Power System Operations and Control
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Module - 3
Lecture – 4

Welcome to lecture number 4 of module 3. In lecture 3 we just saw, the static responses as well as the dynamic responses for the step change on the frequencies. Basically, the step change in the load and there was some change in the frequency and we found that there is a steady state error and that error is not is going to be 0. So that, we have to do some control action because, our intention is not to meet that load whenever it is changed. It is also that we have to frequency to its normal value.

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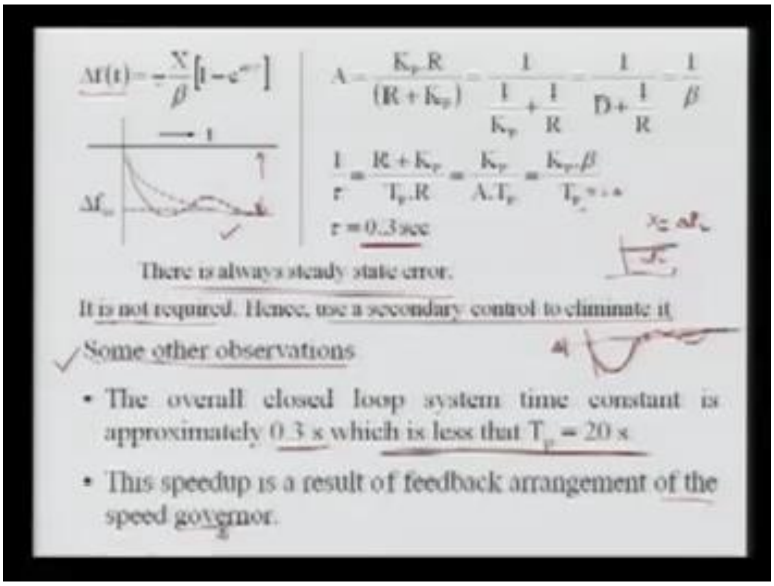

So, if you see here I derived this expression of the frequency that is a time varying frequency. Here, we ignored the time constant of your turbine and governing system and then only we took the power system time constant that is; the t p we considered and then we derived the simplified dynamic response.

So, this frequency you can say it is this x that is changing the load X is nothing, but here X is your changing the load the magnitude from which you are changing with step that we are talking. It is not a gradual change; it is the step change. If your load is gradually changing then what will happen? This load will be met by the governing system as when the load is released and this frequency error will be not maximum.

But here, we have assumed this is your sudden change in this your p l and this is called the step response. So, here this is the negative sign shows that whenever there is a load is increased that is x is positive this frequency will be negative change means it will be lower frequency. And it is you can say exponential 1 minus e exponential minus t upon tau and the tau is the time constant.

So, you can see the frequency response will be here; it will follow this curve and that is shown here. Now, you can see the time constant of this whole response is now 0 3 second. This 3 seconds we considered when the t p was 20 second and for the previous example in the lecture 2 I considered 1 example.

For that case if you consider your r k p d and your t p then we will get the t is approximately 3 seconds. So, we can observe from here there is always a steady state error; means here this is your steady error is existing. So, from this if you are ignoring this; your govern a time constant as well as time constant then you will get the response like this.

But if you are not ignoring, if you are going to consider that, then your response will be slightly here and likely to be settled here. And again, how much repels and how the overshoots and the peak overshoot etcetera is decided by the time constant and the gains etcetera.

So, the here we can see we do not want this steady state error; we want that once load is changed, the frequency should deviate of course. If frequency will deviate then only the governor as well as the load release will act. And then, we want that it should come back to the system.

For example: I want here this graph for the frequency change. Let us suppose load has increased, so I want that higher frequency should go by that is you are changing f to 0. So, it should come and then finally, we want that it should go to the normal value; we want that.

Hence a use of secondary control is required to eliminate it and we will see the secondary control loop. So, this loop which we discussed so far here that is your primary a l f c loop; that is automatic load frequency control loop. Some other observations are you can make it from here and those are that you can see that the overall closed loop system time constant is approximately here it is 0 3 second.

And which is less than the time constant which we consider the open loop time constant t p it is 20 second. So, from the 20 second it has come to 0 3 second so, there is a response becomes very fast compared to this 20 second so, that is very, very good assumption. This speed up is a result of feedback arrangement that we had the feedback arrangement of the speed governor means, we had some arrangements.

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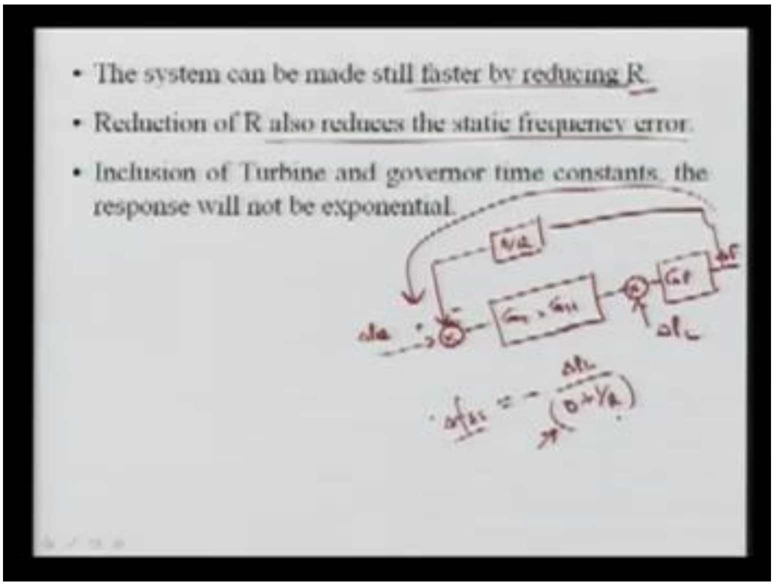

For example, you can see here that is I can say here; this is you’re the turbine and governing transfer functions. I can say G T and here we can multiplied by your G H. Then, we are having here your G P if you remember means, this G P is the transfer function of our system including your. And here this is your changing F and that is here coming through 1 over R that is and finally, here that is coming to be here and this is your changing p c and this is here it is negated, this is your positive.

So, this is we are having 1 loop so; it is a pass if we are not having this feedback loop and that is here that feed loop is provided by the governor here that is R the characteristic. So, this value is only trying to reduce and trying to speed up that the change in the frequency of regulation or the governor will take action.

So, if it is not there then the time constant of whole this will be the same that is 20 second; here they are very fast and they will die out. And here of course, we had this change in loading that is the static loading. So, here I want to say that, the speed up is a result of a feedback arrangement of the speed governor means, that here the feedback arrangement that I am talking here.

So, this is you can set the feedback here; from the frequency it is coming here and that is why we have improved the time response. That is the time constant of the closed loop system now has become 0 3 seconds from 20 seconds so, it is great improvement. And now the system can be made still faster; you can again we can reduce the time constant and then by reducing R. You can see here this R the time constant here; you can say coming into the picture here is R directly proportion to this.

So, what is happening you can see if they are reducing this the k p is very large value. So, it will not affect much but this value, if you are reducing reduce then what will happen your t will be R for radius. So therefore, if you are reducing R then you can see what we are going to get this your system response again becomes faster. And also the advantage of this, the reduction of R also reduces the static frequency error.

Because, you can see your static frequency here; are if you remember this formula this is nothing but, your 1. Here that is a change in your p l or you can say x divided by your d plus 1 by R. So, what happens if you are reducing this; this term will becomes larger. Reduction of R will give larger value of your denominator. And larger value of denominator will say, there is a less value of f s the frequency error.

So, this is also another advantage we want. We are having by reducing this we are reducing the static frequency error that is very good. So, another observation we can see the inclusion of turbine and governor time constants; the response will not be exponential and here as I said it will be some in nature here we will get. And it will get settled in few seconds, few milliseconds and finally, we will get the steady state error here.

Now, with this what we have to do, now we have to design the control law or control and we will see here.

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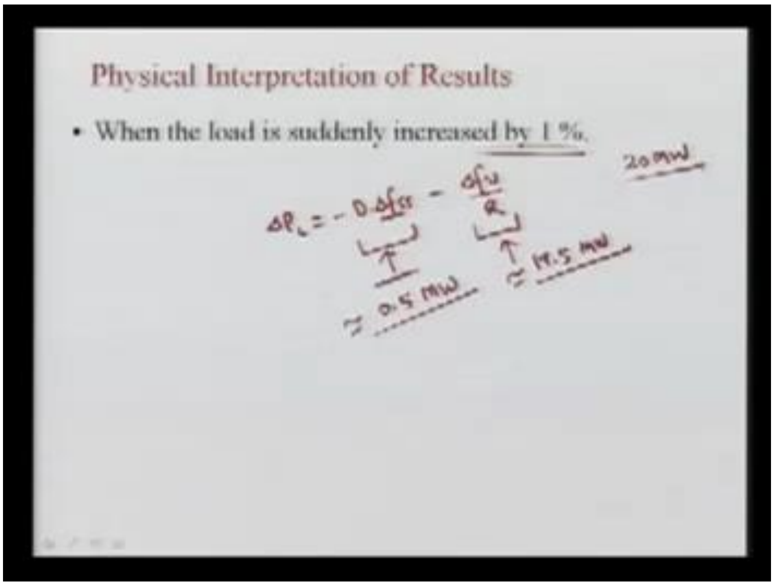

Let us, see the physical interpretation how full this control loop is working. For that, let us consider the load is suddenly increased by 1 percent. Again change may be if you have positive sign or negative sign means you can increase the load, you can reduce the load. But here, I have considered that the load is increased by 1 percent and if we consider the lecture 3 problem where it was 20 Megawatt load was increased we are considering. And for this what will happen?

First this load is increased means load switch is closed means, you are going to draw more load. The governor and the net load release will not act. This load is made in the few millisecond by the kinetic energy stored in the system. So, once the kinetic energy is released then the frequency of the system will fall and once it will fall then, you are governor because; the governor works on the change in frequency.

If the frequency is not change governor will not work because, we have assumed there is an your lower commands. So, your then your governor will come into action and it will try to supply power to the change in the frequency. Similarly, also your this net load release means as I said here this your change in your this power here it is nothing but, I can say it is d into your f s s. That’s minus here, changing your f s s divided by R.

So this is due to the governor, this due to the net load release. So, whenever there is a change in the frequency source first few milliseconds there will be no change and the kinetic energy will be supplying this load release this demand. And then frequency will of course, fall and once there is a fall means, there is a change in the steady state frequencies.

Then, here we will get the net load release by the load components and here the governor will come into the action and it will try to provide and then it will be giving power to this. So there are things and I also explained in the previous lecture, that this component is very very small. We saw in the previous lecture, this is for this 20 Megawatt it was the supplied by here it is only 0 5 Megawatt. And this was giving the lines and here, it is 19 5 Megawatts approximately.

Here it was also function approximation. So, you can see this component is less but, it is still this 0 5 Megawatts is not very less but, compared to this it is very less. So, now what we have to do?

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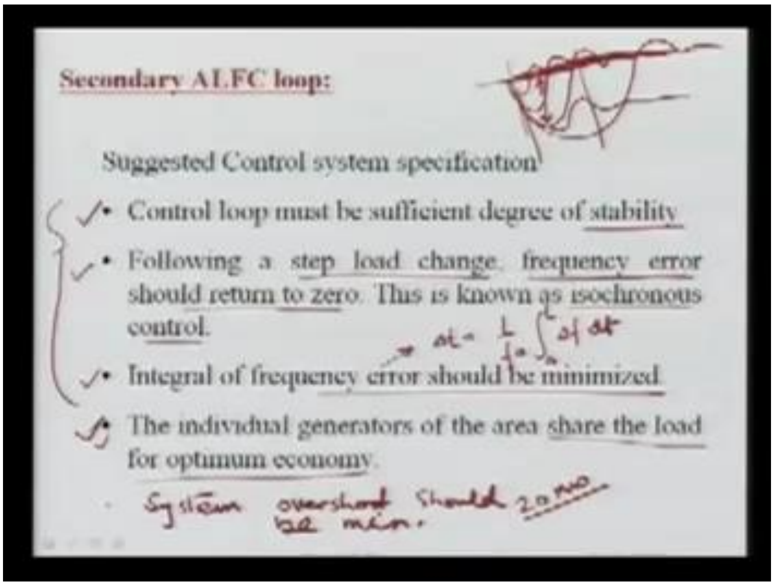

Now, we have to go for the secondary here automatic load frequency control loop and then we required some control system in special occasion. Those are first we have to design a control loop that must have the sufficient degree of stability. So, the control loop here must be sufficient must have the sufficient degree of instability. Also following our step change step load change, the frequency error should return to 0 this is known as the isochronous control.

So, this requirement must be made I will come to again. Here second is your integral of frequency error should be minimized, means we are integrating the frequency error that should be always every time minimal. So that, we can return it to the system we can return it to the 0 error and it will be better. Another that the individual generators of that area; so far we are discussing the single area concept means, in that area all the generators are participating.

There may be possibility the multi area system is where the different areas are connected with the line, we will see in this next slides. So, the individual generators of area suits here the load for the optimum economy means, we have to change the loading, suppose the load is increased. Suppose load of 20 Megawatt is here increased then, we have to share this load to the various generating station. So that, we can keep the minimum cost of generation means we can say economic load displace must be done.

So, this is basically as the latter is but, first for the control here we these 3 specification along with another specification, normally we go for that here this over shoot let the system overshoot should be minimum. Because, what will happen if your over shoot is more. There is a possibility that it may create lot of problem, always we try to have the minimum over shoot and also the settling time that should be the fat enough and it is called your control specification.

Now, to come to this first point here; what we can do, here this control loop must be sufficient. For this we can always the stability is the governing criteria. We must ensure that stability system closed loop must be stable. So, the stability is always a problem in closed loop control. The tighter the error specification the greater risk of, proposed loop will turn unstable.

So, if your specification is very tight means; your air tight is very you are putting in such a fashion that it should suddenly change the error 0. Then, there is a possibility that your closed loop system may be unstable. So, we do not want your control loop system should be unstable. So, we have to very careful about the stability and always it is a concern in this closed loop system.

Open loop system may be stable but, it is not necessary, it is not currently that closed loop system will also be stable. So, we have to decide again in time constants etcetera of your control loop so that, we can get the sufficient degree of stability even though in varying operating condition.

Second is the need for the frequency constancy as we note, that if there is a change in the load the frequency error should return to 0 and here this is called your isochronous; Iso term is basically used; Iso means here it is constant and here the constant is time means it is a constant time. So, we want that no control system time however eliminate that tangent frequency error.

Here we are talking about, the frequency error should return to 0 means your static frequency error. The tangent or you can say diametric frequency error cannot be 0, no control system can be do can do this 1.

For example, let us suppose here as I said we are having the response like this here. We want that this error should be minimized. So what we can do, we can here if we can go here and then you can and it can settle. So you can say, here we still have some error at the beginning. So this is a tangent error so, tangent error cannot be minimized means if you want to have this one completely from here; even though load is increased. And this is your 0 then we can say, your tangent error as well as your static error is 0.

So it is very difficult to achieve but, it is not possible. So, what we normally consider we considered that they were a steady state error must be 0 and also we have to consider that this over shoot should be minimum. And also the settling time means, settling time as you know the settling time here; it should be as minimum as possible then we can say our control design control loop is the best 1.

So, now integral of frequency error should be minimized means, what we are going to do in this tangent frequency error as I said it is not possible. So here, the integral of this i can say you are changing the time that’s the integration of the frequency naught. Here integration of changing frequency with they dt and here from 0 to the time this we want to minimize.

So, this change in the time that is the time error can be expressed in the seconds here and here we want minimize so, that how fast. This basically shows, that how fast you are achieving means this means this there is a possibility that we can achieve here; we can achieve certainly here or we can achieve here and then here.

So, you can see this is taking more time, this is taking less time so we are here the integral of frequency error should be minimized means, we are just achieving in the minimum time this time just we are minimizing.

So, that is also required and that gives you another criteria and as I said, the economic concern is only later on means we have designed this control. Then, we have to decide that which generator will be loaded how much and then so that we can achieve economy or you can say minimum cost of generation and that is very very good.

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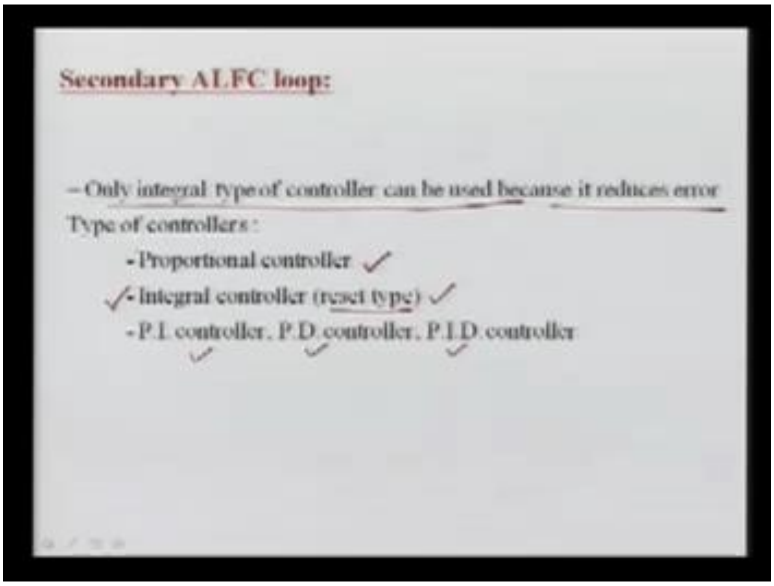

So, in this secondary A L F C loop there is various types of controllers are possible. Controllers can be here you are the proportional controller, can be your integral controller and it is also called reset type. It can be your PI that is the proportional integral controller. This PD controller it is your proportional differential controller and the PID controllers are possible.

So, there are certain advantages over other controller again we will see, these types of controls when we will discussing about the excitation system control that we will compare there. But here this is a reset type because, our error is every time existing. So, our here criteria in concern we can to sue some reset type of controller so that, we can the change in error is maintained to the 0.

So we use the integral controller, so only integral type of controller is used because it reduces the error. Because, our here criteria is to reduce the error and then we decide the gain etcetera so that, we can stabilize your closed loop system should be stable. So, here you can see how we are going to add that.

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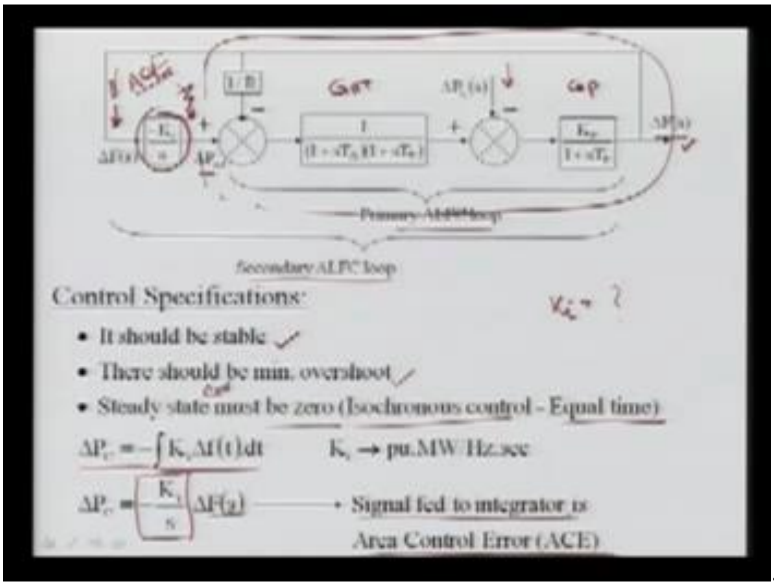

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In this you can see now, so far here from this block from here you can see this is your nothing but, your primary A L F C loop primary automatic load frequency control loop.

Now, here we are adding this p reference that is p c we are going to change and here that frequency we want that it should be integrated; here you can see integral controller and then negative sign here shows. As you know we require when the frequency is negative, we require the p reference should be positive because, when the frequency is less we must increase the power.

So, here the minus term is used K i is a gain and here 1 upon s shows that it is your integral type means this type of controller. So the control is specification again I can let us recap that it should be stable. There should be minimum over shoot and the steady state error here; it is error must be 0 and that is should be isochronous control means equal time control.

Here that the change in the power now, we are lower command that can be given 1 command and based on that we can use and this is negative half integration of K i 1 gain multiplied by your change in frequency with the different integration time. If you are taking here Laplace transform means, we are getting here your K i upon s and here change in reference. So, this signal is set to the integrator is called area control error means that error we are sending here so that, it can minimize.

So, the area which is coming here it is called you're ACE this is the area control error; which is coming here this is basically here the area control error. So, if you are going to add here now we can from this it is coming here with this block already I have used here and then we can have secondary load frequency control loop. And then we will see, now whether this loop is stable and what may be that while your K i and that is very very critical and it decides several things.

So this K i value must be chosen to meet your requirement and we will see now, the static as well as the dynamic performances of the secondary loop as well along with your primary A L F C loops. So, the signal fed to the integrator is called or referred as area control error. So whatever the signal which you are fitting to this integrator is called your ACE and this is called your area control error; this is 1 area we are talking so, this is area 1 here.

If you are going for the multi area we will see, the area control error for the different areas will be the different and then we have to use controllers for reducing that. Now let us see, the dynamic performance or a static performance of this 1. First we will see the static performance then, we will go for the dynamic performance.

Now, we want to complete here you output is your frequency, input is your change in the power. So, we have to write this the transfer function means change of frequency that is output in terms of input. This we can say it is your Gp; this is nothing but, your GHT including I am now combining GH and GT here GHT and then, we will see here what we are going to get.

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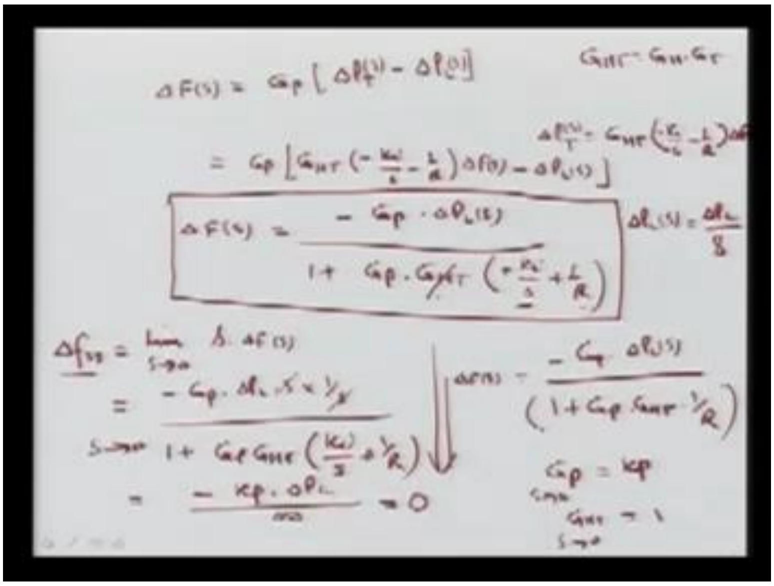

From here, what we can relate this change in this frequency that is I can write the change in the frequency that is F s. It is nothing but, we are getting that is your Gp and here we are getting change in Pt minus change in your Pl. All these are we are writing now I have removed here s but, no doubt this will be the s in the Laplace we are talking Laplace domain. Now this Pt, the Pt change in Pt is nothing but, I can write here they are coming this first you can see from here.

Here this Pt is this signal and this signal, this is positive, this is negative and then that is multiplied by the Gt and that is equal to your here this is nothing but, your pts that is change in here. So, from here this change in f change in f is multiplied and then we are adding.

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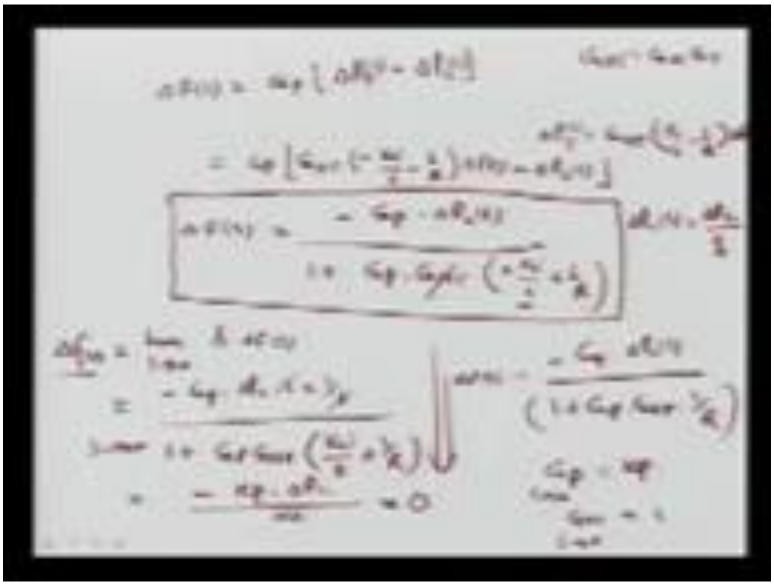

So what we are going to get you can see this p t s is nothing but, here I am going to use the G s t multiplied by the signals which h we are getting that is your what we are getting this change in f is of course, is the multiplication of both and then we are getting minus k i upon s; here minus 1 upon R. So, we are getting this signal from there and it can be here you can say we are using this. Now, we can use this here.

So, what we are going to get now the change in this your Gp, here the Pt we can replace. That is your G s t means your G s t is nothing but, I can write your GH in to GT means it is multiplication and combined. So, here G s t minus K i upon s minus 1 upon R; here change in your f s minus change in your p l s. So, now we can simplify this change in f will be going that side so, I can write this change in f s is nothing but, minus Gp here.

Again Gp into I can say change in the p l s divided by 1 plus Gp into GHT and then it is a multiplication of minus plus K i s now plus 1 upon R because, this minus we have taken that side. If you are going to here then it will be added means, I have taken the minus sign this side and then we are sending here; so we are getting this 1.

So now you can see, the previous case then this was 0. We were getting this multiplied by R and that is the same thing. So, what now we have added in the previous when this K i integral controller was not there, then we were getting this change in f s. It is nothing but, you minus Gp into change in p l s divided by 1 plus your Gp into G s t and into 1 over r; so we were getting this.

Now this 1 upon R is added with another factor here; so this was the case when there was no integrator. In this case we have used the integrator and then it is coming along with here this 1 over R term and then we have to see the steady state response for this. So to this, what we can do? This change in f s s again we can use the final value theorem and that is nothing but, I can write here limit s tends to 0 and here s into change in f s means, first we have to put s and then you have to put the value of s equal to 0 and then you can get it.

Again here, the change in p l that is nothing but, your sum I can say change in p l constant or s upon you can say s because, we are talking about the step response. So, we can put this value and then you can go for this. Now you can put this value here; it is nothing but, you're minus Gp and this value is nothing but, your change in p l you are multiplying by s as this term and here it is 1 over s.

Now, here we are going 1 plus Gp G s t and here K i over s plus 1 upon R. Now, we have to put s tends to 0. So, if you are putting here you can see this will cancel with this. Now what will happen, if you are putting this s tends to 0 means here if you are putting here we are getting some k p 1 over s t means only k p we are getting.

So, this is a constant here it is 1. Here what we are going to get you can see here. This is unity means I can say G p s tends to 0 is your k p your G s t, s tends to 0 means limiting value. It will be your unity and here you can put if s equal to 0 this is infinite. So, what we are getting here minus k p into change in your p l divided by here 1 plus infinite is means again infinite. So, here we get infinite and this is nothing but your 0.

So this is our criteria, that we have to get this value 0 means now it is steady state error here is 0 and it is required. So we can see, the integral controller gives your error 0 and that is requirement and we also verified. So, this is your steady state response of this whole this secondary A L F C that's your secondary area automatic load frequency control.

Similarly, we can go for the dynamic performance and we will see, this dynamic performance gives several K i is very important playing a very important role for this your performance of your dynamic response. So here this is you're the complete closed loop transfer function for which we saw the static performance and a steady state we found that here it is your 0 and that was required.

Now let us see, for this closed loop transfer function and change in frequency, here is related with change in the load and we want to see the performance in sense of this step change of the p l what will be the performance again the K i. Let us, take as the value of K i; we will not put the exact value. To see this as you know what we have to do, we have to again ignore the time constants.

Time constants are Gt here G s t just we can say it is very small so, we can ignore and then we have to sort.

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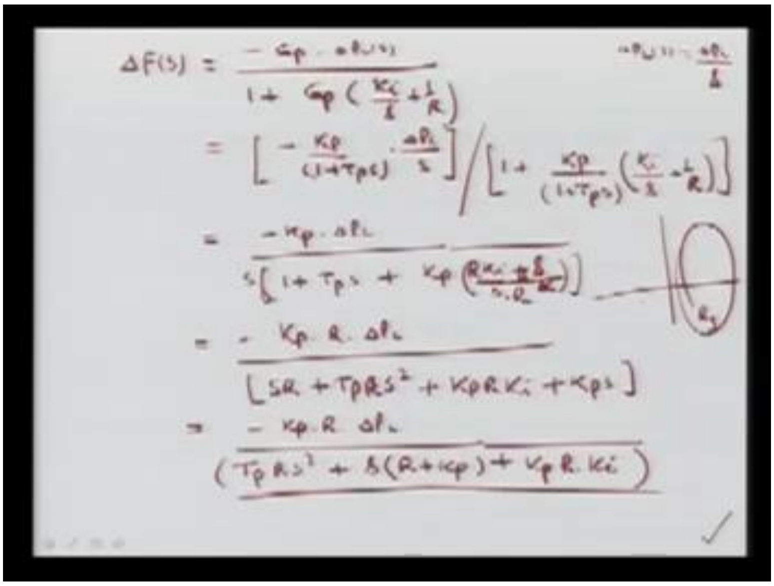

So, this simplified will be again I can write change in your frequency in the Laplace domain. It will be nothing but, minus your Gp here change in your p l s divided by 1 plus it is your Gp and again here Ki over s plus 1 by R and for this we have to derive the response. Here again thus we want to see step response so, the p l s is nothing but, I can say the magnitude of the p l divided by s.

So, we can put that value and we can see what we are getting. So I can again simplify this G p is nothing but, your k p 1 over 1 plus T p s and T p already we saw that T p is approximately 20 to 25 second. Here multiplied by that is just the magnitude that is p l divided by s and that here the complete division will be divided by this. I can see here 1 plus again this k p 1 over T p s and we have here K i that is again of integrator this is your s plus 1 over R.

So, we have to again simplify this you can see the t 1 plus T p s 1 plus T p s is here then, we can remove this so, we can write here again, this we are getting minus k p into change in this magnitude. Here I can say this s can be taken here s and then I can write here 1 plus T p s plus i can say here k p K i over s plus 1 over R. And this is our simplified again and what now I am going to do I am again going to multiply by s r in r.

So, here you can see what we will get I can simplify this; here I will get plus s and here I can multiply R and here I can say this is a s r. So, this s dot R is multiplied everywhere so what we are getting? This s s will be concealed and R will be there and R will be going up. So, I can write here k p into R into change in p l and here I can write this value is coming here first. So it is SR plus T p s t p R s square this is quadratic term just we are going to get you can see here plus here we are getting the K p R K i plus here K p s.

So, we are getting this much we can say this is T p Rs square and S term here is plus R and plus k p is there and here we are getting this constant. So again, we can simplify this and we are going to get here minus k p into R into change in p l and I can write here the Tp Rs square plus here S that is the s domain here R plus your Kp and we are getting some constant that is Kp R into Ki.

Now, we can see this denominator is a quadratic equation means we will have the true roots and the true roots will be your Tp and t are fixed. That’s basically relate with the already designed parameter because, you are governor once you have set it is constant. But, the K i that is the integral k n that we can change, we can set for of the system performance.

So, this decides this characteristic root of this is very very important to decide whether your system is stable or not. First criteria that we have to meet, that it must so that we are having the stable closed loop means this loop is a stable loop. Here all the coefficients are positive, here the T p is positive, R is positive Kp is positive. All means all the here constants are positive.

So, this gets 1 criteria that it will be that means the possibility of the stability is very large. If any 1 of them is negative then it will be unstable 1 root will be lying in other left you can say right hand side of the s plane and that is not required. Again the right hand side you know here in the s plane, if you are talking this is your left hand side. So, all this roots here must be side and this is your called right hand side we do not want here unstable side; here is a stable side.

To see the performance we can again draw here the characteristic equation and then we can decide, what should be the k because, this k is very very important which decide the criticality and the overshoot under the performance of this. So, here just it is a denominator and it is also known as the characteristic equation this gives information whether your system is stable or not. And for this let us, see here what we are going to get in the characteristic equation.

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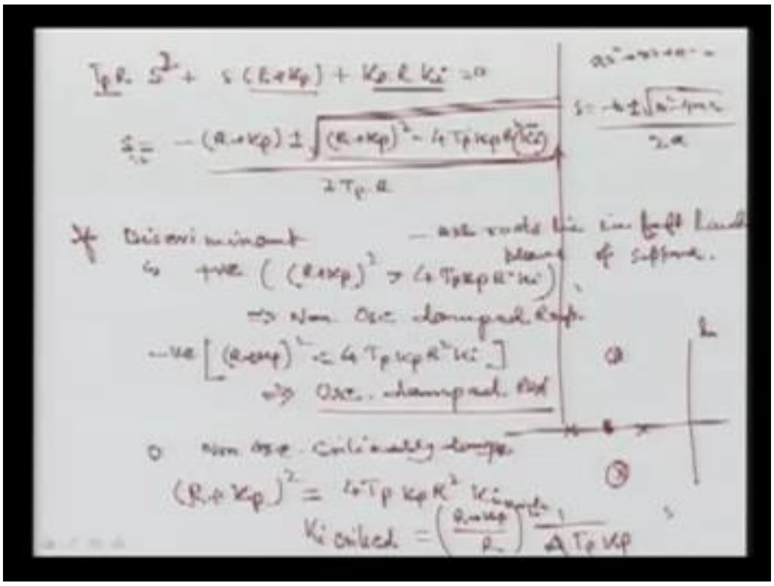

It will solve this what we can say this s means I can say this equation which we wrote here. That’s a T p Rs square I can say I can write the T p Rs square plus s R plus Kp here plus your Kp into r into K i is equal to 0 and then we can solve the this is your s square term. So, s I can write it will be minus R plus Kp plus minus here I can say R plus Kp s square minus 4 ac; 4ac means 4 this is you’re a this is your let us suppose b this is your c.

So, we know this if you’re a s square plus b s plus c is equal to 0 then we can see as we can write minus b plus minus b square minus 4ac divided by 2a. So, using this here this is basically discriminant we call in the under root term; this is a root of quadratic equation. So similarly, just I have written a is your we can say this your Tp Kp R square into K i divided by here 2 Tp into R.

So, this is we are getting the roots are this now, you can see this term is negative, this term is less than because this is all positive value so, this is again reduced. So, even though if you are adding the positive term here you will get the negative. So, this shows that the all the coefficients are positive so this gives that all the roots will so; this shows that all roots all the roots here 2 roots basically they will lie in left hand plane of s plane we are talking.

Now, this discriminant here that it may be positive, it may be negative, it may be 0 means, no value all the values are here; positive means here if this is more than this it is positive. If this value is less than this it will be negative and if this both will be equal then it will be 0. So, the discriminant means that I can say here this value is a discriminant here under root term. If it is 0 means we can say if discriminant is positive when it will be in that case it will be your R plus Kp s square will be greater than your 4 Tp Kp R square into K i. So this is positive and this will show, that we are getting the non-oscillatory time response.

Another possibility is that it is indicative, in that case what we will get here; your R plus Kp that is square is less than here the value is 4Tp Kp R square K i. And now, this will give your oscillatory why it is so? Oscillatory damp response. If this is less than this you can see this we are getting the roots imaginary roots. If this is less than this means, we are getting negative sign here and the square root of negative is imaginary term.

So, what we are getting in this case if it is positive we are getting all the here this is your s plane. So in the first case, if it is positive we are getting all this your roots and your this axis that's a real axis. This is your imaginary axis, here it is your real axis. So, all the roots are here then it will give the non-oscillatory means it will not oscillate and it will be the damp means, damping will be achieved.

But, here if it is a negative means we are getting the roots here and here and then it will be oscillatory. So, we are having the imaginary term means we will have the oscillation frequency and that frequency is decided by here; how much negative we are having. And then our response will be the oscillatory; so this is called oscillatory damped response.

Another possibility that it will be 0 and here it is called now, non-oscillatory critically damped. What does it mean? It means, the if this is 0 means both roots that is the s1 and s2 they will be on the same point means, here I can say the if I produce the dot point. So, here both roots will be here lying at the same point.

So, it will be non-oscillatory of course, because they are lying on the real axis but, it is called critically timed and then we will see here. For that condition let us see, for the critically damped here we are getting the value of K i critical and we are going to achieve that's your R plus Kp square. That will be equal to your 4 Tp Kp R square and here it is your K i now this critical because others are fixed; only the K i is set in as a fashion.

So that, we are getting this discriminant value is 0 and we are getting the critically damped non oscillatory performance. So, here we can say we are if I divided here we can again write this K i critical will be equal to I can say R plus Kp divided by R; here it is a square this value and then we are getting 1 upon four 4 Tp Kp here. So, this is the critical again when we are getting the non-oscillatory critically damped.

To see the performance again I can see this sub critical values are required normally and then it will be K i is less than this K critical what will happen. This is the critical when it is 0, if this value is less what will happen? This will be positive and this is a positive then, we will get the non-oscillatory damped response.

So, we will see here again what we are going to do and if again this value is increasing then it is going to be negative and negative. Once this is now a negative then, we will get oscillatory. If this is positive more than that what will happen? If this K i is more than this will be negative, if K i is less this is positive. So, we will see this is the performance here what we are going to get here.

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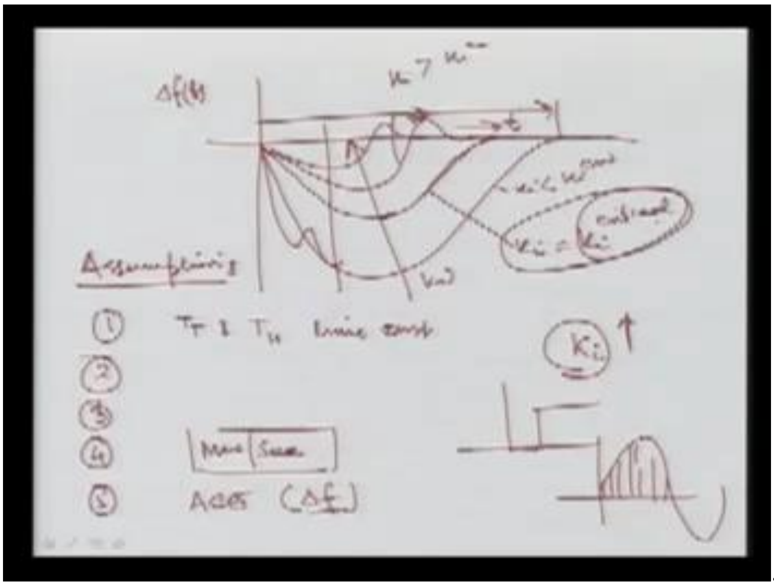

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Now you can see the performance, that's I want to show this variation of this your change in your frequency. This is your time, this is your change in frequency with respect to time. So what we are going to get here, we are going to get let us suppose this. Here if this value is somewhere there let us go critical I can say. Let us, go this is your K i is here is equal to your K i critical value.

Now, if this K i as I said the K i is increasing it shows that we are going to get the oscillatory response. So if this is the K i critical from that if you are still increasing what will happen? You will get your oscillatory response and finally, here like this. So this is you can say change in K i just you are increasing.

So, this will give you're the critical value where, it is critically damped and others here is critically over damped and we are keep on doing this here. This value is K i is less than k i critical and these values are K i is greater than for this here; K i is greater than K i critical value. So, this critical value is calculated and based on that we set our controller so that we can get the proper response.

So this is the dynamic performance and you can see here, we are this getting the 0 a steady state error. But only just we have to see by setting the value of K i, that is very very important and that can be changed because, it is a controller gain we can change. And then you can say your performance time is also changing. Here this is a settling time is here; you can say the settling time here for this.

So, we want how much over shoot? And how much quickly that it is settling this. So, the K i is very important parameter and that is basically decided once we calculate the critical value, then whether we are going to increase or decrease you can achieve the performance accordingly. In this whole process we have assumed several things and now I can summarize this what are the assumptions that we have made.

First assumptions we have made that, the hydraulic and the turbine dynamics means your governor and your turbine dynamics were neglected. But they can be included in the simulated of the graph means, we can include them if we are going for the analyzing using the computer programs you can include. And then you can see the performance as I said here, what will happen? They are the dynamics will be also included and it will be some oscillatory and finally, it will be settled in the that time period.

So, first 1 is that that we have include this you can say t and we have neglected the t s time constants. So, these are the assumptions that we had made and the assumptions are well valid because, here the time constant of the t t and the t s is very less than the Tp. So, we have ignored and only the change here will be in the fraction of seconds.

Second assumption that is we have made, that is speed changer response was assume instantaneous means, it was thought that the speed changer that is your governing system it is instantaneous, when it is required certainly it is k but, it is always it is not true. Also third we assume the all non-linearity in the equipment such as dead band, normally what is dead band means we have ignored this non-linearity of dead band you can see here we are having some dead band and then your.

So, operating so this is your dead band. So, we have neglected all the dead bands non-linearity in the equipment in this analysis. The fourth assumptions I made that it has tactically assumed that the turbine can change it torque as fast as it is commanded but, it is not so. There is some ramp rate means, normally the Megawatt per second it is the technical characteristic of this machine that, if you want to change 20 Megawatt power it will take several seconds.

So, it is not instantaneously so, we have assumed that it will when command is given it will take care but, it is not so. So, this is called the ramp rate in fact we ignored Fifth assumption just we made that is also very important. We have assumed that, ACE is our label as a continuous signal this area control error ACE and this is ACE is nothing but, your change in frequency. We have assumed that it is a continuous signal that we are getting.

But it is not so because, we are using some measurement circuits and that measurement circuits basically depends upon the sample data acquisition means, we are measuring at certain interval of time. So, if your frequency here is for measuring this means every points we are measuring and then we are calculating the frequency. So, it was assumed that it is a continuous but, in reality the measurement of the frequency deviation that is change in delta f here; take place this continuity in the sample data fashion.

If the sampling rate is relatively high, compared with the change in the response then the means this whole analysis will give the portrayal. So, we have to have the fast analysis very sample data should be very fast means frequency should be very high. Then, we can say this analysis is valid; so far just we analyzed this A L F C loop again primary and secondary it is a low frequency control loop for the single area system.

But in the practice it is not on single 1 area system; we can have the different area system they are connected with some. Then the performance of the system will be totally different, when we have to analyze the other areas along with the primary area. And then, we can see what will be the performance and what will be the advantage of having the line connection between the 2 different areas. So before that let us consider some this control area concept.

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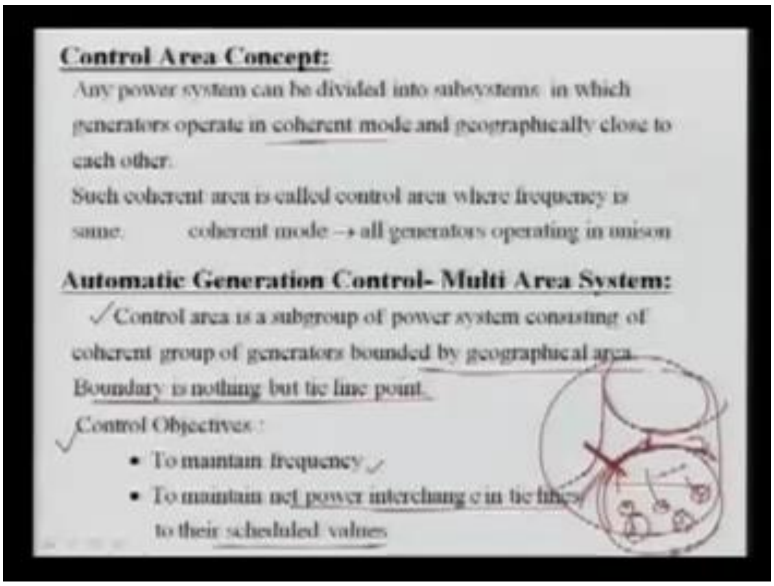

Any power system can be divided into sub systems, in which generators operate in coherent mode and geographically close to each other. I want to say that Coherent means, they are operating in the coherency means whenever there is some disturbance the oscillation of these generators are corresponding to same. Because, there will be deviation suppose there is sudden change in the load.

So, the generators which are in the coherent mode they will oscillate and the relative oscillation between these generators will be 0. So, that is called it is a coherent mode and also they must meet geographically close to each other. For example, in a big power system here this is a big power system we have few generators.

These are sides and they are connected with the some transmission lines here the network and there is some change here in the loading what will happen? There angle of separation will change because, they have to supply more demand if here and it is not a steady state change. Because, there will be oscillating to meet this the angle delta will change will settle it will take some time.

So, the oscillations or rotation change or speed variation is relative speed among them is 0. Then, we can say it is coherent mode and also there must be geographically closed here; then we can say this is one control area, we can have another control area, another control area here. So, such coherent area is called control area where frequency is same means here the frequency we are talking the same.

Similarly, here the frequency is same so, we can have the different area. The coherent mode all generators operating in union. So, in the multi area system the automatic generation control normally we should divided the system into the different control areas. So, the control area the discretion just I am talking; the control area is a sub group of power system consisting of coherent groups of generators bounded by geographical area.

The boundary is nothing but, a tie line point means, here they are connected by some tie line, they are connected by some tie lines and then we can say this is boundary. Control objective here are to maintain the frequency of this various system, to maintain net power interchange in the tie line to their scheduled value. So, we have to just maintain the frequency of all the areas and also to maintain the net interchange power between the

2 areas interchanged areas; through the tie lines to their scheduled value of how much interchange is permissible that's pre specified.

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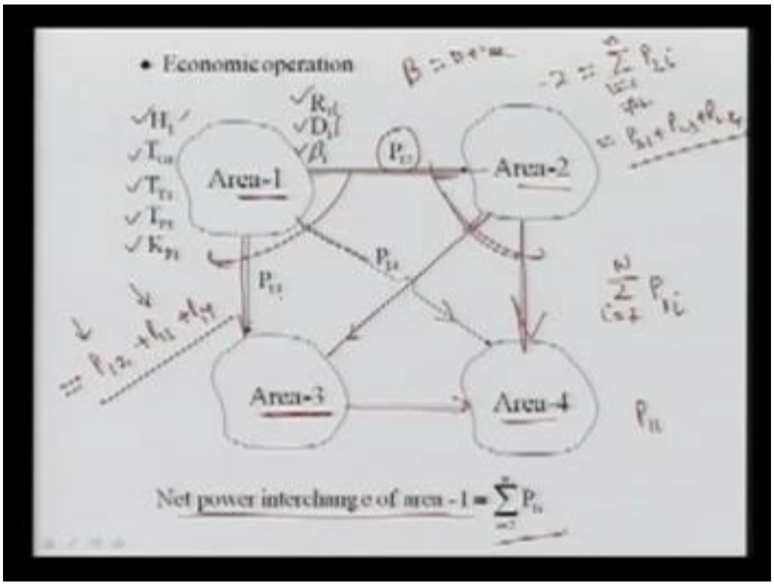

Now, you can see just here shown these 4 area system and all the areas are connected by the tie line. For example, area 1 is connected with area with area 2 with this tie line and the power which is flowing this P12 that is going here. Similarly, this area 1 is connected with area 3 and here power is again the tie line connection and the power is flowing 13. Here we are talking from 1 to 3 it is some value it may be negative or positive.

From the 3 to 4 we have another here; this tie line from 2 to 3 we are having this; from 1 to 4 we are having this tie line and 2 to 4 we are having this tie line. So, all the areas are connected and we know the parameters of each area is nothing but, it is the combined inertia constant that is H1 because, they are different machines there may be 10 20 30 machines.

So, the combined inertia constant that we can calculate let us say H1; the combined TC1 that is the governing time constant. Here the combined TT1 that is the turbine time constant; here the Tp is the combined power system time constant of area 1 and Kp is you can see gain of the generator gain that is Kp i of area 1. We also have some other parameters in this area 1 that is R that is regulation.

We had the load that is a frequency dependent load and related with the constant D1 and that is your bias factor B1. Because, they are related here nothing but, the origin of the b is nothing but, your d plus 1 over R. So these are changing, so this will be also changing. Now, the net power interchange from the area 1 I can say it will be the summation of all the powers that they are going from this area.

Again this power is the as I said is algebraic sum means, here we can say this is your summation of the power from area 1 to the various area i and here i is equal to 22 various areas that is your area in this case four area. So, I can say this the net interchange will be nothing but, your P12 plus P13 plus P14. Because, we are having 3 area so the net that is going it is the addition of all the power some power may be coming that is true.

So, here that is it is algebraic sum so if it is value is coming then it will be negative and it is so the algebraic sum I had this boundary and that is related here. Here we are not writing i is equal to 1 because, P11 has no meaning. So, it is not in power in charge it is inside. So, it is always here from 2 to n means, number of areas and then we can write the net interchange of area 1 we can write here.

Similarly, we can write the net area interchange of 2 it will be summation P2 i; h ere i is equal to 1 to n but, not 2. So, what will be this value? We can write P21 plus P23 plus P24. So, we can write the summation of the power here; those are coming out whether it is negative or positive and then we can add together and then we can get net area interchange. Now, another that we have to here for simplicity we can consider the 2 area system.

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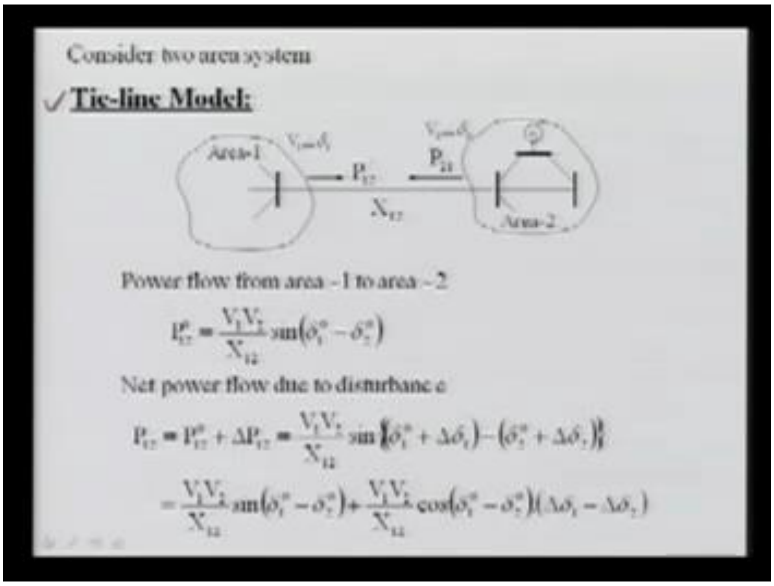

Here the 2 area system has been considered and then, we have to model this tie line power flow and this modeling will be included in your that is an area load frequency control. So, this tie line model we will consider in the next lecture that's lecture number 5. So, now I can recap what we did here in the lecture number 4. We saw, that the secondary or you can say the secondary A L F C control loop design to remove the frequency error.

And we saw the performance of this secondary A L F C loop that in a steady state we got the 0 frequency error and that is required. We also saw, the dynamic performance that a dynamic step response that we saw if whenever there is change in load what will be the dynamic and we derive that curve. And we found that the gain is very very important here as I said this gain K i is very very critical and that we calculated.

So, we saw this, by setting this value gain we can get the different performance as means in terms of your settling time difference between your over shoot and this K i that we calculated. But in all the cases we found that if you are using the integral controller it is reset control, it is reducing your frequency error at the same time here we can see from this equation it is a stable control loop and then we also verified here.

So, you can see from this we say this is stable it's from this graph you can say it is stable and we made the various assumptions we justified that. That's how it is true and now in the next lecture we will see if the 2 areas, so far just in this lecture after the lecture 4 we discussed the single area. Now, we are going to consider the multi area and primarily I will consider the 2 area.

Then, we will model the tie line models and then we will see how this blocks, now they are going to be added together and what will be the advantages that we are going to have with that tie area of control.

Thank you