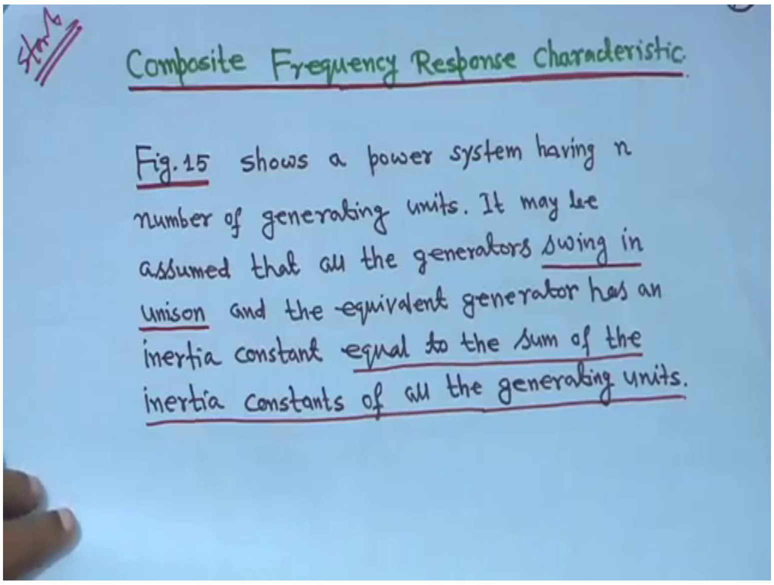
Power System Engineering
Prof. Debapriya Das
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 52
Load frequency control (Contd.)

So, we have seen that degree, degree of stability for a, you know for an isolated system. I have showed you that high, how that your I that degree of stability, that is the Eigen values real part, I mean the in general, Eigen values is very close to the origin and lying on the left half of a base plane and by varying the integral controller k Eigen setting that we can shift that Eigen value as much as possible away from the origin. And that is actually, we define degree of civility and based on that we are getting some optimum values of integral controller gain settings.

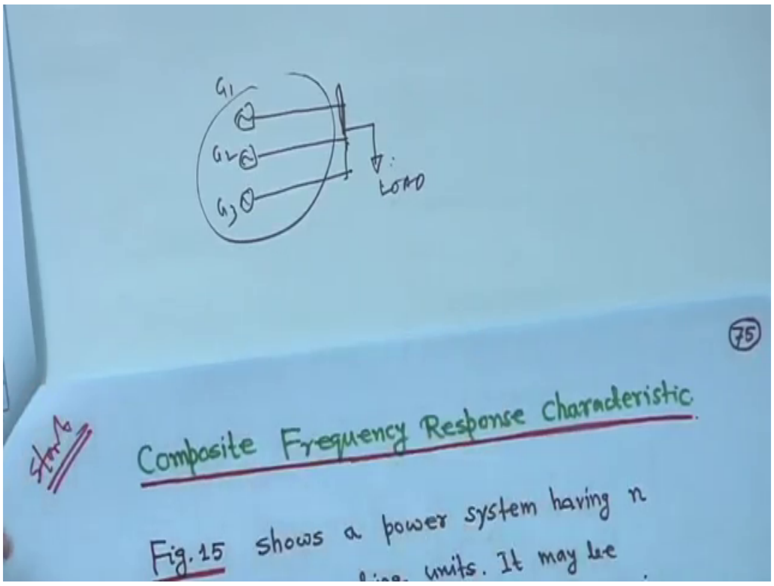
(Refer Slide Time: 00:54)



Now, in that case, this is the only thing I have told, but there are many other techniques, like many other techniques to obtain the optimum values of integral controller gain settings, that is, that will give much better response than what I had been shown, but those things are not possible in that classroom because you need to write coding and then, you have to see the, how things are happening. Similarly for, if you if you use PI controller or PID controller or a combination of your I integral and derivative action for that also, it is not possible to do that exercise in the classroom. You need computer and you, you need some optimization technique.

So, those things cannot be, it cannot be taught here. But general thing is, as far as things are concerned the classroom exercise and hope you have understood this. Now, next is the composite frequency response characteristic right. For example, before showing this, suppose you have a system.

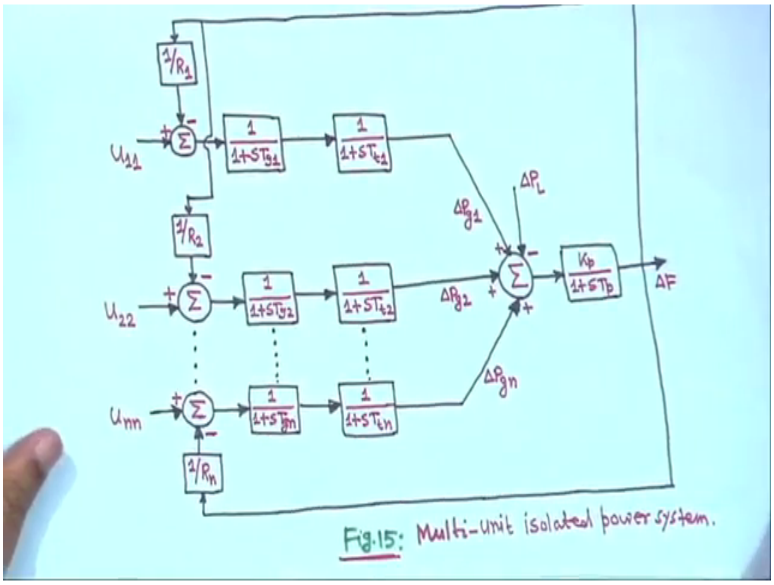
(Refer Slide Time: 01:53)



Just isolated system not interconnected with anything and you have the load. Say, this is the load. And you have many generators, say suppose, they are connected, suppose you have many generators; they are connected and they are supplying this load. So, this is your load and this is your generator, say generator one, generate two, generate three and so on and you have to find out what is the composite frequency response characteristic.

So, in this case, so many generators are there and they are in parallel. So, we will assume that all the generators are in coherent group; that means they swing in unison, that means, their increase or decrease of the speed remain same so; that means, now we will come to the composite frequency response characteristic.

(Refer Slide Time: 02:36)



So, suppose you have you a have n number of generators. And supplying a load just - just now I showed you that your, that suppose you have these three generators and this is the load, you may have a in general if you generalize it. suppose you have a n number of generators, so in that case how the block diagram will be, because single area block diagram we have seen and we will consider here, you know to just to save the space same thing. We have taken this non d type turbine.

That this - this is the governor time constant and this is just non - d type turbine, the steam chess time constant. So, suppose you have in this case, earlier for single area case or your isolated case only, one - one P g, that is delta P g was there, but you have n number of such unit. So, things are very simple for example, this part this; part K P upon one plus ST p, it will remain same because you have, suppose you have three generators, they have - they may have your different age, the inertia constant H1, H2, H3 and, and of course, you can find out the equivalent H of this thing one numerical. Previously, you have shown and in the past system analysis course in the your previously which I recorded that thing, you have seen it that for transient stability analysis, that how to obtain the HP valiant has been shown there.

So, if you have a H1, H2, H3 - it can be represented by an H equivalent and only a single, your what to you call - that power system time constant and one single K p.

That is, that is this one. So, even in n number generators are there, this block will be only single block. So, K p upon one plus ST p, assuming that H can be in equivalent H, you can obtain further all the parallel connections. So, it is a single one and it can be, I told you the all the generators are showing in unison. So, they can be represented by a single frequency.

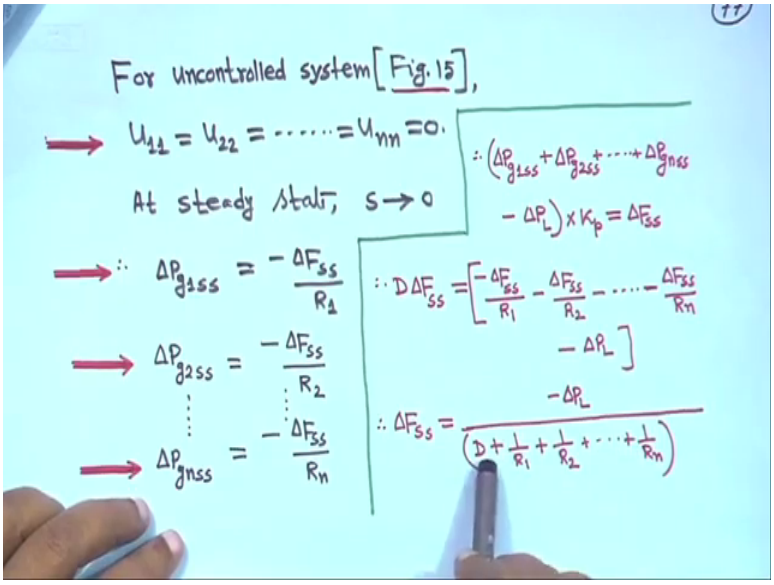
So, there is a single frequency deviation you have taken and even if you have different H1, H2, H3 their equivalent can be obtained. There if parallel, so, and in that case your this, this power system, this is power system transfer function we call. K p upon one plus ST p, it will be single one now and different unit they, they may have different governor - a turbine time constant. So, it has been taken like this. So, earlier we have seen for isolated case only one u was there, but you have - you have so many units are there are - so many units are there. So, input to each unit u 11, u 22 up to u nn. What is u 1 -1, u 22, u nn, we will see later.

Now, all this the plus feedback and now, from here this is per unit one, it is 1 upon R 1, that this delta F is coming 1 upon R 1. Similarly, for unit two, this delta F is coming here - 1 upon R 2 and similarly for nth unit - for nth unit I make it the make, made it this way. So, it is 1 upon R n, that is your, your this feedback for nth unit and here it is u nn and here, you have passed this for first unit, this is for second unit, this is for third unit and this is your generation for unit one delta P is your generation for unit two delta P g2 and generation for unit three delta P g2, sorry, into it - it is delta P gn, that means, delta Pg1 plus delta Pg2 up to delta P gn. This summation and this is the load here only, single load I told you only single load easier. And that is your single load and it can be, whole thing can be represented by single time constant.

Because single H, we can make it and therefore, K p upon one plus ST p and the output is the delta F. The frequency deviation, this is that, it is actually very simple diagram actually there. So, you should not be very, you know very much worried about looking at this diagram. This is very simple, first you draw for a like the way you did for single area system instead of your, this your what you call - delta P g. Make delta P g1, this is the first one and delta F is same from everywhere, from delta F1 upon R 1; come from delta F1 upon R 2 from delta F up to nth unit 1 upon R n, same feedback plus minus and this is u 11, u 22, u nn. What is this? I will come, I will coming now.

So, this is figure 15. This is multi unit isolated power system. It is not interconnected anything as soon as you interconnect the power system, the tie line model; tie line means that a three phase transmission line. And if two power systems are connected by tie line, we call. So, those models will come later. So, this is your, you know what you call - that isolated block diagram for multi unit system you have so many generating units. So, this is multi unit system. Now, for uncontrolled system I mean, when system is not control and control un - control u 11, u2 - 2 up to u nn; all will be zero. All will be zero.

(Refer Slide Time: 07:21)



So, for un -control system u 11, u2 - 2 up to un is equal to zero. So, as steady state S tends to infinity that we, sorry, S tends to zero at steady state. So, let me T tends to infinity. So, delta P gss is equal to minus delta F SS upon R 1. This we know earlier, earlier for single unit we have seen delta P gss is equal to minus delta F SS upon R.

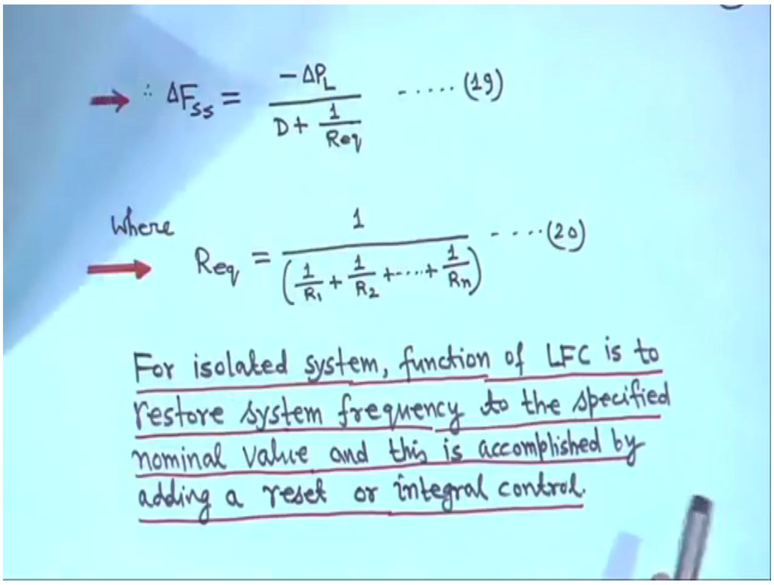
But that is, so many units are there, but meaning is same. So, I mean, even u1 is zero and if you make, make all the block diagram that is your T tends to infinity, so S tends to zero if you make all S zero. So, same philosophy will be applied here. So, delta Pg1ss is equal to minus delta F SS upon R 1 delta Pg2ss minus delta F SS upon R 2. Similarly, for nth unit delta P gnss is equal to minus delta F SS upon R n. This is known to us. Now, steady state values out here when all the, all the in the block diagram, if you make it is S is equal to zero, you can do yourself. So, this is one, this is one, this is one, this is one, this is also one and steady state value delta Pg1ss, delta Pg2ss, delta P up to delta P gnss at all minus delta P1 into K p is equal to delta F SS.

So, here it is delta Pg1ss plus delta Pg2ss plus up to delta P gnss minus delta PL into K bracket close into K p is equal to delta F SS for single area system only, delta P gss was there. And these things are not there, but you have n number of units; so delta Pg1ss delta, P g2ss up to delta P gnss. It is summit of all minus delta PL into K p is equal to delta F SS because at S tends to your, what T tends to infinity, S tends to zero. So, in this block diagram you can make S is equal to zero also and this is your all use zero. So, that will give you a steady state block diagram not showing here, but it is understandable to you know.

So, that means, and K p is equal to 1 upon D, K p is equal to 1 upon D, if you put here, K p is equal to 1 upon D, then it will multiply it by D delta F SS. So, it will be D into delta F SS. So, that is we are writing D into delta F SS is equal to this one and this one, delta P g1sss, delta P g2sss up to delta P gnss, you will substitute here, you will substitute here; all this is put it here. So, this is, you put it here and the minus delta F SS upon R 1 minus delta F SS upon R 2 minus up to minus delta F SS upon R n minus delta PL. Or upon simplification or delta F SS is equal to minus delta PL divided by D plus 1 upon R 1 plus 1 upon R 2 up to 1 upon R n.

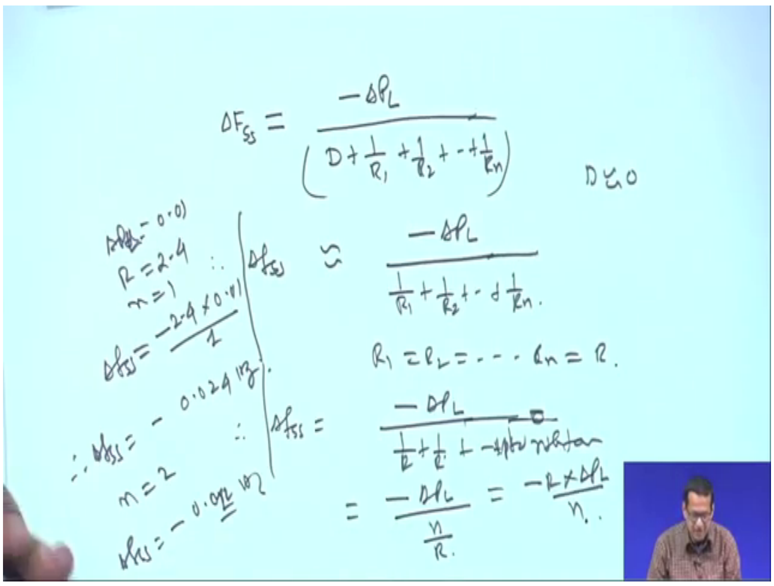
So, this is the steady state, your what you call - if the you, if it is a composite system, I mean. So, many units are there. So, this is the expression further steady state error. So, in that case what will happen that I will come to that? So, this is your same as before if - if you have only one unit, then this one or two one or in term will not exist. It should have been become D plus 1 upon R minus delta P1, but because of so many units are there, so, that is why minus delta Pl upon D plus 1 upon R 1 plus 1 upon R 2 up to plus 1 upon R 1 or you can write or you can write the delta F SS is equal to minus delta P1 upon D plus 1 upon R eq. This form you can write earlier for single unit we are writing minus delta Pl divided by D plus 1 upon R, but instead of R you make 1 upon R eq – R eq.

(Refer Slide Time: 10:40)



And where R eq is equal to, you can make 1 upon bracket 1 upon R 1 plus 1 upon R 2 plus up to 1 upon R n. Just - just simplifying this equation, just simplifying this you are putting in the per D plus your 1 upon R eq and your R eq, we are putting actually 1 upon 1 upon R 1 plus 1 upon R 2 up to 1 upon R n. So, 1 upon R eq, actually will be 1 upon R, actually will be 1 upon R 1 plus 1 upon R 2 plus 1 upon R n, I mean this thing, this thing. So - So, for isolated system, the function of 1FC is to restore system frequency to the specified nominal value and this is accomplished by adding a reset or integral controller.

(Refer Slide Time: 11:45)



So, before – before that, before that just have a look, just have a look that your delta F SS, actually delta F SS I am writing here delta F SSS is equal to your minus delta P1 divided by D plus 1 upon R 1 plus 1 upon R 2 plus up to 1 upon R n, say. D is actually very small, D actually very small. So, because it is a K pTp, all you have seen and K p will got that is your 120. So, D will be 1 upon 120. So, D is very small. So, this can be just - just look at that, this can be approximated, say, I mean approximate one minus delta P1, if D is neglected assuming that the approximately zero.

So, in that case it is 1 upon R 1 plus 1 upon R 2 plus up to 1 upon R n. For example, if you assume R 1 is equal to R 2 is equal to R n is equal to R. If you assume all, then delta F SS will be minus delta P1 divided by 1 upon R plus 1 upon R. Up to your one n - nth term. Up to it will go to that your, what you call - nth term; that means, say it is up to nth term. That means, this one actually will become minus delta P1 divided by N divided by R. Because, you have N number of one; that means, it will be minus R into delta P1 divided by N. That means, if N is equal to 1, that is the single unit, whatever you have seen earlier in that case steady state error will be minus R into delta P1, but when if it is more than one, then basically steady state error of frequency is you are decreasing.

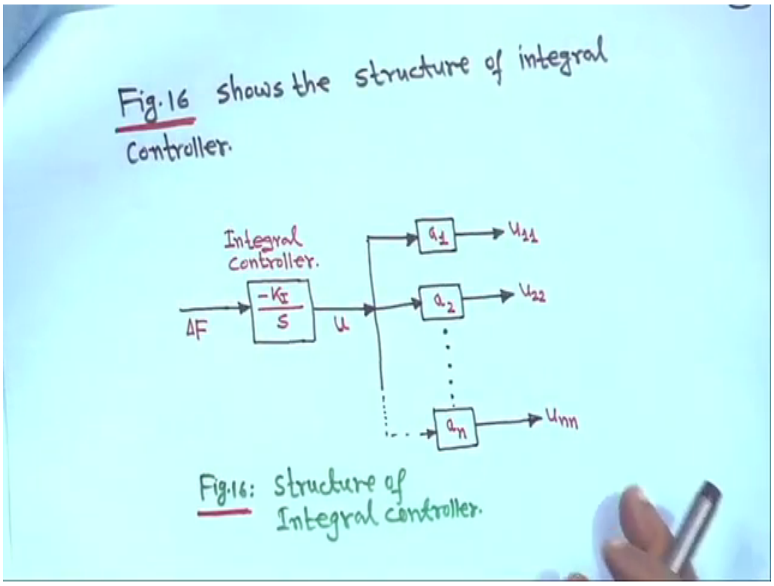
That means your delta F SS is equal to say, suppose, your delta PD, sorry, delta P1 is equal to say 0.01 and R is equal to 2.4, so load increase; that means, this one will be minus 2.3 and say, n is equal to 1 so minus 2.4 into 0.01 divided by one. So, delta F SS is equal to minus 0.024 hertz. So, if n is equal to 2, suppose if n is equal to two, so n, it will be delta, a phases will be minus 0.012 hertz.

So; that means, if you will put more units, since parallel the steady state error is actually - actually that value is decreasing. It is decreasing so; that means, your that departure of the system frequency from its nominal value will be less, if you just, you have to call if you just make it your - if you put more units in parallel. So, so that; that means, what this value will decrease if you have more than one units? This value will decrease. So, that is advantageous if more you in general you will find more units are operating in parallel, not one maybe not two, maybe more than that in any power system.

Now, this is the, but the steady state error will exist if you - if you really put three four units steady state error will be there, but your objective is to eliminate the steady state error to eliminate the steady state error, what we do you need - integral function integral action. So, what we can do is that, your integral controller suppose is needed actually - actually for a thermal power, thermal power plant. Generally, integral control, integral only, only integral control action is recommended and, and an also we have proportional is also possible, but derivative control action for thermal power plant actually, generally is not recommended. So, results what is the reasons? Another thing beyond the scope, then we have to go much into detail, but for thermal power plant, generally utilities the paper integral controller having very small gain setting reasons, I will tell you later.

So, but you have to, you have to go for integral control action.

(Refer Slide Time: 15:50)



So, in that case what will happen? Suppose, that u 11, u 22 up to u nn, suppose you have this block diagram, you know earlier we have this block diagram. This is your u 11, this is u 22 and up to u nn, n number of units from where this u 11, u2 is coming? Actually, this is your frequency deviation delta F and this is your integral controller minus KI upon S and this is u. And so, u 11 and your this u, actually your what you call - in part of that is going to unit one, going to unit two two and going to unit n.

So, this is u and this is u1 or actually a 1 into uu22 is equal to a 1 into u up to u nn is equal to n into u. So, this is structure of the integral controller. Basically, we have seen, we have seen that in general, the steady state value of u actually as in equivalent to your load demand. That we have seen, also I have shown you that steady state value, actually is equal to load demand. So, suppose load demand is one load demand is say, for example, per your ten megawatt. So, a steady state U also will, so, ten megawatt. And all the, and this ten megawatt, this has to be shared by this unit, among this unit the ten megawatt has to be shared.

So, in that case u and this a 1, a 2, a n whatever it is, you, if you set arbitrary values, suppose, it a 1 plus a 2 up to a n, its summation should be one and if suppose, load suddenly ten megawatt, load is increased, for example, then ten megawatt you have to - you have to say you have to share among this unit such that your well cost will be minimum. Again, I am telling you that again, that economic load dispatch concept is coming here, but what we will do that; that means, and just I just instead of setting arbitrary values of a 1, a 2, a n if you get how much this out of ten megawatt, how much that suppose you have instead of n unit, suppose you have three units and every unit has its different well characteristic, so accordingly after economy, suppose ten megawatt how you - how you can distribute among these three generating unit such that well cost will be minimum.

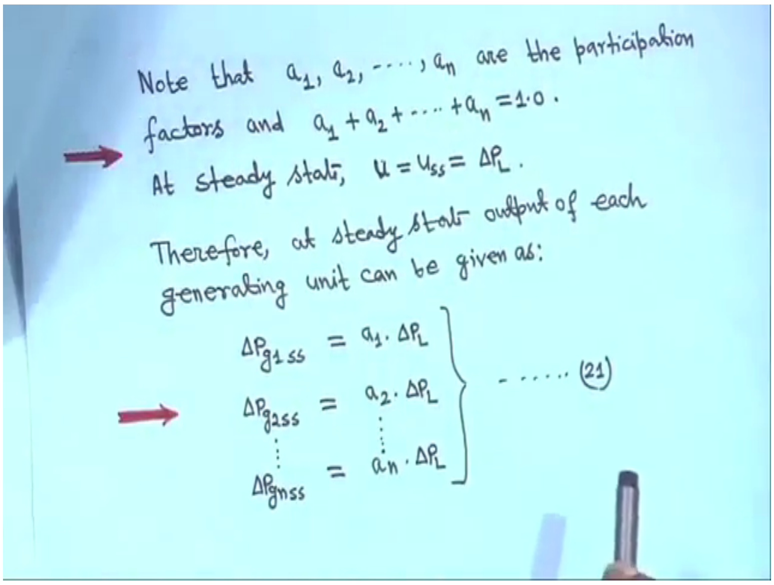
So, in that case, this a 1, a 2, a n you have to decide, but just I am telling you for the sake of understanding, suppose you have a ten megawatt. Ten megawatt power demand increase and suppose this a 1, if you put 0.4, this is you 0.4 and this is your 0.2, because summation should be one. So, this one what will happen? u 11 output will be four megawatt, then four megawatt and two megawatt; that means, this unit actually will generate four megawatt. This unit will generate four megawatt, if it is a three unit system and this unit will generate two megawatt. Total will be ten.

Because this ten load increases ten, So, that means, this a 1, a 2, an; you have to set, but its value will be less than one and if any - anything you set it to zero for example, suppose three units are there instead of nth unit suppose this is your third unit and if you put this one is zero and this was a point four this is 0.6. So, it will be your what you call that for your four megawatt it will be 6 megawatt at steady state when you will go for transient response; that means, this generator will generate four megawatt this will generate six megawatt this will not generate anything at steady state, but at during transient it has some effect because its transient it will swing right some oscillation will be there after that it will be settling to the steady state.

So, if - if this is a zero, if this generator is not, you are what you call - responding to the steady state to the increase of the load, but transient will be transient, some issues. So, you are what you call - this generator will show that is generating some power, but at the steady state you will find this is zero. So, that is why this is the control structure and this is their, this is your an input to this controller is delta F, the frequency deviation because our objective is to connect the steady state error in frequency to zero. So, a – hence, this u 11, u 22 and u nn, all will - all you have to go into the input to the each unit- this 1D1 1, u 22, suppose if you have n number of units, then you will n.

So, this is actually your, what you call - the structure of the controller that means,

(Refer Slide Time: 20:01)



That – that is I have given, let they elect a 11, a 22 up to n are the participation factor we call. And a 11a, sorry, a 1 plus a 2 up to an summation of all a is equal to unity. Just I told you and at steady state I told you that u is equal to u steady state is equal to delta P1, this we have seen also in the further single area system, this has been shown therefore, the steady state output of each generating unit can be given as delta. I just told you delta Pg1ss will be a 1 into delta P1, delta Pg2ss is equal to a 2 into delta P1 and delta P gnss is equal to AN into delta P1. So, these are the steady state power generation by the generators.

If you go for simulation, you will see that your what you call - this power had been generated by this generator. So, that is - is that your what you call - this is that your composite - composite system. Another thing is there, if time permits I will tell you, tell you those things that generally, particularly for thermal power plant, thermal power plant hydro power plant, we cannot consider in this course, then it will - it will - it will take long time. So, all you will restrict ourself to the thermal power plant. So, these are all steam turbine generator, but the hydro, but if you consider hydro power plant, then in that case the hydro governor is a different type. And hydro turbine also have different transfer function.

So, we will, that will not consider that we only restrict to ourself, to the your what you call steam turbine. So, every - every generator, every generator cannot generate power the way you want. Because you have lot of your, what you call - that your physical constant. I mean we just - just if you ask that in it, power can be generated in ten megawatt just in one minute. It is not possible for the generating units due to due to due to its many physical constants are there, that is why that power, that output of the generator whatever you have shown here, that we have not considered that you are, what you call that – that, those - those rate limit because it has some generation rate limit.

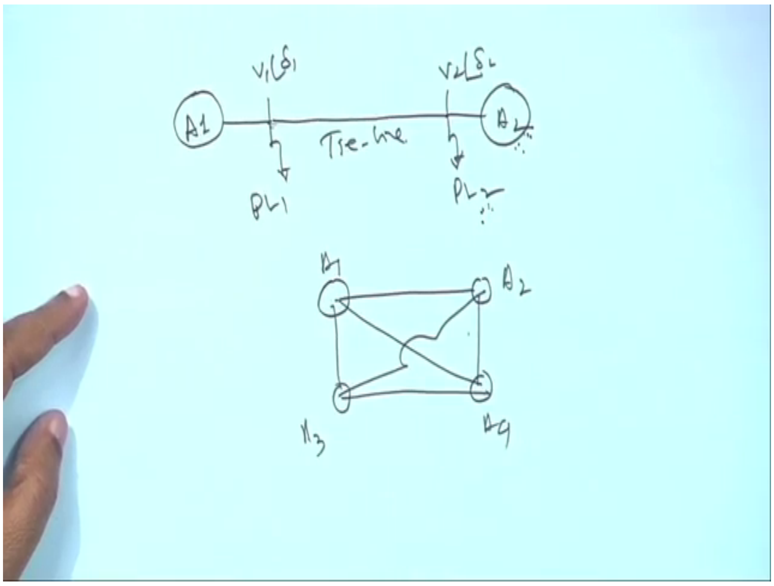
Later, I will show you how it can be incorporated, but it is at that time as soon as you consider that your rate limit, the system will become non-linear. So, we do not want to do, do that here, but as soon as any non-linear, because this is a non-linearity because every generator has some restrictions when we will go for simulation, those restriction you have to impose at that output, at the output of this you are what you call - this power generation. Another thing is there, this is the governor model, we have seen those things I will not cover, but giving some ideas that every governor had dead man. Dead man means the magnitude of sustain speed change within which there is no change in the wall position. So, the dead band dead band is there.

So, if you consider the governor dead band. It has some mathematical analysis, but here we will not consider if you put generation rate limit. If you put governor dead band, then in the response you will see a very long sustained oscillation. Instead of going, it will go steady state, I know it for - for after long duration. Because of the dead band, because dead band actually gives that long sustained oscillation although it is stable, it amplitude is small, but it will provide your what you call - sustained oscillation. So, those things are there in AGC, but we will not consider even this controller also for any system; any system you take in reality, basically all systems are continuous system, even power system itself is a continuous system. But this controller, controller part is always in discrete domain, because if this output, whatever you give it to a feedback to the controller, whatever feedback this is your giving actually.

This is actually sampled at every sampling instant and for AGC; you will find it he may be sampling instant. Maybe one second, two second, four second; you know six or eight second, whatsoever even, may even it can go up to 32 second that you are sampling instant and accordingly that, how this accordingly that controller will operate. Even this u also, this u also it can be, it can instead of giving continuous feedback to the unit, it can give it after some sampling instant. So, those things are beyond the scope, but giving you some ideas regarding this concept, we will already consider about what you call - the linear power system.

Next it, next whatever you will consider, we will consider that you are what you call - interconnected operation of power system. That means, two - two power system or n number of power system, suppose they are interconnected; for example - for example, and then, the concept of control area actually coming.

(Refer Slide Time: 24:49)



For example, suppose you have a power system, you have a power system and you have another power system. You have another power system, suppose this is your area one and this is your area two and here, you have voltage V1 angle delta one, V1 angle delta two and this line, this line we call actually tie line, this is a single line diagram.

So, basically the here, this side a power network - very huge network, they are all, all power network interconnection is there. This - this side, this side it is interconnection is there. And in between that, these two power system are interconnected by tie lines. Tie line means, basically it is a three phase transmission line. And load is, here load is here and load is here. They are interconnected. Suppose, suppose this is my area one, I am putting delta P1 - 1 and this is the load at area two delta PH, sorry, P1 – 1, then suppose this it is, it is expected; it is expected that this power system or this area, we will accommodate its load by its own generation similarly, here also.

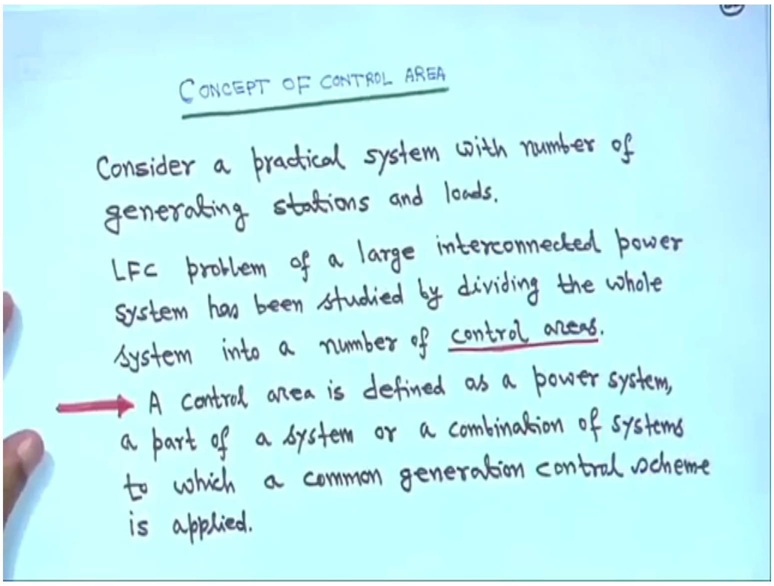
But question is that, if this, suppose this demand is more and this area whatever is power generation capacities, they are failed to meet the load demand, then additional demand will come from this - from this area, assuming that this power system is sufficient spinning result, such that it can supply its load. So, if it is - so, if it is so, then, the in that case, the power will flow through the tie line. That means, it is it is helping this area or in other way also, that is that where they are interconnected operation. Actually, the main benefit is the cooperative assistance between these two areas. In general you have so many areas. So, they are, they are - they are interconnected. So, this is the advantage of your what you call - that when two power systems are your, your what you call - that interconnected.

It may have so many areas, suppose this one, this is another area, another area, another area. So, it may be connected like this. It may be connected like this. So, if you make more connection by all this tie line, suppose this is power system one, this is power system two, this is power system three, this is power system four; so all these things can be connected together such that, one can help each other. So, that is that coopering assistance actually, is one of the plan benefit of interconnected power system. So that is why we will move to your what you call that - your interconnected operation of your power system.

So, we will consider in this, in this course, we will consider only two area system and that means, two power system interconnected like this, this one we will not consider because it is not for the classroom purpose. The modeling will be block diagram representation is much bigger and analysis will be little bit lengthy.

So, we will only restrict to the interconnected operation of this one. So, so in that case what will happen - that I told you that E2 area, three area whatsoever the concept of concept of control area comes.

(Refer Slide Time: 27:41)



So, consider a practical system with number of generating station and loads. I mean this system, this area one, this is actually area one, this is area two. So, in this system; in this system there are many generators because it is a power system. It is a huge power system. Suppose, you have one: so for example, suppose one powers, one power system you have in Chennai, another is a Bengal, Bangalore and suppose two power system an interconnected by these three phase transmission line.

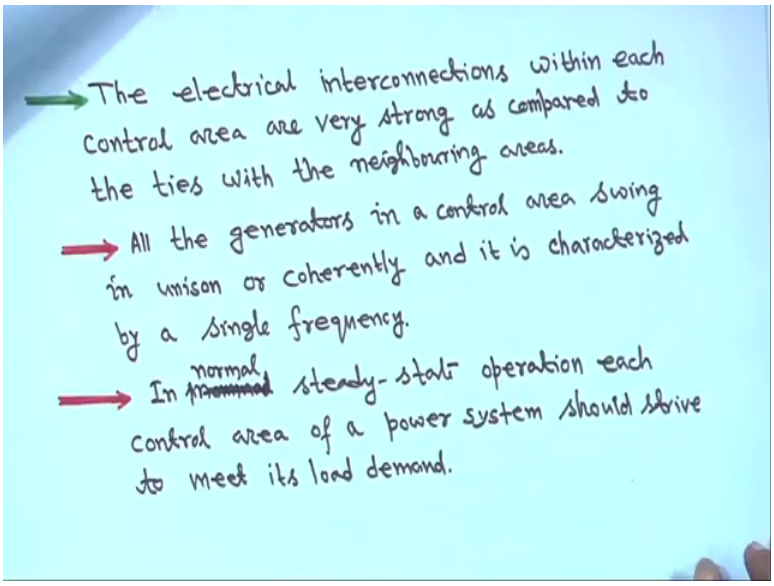
So, this is and then, and then power system you have so many generators. And interconnection, all the substation loads everything line, everything is there. Here also, there, but they are interconnected and if I need power, I can purchase from this area are, from this area either of this area. So, it is a planned benefit. For the interconnected operations, the cooperating assistant, it helps actually rather than you have accommodating this, but it is expected that all that, all the generation in the particular area will accommodate its own load disturbance or own load increase.

So, in this case, the concept that is why concept of, concept of control area coming whatever I am telling. So, LFC problem of a large interconnected process you have been studied by dividing the whole system into a number of control areas. For example, this one I just showed you, may be if this thing you divide, you just divide it different region and this is, it can be divided. In the number of control areas. So, that means, a control area actually defined as it. So, it may be a power system, it may be a part of the system or a combination of system to which a common generation control scheme is applied. That means, each area, whatever you have that you can apply, a common generation control scheme.

So, it may be a power system or maybe a part of a system or maybe a combination of system to which a common generation control scheme is applied. So, this is the concept of control area; area means it is basically a power system, a part of a power system. Why are generating stations are there and it is and so much several loads are also there? It is like a power system network, actually concept is but this is a concept of control area.

But all this a common generation control scheme can be applied.

(Refer Slide Time: 29:50)



So, the electrical interconnection within each control area are very strong. That means, it is a power switch. It is the power system network; it is a power system network you have so many transmission line connected. You are among various bars. Among various bars, but it is a power system network. So, and you are what you call with each - control area are very strong as compared to, try the tie lines with the neighboring area. Tie line means, only this one, only it is connected like this. So, only few lines for each one is a power system, you have several bars - bars and several transmission lines are connected.

So, and all the generators in control area, the swing in unison or coherently and it is characterized by single frequency; that means, they are in coherent group, they swing in unison. That means, there increase or decrease in three, it is remain same. That means, they can be characterized by single frequency - this is the assumption.

And in normal stage operation, each control area of a power system should strive to meet its load demand. I told you under normal operating condition, that suppose load demand is here P, this PL2 – PL1, we, whatever generating units are here, it should accommodate this whole load. Same is here under normal operating condition, but if I need power or some load demands on an increase, then I can borrow power from the adjusting, you are what you call from the neighboring areas; if I have sufficient spinning reserve.

Thank you, we will be back.