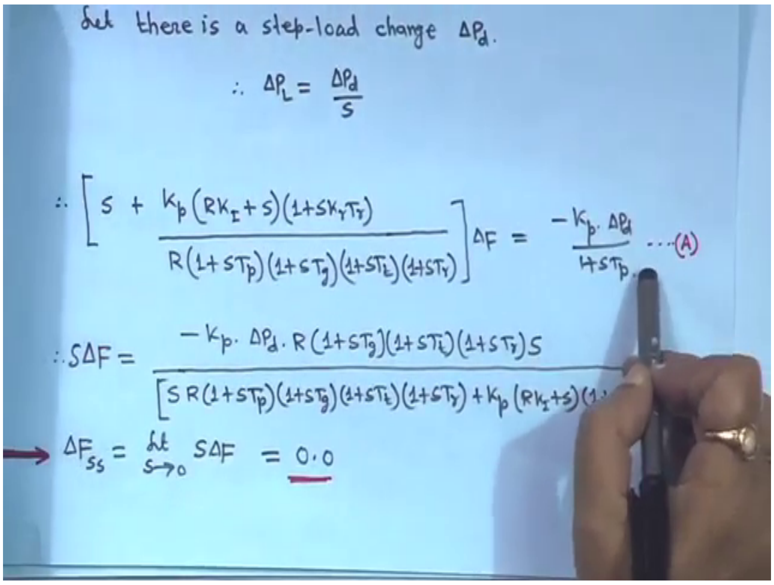

This equation, I mean this is actually equation A. This is equation A, I have given this number as A, instead of any other thing I have put A, so from this equation only - from this equation only. So, delta F can be written as this - minus K p into delta P d into R into 1, plus STG into 1, plus ST t into 1, plus ST r, divided by SR into 1, plus ST p into 1, plus STG into 1, plus ST t into 1, plus ST r plus; this is A plus I, there plus K p into RKI plus S into 1, plus SK r T r. Say, this is equation B. This you are getting from equation A.

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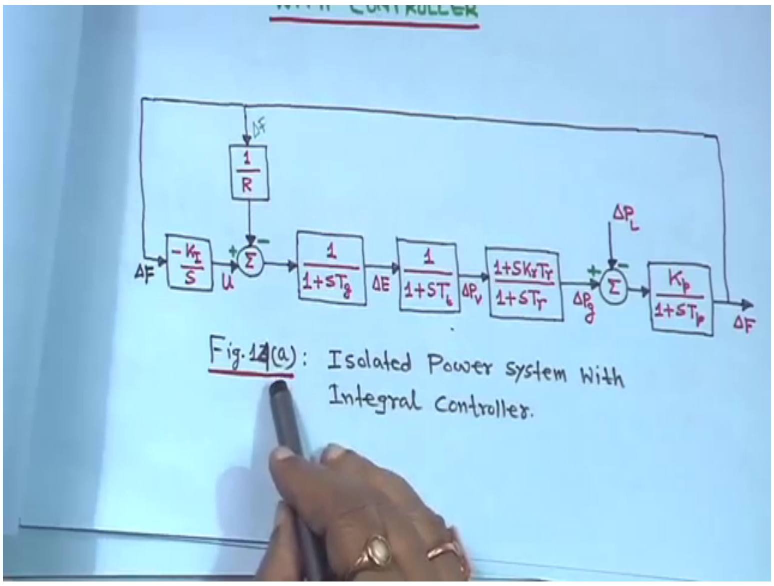

Now, from figure 14 a, that means, from this figure: from this figure, just hold on. From this figure; from this is actually 14 a. Figure 14 a - from this figure, that U is equal to; if you look into that U is equal to minus k I upon S into delta F, U is equal to, Minus k I upon S into delta S; that means, from this is U is equal to minus KIS upon S into delta F, that is S into U is equal to minus k I into delta F, so that means; S into U is equal to your minus k I into delta F and this delta F, you substitute here. You substitute here delta F!

If you substitute delta F, you will find that S - it is minus minus plus and SU will be - is equal to and for your steady state error, for U it is limit S tends to 0SU. Is equal to – here, you put your; what you call that S tends to 0. Basically you will get, K I K P delta P dR. Your denominator K I K P into R. K I K I will be cancel, K P K P will be cancel, RR will be cancel; is equal to delta P d because here, you put S is equal to 0. So, all this three terms will be 1 – 1 – 1. Here, if you put S is equal to 0. So, first term is zero; first term is zero and second term, if you put S is equal to 0, it will be K P R K I.

So, k p R into K I; we are writing k p R into K I and here, if you put all S, this will be one. This term will be one, this term will be one and it will be K P K I delta P d into R. So, ultimately three terms will be cancel. So, at steady state, you will get that value of this thing. Your what you call is, equal to delta P d; that means; that means, at steady state value of U will become value of the step disturbance. Your whatever it is; that means, it is whatever I mean, philosophically whatever load demand has increased. In this case, say it is increased case, it increased or decreased – does not matter!

Suppose, it has increased right though; that means, if it is a steam turbine, It is a steam turbine. So, that equivalent amount of steam will be going as an input to the turbine, such that at steady state that your, what you call in per unit value; that it will match to that your, what you call the power generation value. I mean, increase rather increase load demand value. So, whatever power will generate, the delta P g will become delta PL. So, that is why at steady state, whatever value will be; that is equal to, actually will be become delta PGS.

That is why, that U steady state value, we have taken like this. So, from your assignment numerical problem without looking into your, what you call - without looking into data or everything, you must know that suppose some; suppose it is R, suppose delta load demand has increase to your one megawatt. Then, what will be the steady state value of

USS? So, USS also will be one megawatt. So, this is; this should be something like this. That is why I told you, even if you take proportionally integral controller, you will get delta P d value, also even if you take PID controller; again, USS will become delta P d also.

So, whether it is PI; your IID or P d, I mean all sort of combination, whatever you take except proportional. Proportional cannot eliminate the steady state error. Except proportional, if you, integral action is there. If integral action is there, then it will be U; steady state will be your load disturbance. It may be combination of integral and derivative, it may be combination of PID, it may be only integral. So, those things case, it will be P d.

But if you take P d or only proportional, something like this or only, derivative something like this, it will never be like that. It will show some other; your what you call - USS may become your load; disturb may be generation, you will find frequency; you will show steady state error. Frequency will show steady state error. So, though those things, but in that case, if you is PI, your integral; integral derivative or your proportional integral controller, you will find frequency will become zero.

But if we, integrator is not there, those frequency will not be zero. Steady state value, it will so, but at a steady state, if you check for all this PIPID, all these things. In this case,, both in this case, both cannot be made your, what you call - this two is steady state value USS, but steady state may be delta P d, may be achieved with proportional or P d or everything, but frequency will never become to deviation, will never come to zero.

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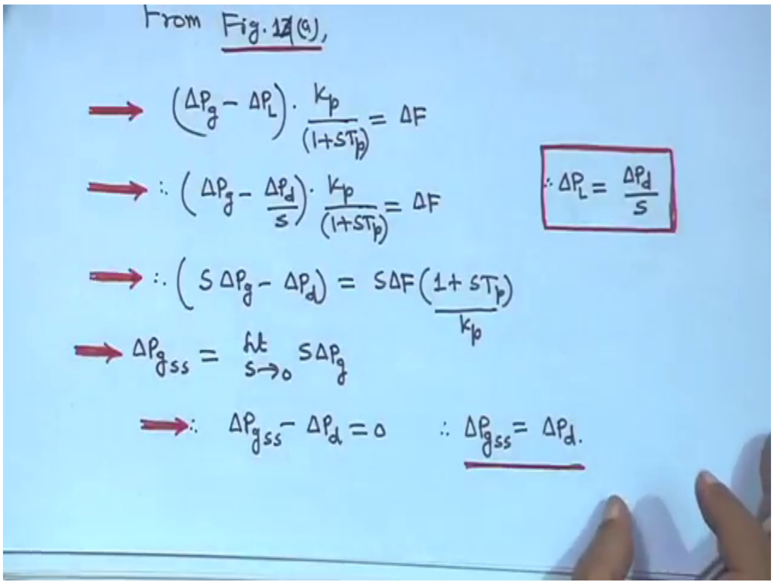

So, this is one thing and from figure 14 again, we know the balance is delta P g minus dealt; this - this is known to you, delta P g minus delta; this is 14 a. Figure 14 a.

Delta P g minus delta PL into K p upon 1, plus ST p is equal to delta F. So, here it is also delta F. This one, we are writing and dealt it is a step disturbance. So, delta PL is equal to delta P d upon S - say. So, delta P g minus delta P d upon S into K p upon 1, plus ST p is equal to delta F or SS delta P g minus delta P g is equal to your S delta F. Into your 1 plus, just multiply cross multiplication - 1 plus ST p upon k p.

Now, steady state value for delta P gss is equal to limit S tends to 0 S into delta PG. Look every time in bracket SS, I am not try to put S – S – S. Things become clumsy, but it is understandable to you that it is all, it is a lap lace function. Your function of S. So, delta P gss will be limit S tends to 0 S into delta PG, so; that means, your what you call - that means, this one, if it is limit S tends to 0, if you take this side, will become zero; both side you take limit S tends to 0.

So, this will become delta P gss, this will become minus delta P d is equal to this. S into delta F - this thing, if you put like this, that S into delta S tends to 0; mean this term will be your one. K p will be there and we have seen that S into delta F limit, S should be delta FSS and delta FSS is equal to 0, we have taken.

That means, this will become actually delta P gss minus delta P d is equal to 0. Then, we have steady state delta P gss will be delta P d. So, this is if you have anything, just let me write one line for you.

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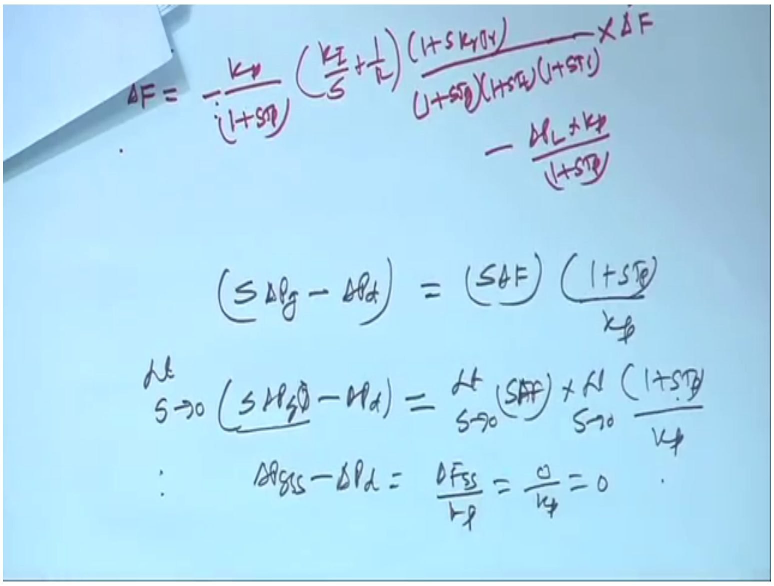

This equation, this equation we are writing actually S delta P g minus delta P d is equal to S delta F. Into 1 plus ST p upon k p. So, both side you take limit S tends to 0. So, this is S delta P g minus delta P d is equal to limit S tends to 0. This is S delta; sorry, delta F. Into your limit S tends to 0, 1 plus ST p divided by k p.

So, this is limit S tends to 0, S delta P g is this one, is delta P gss, this one will remain as delta P d is equal to; this is your delta FSS divided by k p. Because it is tend to 0. So, it is k p, but this one delta FSS. We have seen that zero by K p is equal to 0. That is why delta P gss minus delta P d is equal to 0. So, that is why your delta P gss is equal to delta P d. So, steady state, here no question of even, if even - if your D term is there, but when you put the controller steady state, value will be exactly equal to the load disturbance.

Suppose 0.01 per unit to load disturbance, so, at steady state delta P gss will be equal to delta P d. Now, if you suppose with that integral controller, some gain KI.

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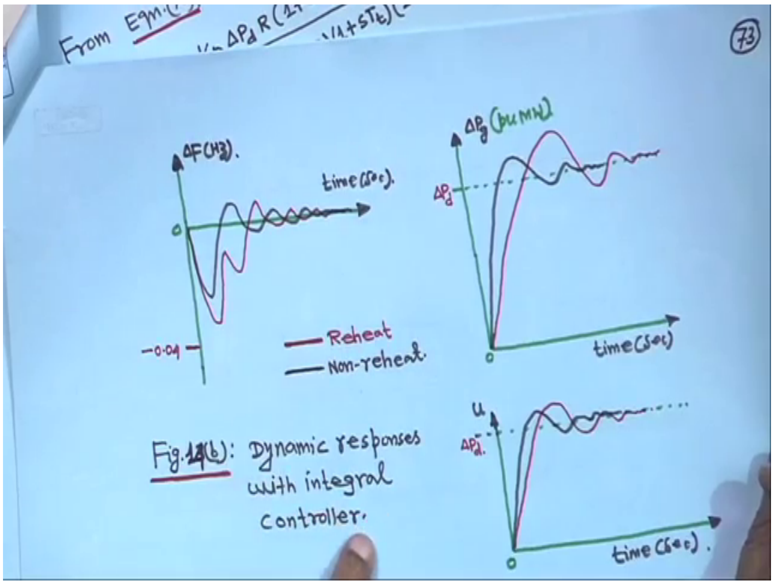

I will show you some pattern of response. If you plot this, so, there will be no steady state error. This is the frequency deviation. So, at it will after some transient oscillation, it will settled to your deviation, will settled to 0. So, black one is non - reheat and for reheat type, it is slightly peak; is slightly higher and slower because of the reheat time constant is there.

Here also, black one is the non - reheat time and this one is, your red one is the reheat time. So, this is dynamic responses with integral controller, there generation, this is delta P d is the step load disturbance and black one is the non - reheat time and red one is the reheat time, ultimately it is settling to your generation, but this will go to positive because if it of course, this is taken as a load increase, your load increase as only frequency show into the negative side, Then it will oscillate. And this is your delta P g and your per unit megawatt, this is time and this is U, sorry; this is delta P g and this is U. Plot will be more or less, pattern will remain same for you.

U also will leads to the your what you call that generation, this is delta PG; both are same. U also will reach to this same, your what you call that - same steady state value. I told you that steady state value of U. So, U should match to the generation, what you call - the steady state value of the generation. So, characteristic more or less, this one - this one more or less I mean, steady state value, there are same, but more or less after some, showing it will be there.

So, done and if it is a load decreases, if load decreases, say; that means, it is going to the negative side, I mean load decreases, then this frequency actually will start swinging from the positive side and generator generation will settle to the negative side. That means, a meaning is generation decreases, U also will be like this. So, in that case, if you take the image of this one, so, response will be something like this. So, this is your for load increase. This response is for the load increase dynamic responses with integral controller, but this response is from increase of the load. Load has increased, that is why frequency is initially going to the negative side.

Now, if you take that single area, your non – reheat; non reheat type. This is a non - reheat type.

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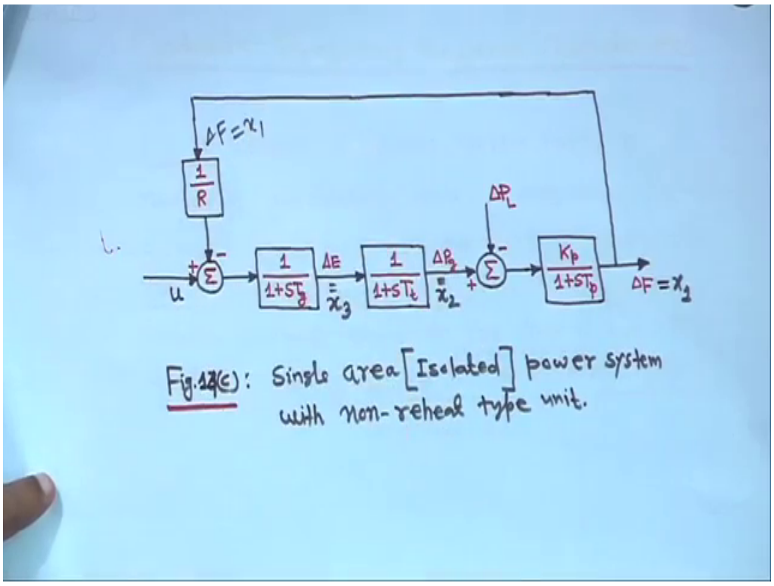

So in that case, your 1 plus ST r upon 1 plus ST r. Term will not be there, there term will not be there. So in that case, it will be your, what you call - this will be your simpler three state variables. One is this is x 1 this is x 2 this is x 3 this is your U and this is your delta F, is coming here; that means, your here it is delta F is equal to your x 1 this state variable. So, this is figure 14 c. So, if this, you have; so to, how you write down the state variable equation x 1 dot x 2 dot x 3 dot; how you can write? So, just for the previous thing, I have shown you how to make this state what you call, X dot is equal to X plus B plus gamma P form. So, if you write x 1 dot; here, know derivative term is there. So, if you sense are straight forward.

So, if you, if you; you can easily write this state variable equation. So, before your what you call - after that, we will come composite frequency response characteristic, but before this, one more thing I will tell you that you can, you - you should know this, that one more thing that is, I will make it here for you, that is actually call that your degree of stability.

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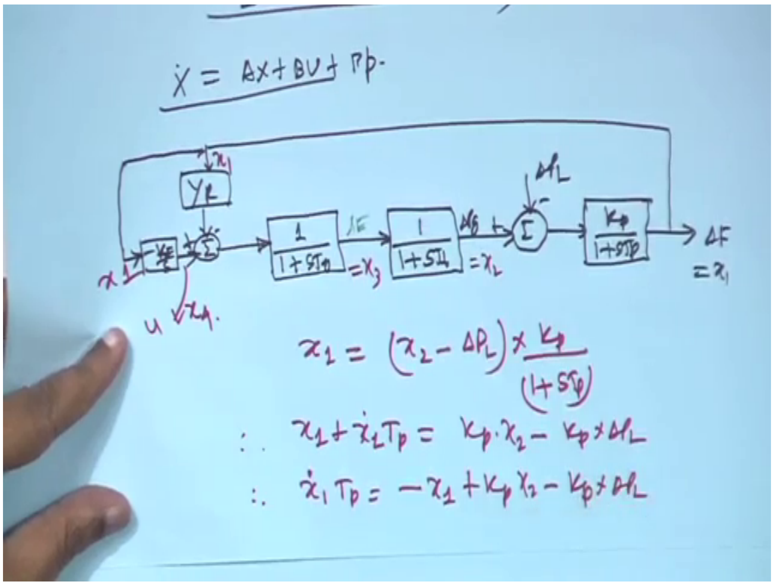

We call degree of stability. Some we defined this as a, say it is Rho. So, what we can - what we can do is that, we know the equation that X dot is equal to AX plus BU plus gamma P. This, we know!

Now, look at this diagram. Look at this diagram, this non - reheat type diagram; only we take this one, then it will be easier for you to understand this. Take suppose, this diagram we will take. This diagram we will take. So, in this case, for your, what you call - for a control mode; for a control mode I will draw this diagram for you; for example, this is your, just try to understand - this is your 1 upon 1 plus ST g. This is your 1 upon 1 plus ST t, this is your minus delta PL - the load. This is your K p upon 1 plus ST p, this is your delta F. And this is your delta P g and this is your delta E. And there, your then, this is your minus thing is there.

This is 1 upon R and it is coming from here and suppose, you have a integral controller; here integral controller, here minus k I upon S and this is the thing. And this is plus. So, this is minus k I upon S and input to this, this is your delta F. You are taking x 1 and here, this one, we are taking x 2 and here, we are taking x 3 and this was actually U. This is u from this diagram. If you put output of the controller, earlier, we have seen that if you put integral control, u will not take; we take this as a state variable. We will take this one as a x 4. So, x 1, x 2, x 3, x 4, now, if I take non -reheat type, it will be one more equation, that is, x 5 will come.

But in this case, it will be, suppose your x 4. So, so these are the equation, this is x 1, x 2, x 3, x 4 and that means, input to this is, here also, x 1 and here also it is input to this. Here also, it is x 1. Now, what we will do? We will write down the state variable equation x 1, x 2, x 3, x 4, but whatever I will show you, that what is degree of stability, we will find things are very interest in - in this case, x 1 is equal to from this, from this diagram. Here, you can write your this is x 2; x 2 minus delta PL into K p upon 1 plus STP. So, go for cross multiplication. If you do, it will be x 1 and I told you S into x 1 means it will become x 1 dot into T p is equal to K p into x 2 minus K p into delta PL.

That means your x 1 dot. T p is equal to minus x 1 plus k p, x 2 minus K p into delta PL. That means; that means this equation - this equation you can write x 1 dot is equal to minus 1 upon T p plus K p upon T p x 2 minus K p upon T p delta PL. Say this is, I marking as equation because several times we are using is a small a equation A. So, this is first equation for x 1 dot.

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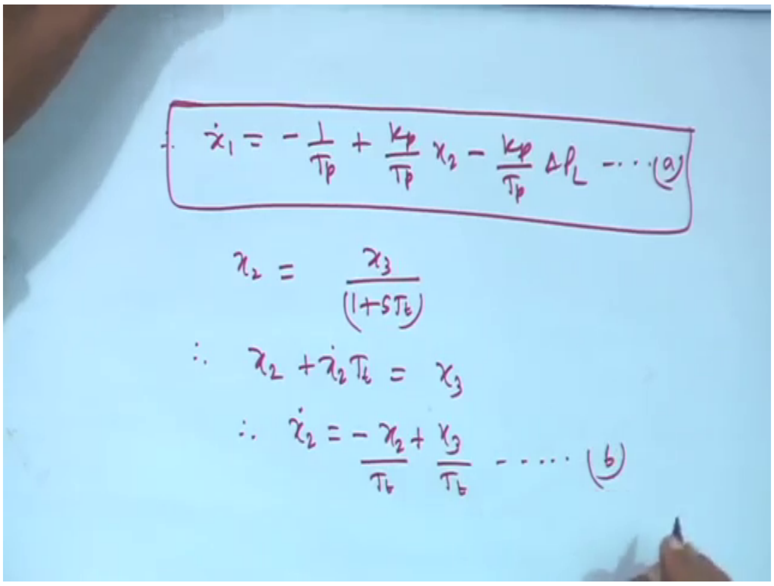

Similarly, when we will come to x 2, x 2 is equal to X 3 into 1 upon 1 plus STt. So, x 2 is equal to x 3 upon 1 plus ST t cross multiply. Therefore, x 2 S x 2 means – x 2 dot TT is equal to x 3. That means x 2 dot is equal to minus x 2 plus 3. Divide! This is, your what you call - divided by TT divided by TT. So, this is equation, your what you call say - equation B. That means, for this equation, this equation x 2 dot is equal to.

Next, is your x 3 dot. You come to that, x 3 will become, that is your x 1upon R and this is x 4; state variable is taken. So, x 4 minus x 1 upon R into this one is equal to x 3. That means, if you look into that x 4 is equal to your, what you call – x 3 is equal to from here only, x 3 is equal to this is - x 4.

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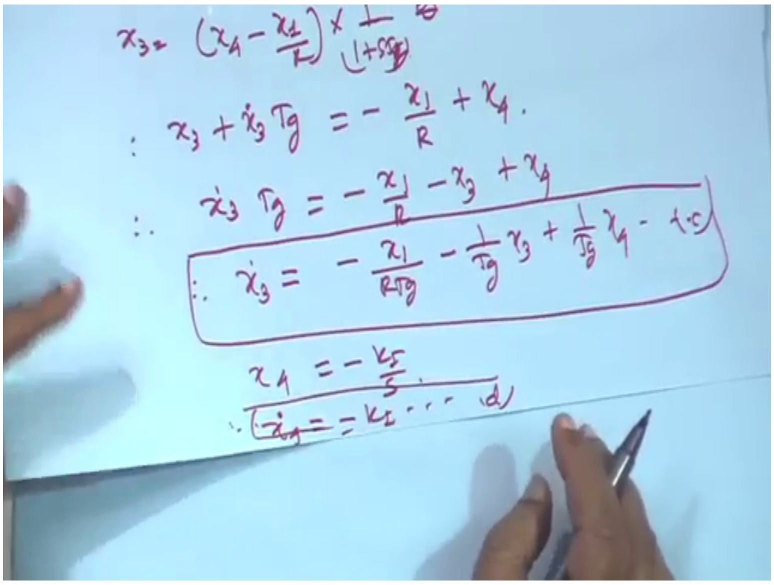

We are not taking U, this is x 4, x 4 minus. This is minus x 1 upon R. So, it is x 4 minus x 1 upon R. Into 1 upon 1 plus STG. Is equal to your, what you call – x 3 x 3 is equal to this one. So, this is your T g.

Now, go cross multiply - cross multiply. So, it will become x 3. Then, SX3 is x 3 three dot multiplied by T g is equal to minus x 1 upon R plus x 4. So that means, your x 3 dot T g is equal to your minus x 1 upon R then, this 1X3. So, it is minus x 3 plus x 4; that means, x 3 dot is equal to minus x 1 upon RTG minus 1 upon T g x 3 plus 1 upon T g x 4. This is equation say, C. This is your third equation - this is third equation and this is your second equation. This is second equation, third equation.

And one more equation is there, that is your, this one, this x 4 is equal to x 1 into minus k I upon S. We have taken only integral controller. So, x 4 is equal to; x 4 is equal to, if you take is equal to your minus k I upon S; that means, your x 4 dot x 4 dot S x4 is x 4 dot is equal to minus KI; this is the equation D. So, there are four equations; four equations. So, one by one I will rewrite this equation in one place. So, first is this one – x 1 dot. So, x 1 dot is equal to x 1 dot; is equal to here, here.

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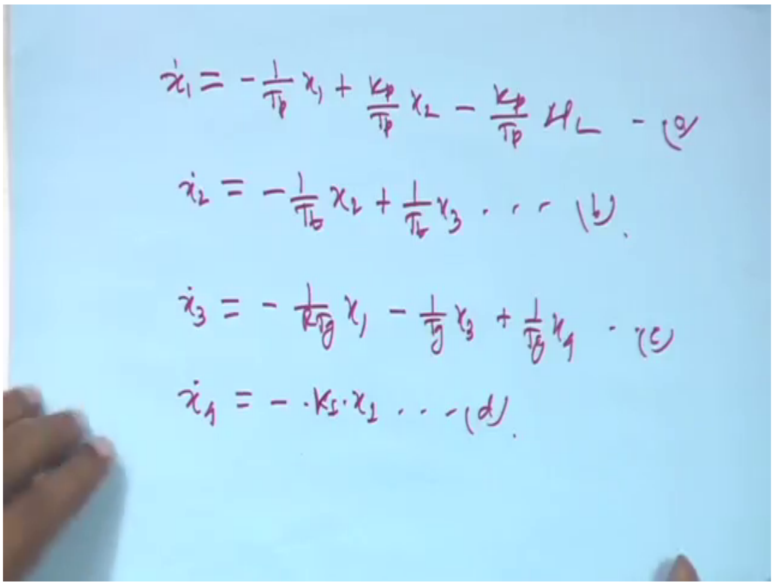

I have missed x 1. Here, it is x 1. I have missed it. Because no students sitting in front of you, That is, if I miss anything, that anyone will correct because everything I have to, have making it here. So, I miss this one. It is minus 1 upon T p x 1. So, x 1 dot is equal to minus 1 upon TPX 1 K p upon T p delta PI. This is your equation A. Rewriting similarly x 2 dot is equal to this one – x 2 dot is equal to your minus 1 upon T t x 2 plus 1 upon T t x 3. This is equation B.

Similarly, if you come to equation C, that means, this one - this 1X3 dot is equal to x 3 dot is equal to. It is minus 1 upon RTGX1 then, minus 1 upon T g x 3 then, plus 1 upon T gX4. This is equation C and equation last ID, that is x 4 dot is equal to your minus, your what you call, no here also, I have missed one thing. It is XI XI, it is x 1. So, it is actually into x 1. So here also, I have missed look – x 4 dot is equal to minus k I into x 1.

So, x 4 dot is equal to minus k I into x 1. So, x 4 dot is equal to minus k I into x 1. This is equation D. So, these are the all four equations. Now, in this equation as U is taken as x 4 state variable, so, no U is involved. So, this equation can be made it a X, your in the form of this equation can be written in the form of X dot is equal to AX plus gamma P. Because no U is involved here, no U is involved here, So, if we make; that means, this side left hand side.

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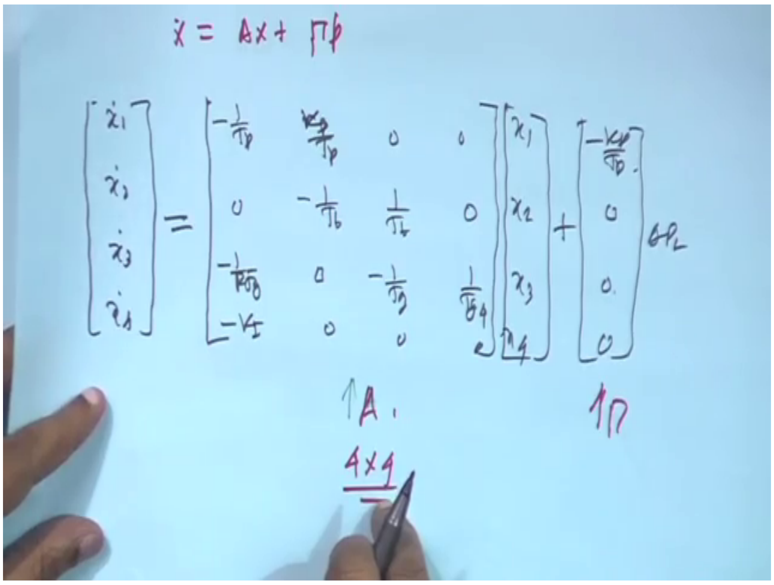

It is x 1 dot x 2 dot x 3 dot and x 4 dot.

This one is equal to your this matrix. You make minus 1 upon T p first. You make this one x 1, x 2 then, x 3 then x 4 so minus 1 upon TPX1 then k pupon TPX2. Other things are not there, zero – zero. Then, plus U is not there, gamma P is there. That is, your delta P1. So, delta P1 is here so minus k pupon TP. Then, x 2 dot, it is first one is x 1 is not there. Minus 1 upon TT and this one is 1 upon TT and this is your zero, because 1 upon T t x 3, 1 upon T t x 3 here and here, x 3 dot. First three terms is there, fourth term- your first two term, second term is not there.

So, it is minus 1 upon RTG that is x 11 upon RTG x2 is not there. So, zero minus 1 upon T g that is the third term. And forth term is 1 upon T g4. And we are forth equation only. First term is there minus k I and here, all are zero. This is zero, this is zero. Here, it is this term k I and all other terms are zero. All other terms are zero, that means, for this, your what you call - for this system, if you take integral controller, so this is the state variable equations. Hope everything is correct, only couple of places I missed x 1, because everything is writing here and you people are not sitting in front of me in the class.

Student always immediately point outs, sir that – that, that you are missed, but here, but anyway this equation is correct one.

So, this is your a matrix, this is your a matrix. And this is your gamma matrix and this is your a matrix. So, this is your gamma matrix. Now, question is that, this stability of the system depends on KI. Though this is a, all the parameters are known except KI. So, in this case what you can do is - the degree of stability row you have four Eigen values, because this a matrix order is four into 4 the 4 Eigen values are there. It may be if matrix are symmetric matrix, symmetric and real, that all Eigen values will be real.

But in this case, matrix is not symmetric matrix, but these elements are real. So, Eigen values may be complex, conjugate, may be real. I also do not know, depending on the parameters, but at least 4 Eigen values will be there, because there are four, your what you call - that your 4 order of the matrix is 4. So, characteristic equation will be your of forth order; that means, this is the a matrix. That means, if the characteristic equation is like this, if it is like this. That means, characteristic equation, you can write that lambda I minus A, it determinant will be this equal to this, is zero from that you will get all the equation. Actually, lambda; actually, lambda is like this, but this write become my habit.

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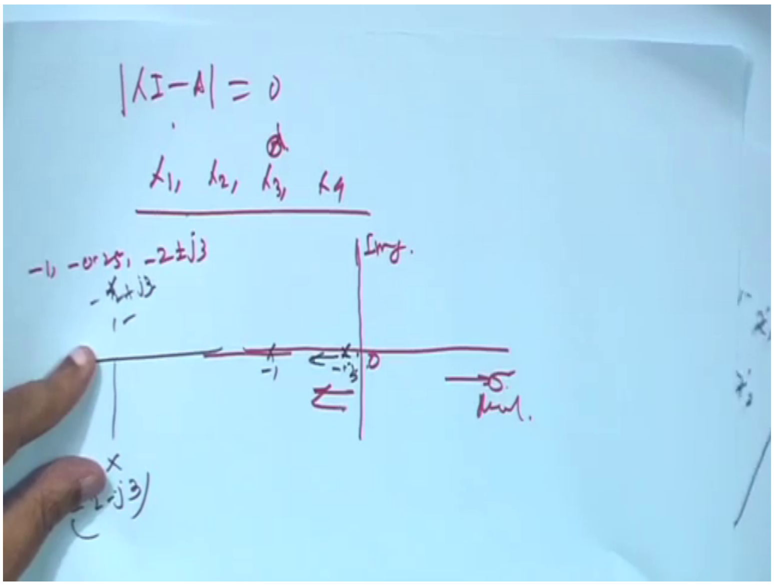

So, it is lambda one, lambda two, lambda three and lambda four. There are four Eigen values. It may be - it may be real, it may be complex, conjugate, also pair of complex - conjugate also; we do not know! But for the sake of understanding that first thing is, that all this Eigen values, if it is that real part, will lie on the left half of the S plane. This is your real part. And this side, your this is your real part is sigma. Or I can pay real part. And this side is your imaginary part.

So, one side we made sigma, other side you make your what you call – Omega. I will not put some other symbol. You can put, say this is imaginary part. And this is your real part. There is a put sigma Omega, something, say this is imaginary part, this side, this is zero. So, it is more sensitive to the stability for the system for a linear system. So, this is minus 0.25, so that means, for each value of KI, whatever you have got for each value of KI, what you will do that you find out that which will the for, you said k I is equal to say zero, then k I is equal to say 0.050, 0.01. Like this one increasing and then, degree of stability actually Rho can be define as. It is maximum value of real of lambda I that you take.

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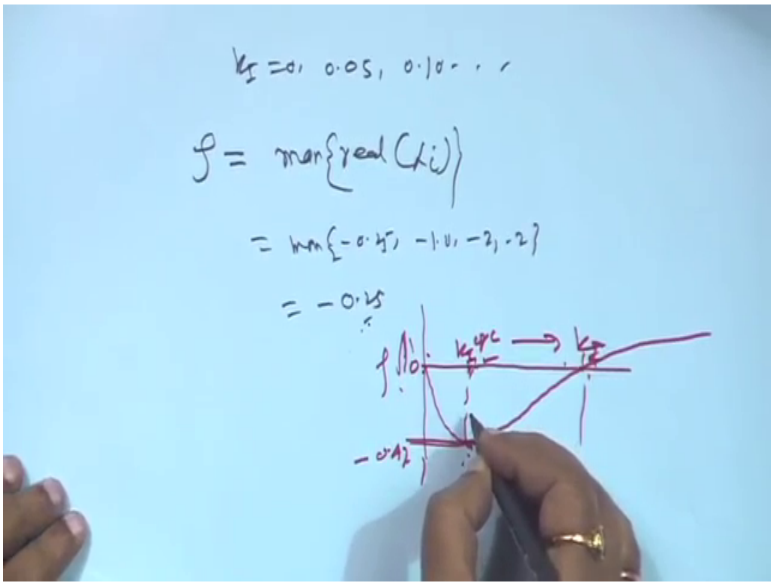

That means for, for this previous page, suppose Eigen values are like this, a mac max; only real part you take. That means, this one is equal to maximum of it is real, is coming minus 0.25, then, minus 1.10, then another - other two real is minus 2 minus 2 because Eigen value as minus 2 plus minus J3. So, minus 2, minus 2 and maximum this is minus 0.25; that means, which is very close to the origin, this Eigen values more sensitive to the your system in stability. That means, for k I is equal to 0, you will get some value and find out the Rho value.

Then, increase the value of k I is equal to say, 0.05, 0.1; like this, what you will find this Eigen value particular? This Eigen value which is very close to the origin, it is actually moving in this direction, that means, it is moving away for some value of KI, going – going; suppose, k I is going, going on increasing up to certain point, this value will be shifting from this; from this value from this side to this side. Forget about to others observed this shifting. So, for certain values of your what you call - k I after that, further increase of KI. Again, it will start moving toward this side, toward this side I mean - positive side.

So at certain point, maximum shift will be there, after that again it will try to move to the, your this side; that means, if you plot like this, I mean, if you plot suppose this side; suppose, if you plot, suppose this is your, suppose Rho value, Rho will negative, assuming the system is a stable here. So, this is zero and this side is your k I value. Here, increasing the k I value Rho will become something like this and finally, it will cross like this. So, this is actually from this, from here to here. For this range of k I system will be stable and this is that, whatever maximum shifting will get, whatever I am telling that your, this is your say k I optimum, this is optimum value and from here, that as k I is going on increasing. You increase it; this Rho will be increasing up to this.

After that, you further increase of k I that Rho will be decreasing. That means, from there it will shift to this side; that means, k I is increasing up to this. After that, it will move to this; that means this. That means, in terms of that Eigen value analysis, that this is actually that optimum value of KI, but from here to here, this is the range for which your system will remain stable, although response may not be better with this kind of technique. With this value will get the best part dynamic performance. So, whatever it is, that degree of stability means; you have to find out the character roots of the characteristic equation and then, you have to take your, what you call - that Rho is equal to max of real lambda I.

That is maximum of all the real - real Eigen value. Real part of the Eigen values and here, it is minus 0.25 is the maximum because negative sign is there. So, this is maximum which is very close to the origin, that we will take and we will change the value of KI. So, this value will shift for some value of K up to certain values of k I after that, further increase it will not move away, it will go toward this side. So that is, this graph that up to certain value. Suppose, this will go suppose, it has come up say, minus

0.47. Say, from minus 0.25 and after that is going down and this is the optimum value for which, perhaps will get the better response.

But for other techniques are there, further much better response can be obtained in this one, but this is actually call the degree of stability and this is the range from which your system will remain stable. I mean, all Eigen values will lie on the left half of the S plane. Beyond this value, it is going to positive side, means Rho is positive. Means, the real part of Eigen values becoming positive and system will become unstable.

I hope you understood this and forgive me for making to your, what you call writing error, because I am recording here and everything making it from memory. So, well anyway, everything is corrected. So, thank you very much.

Thank you.