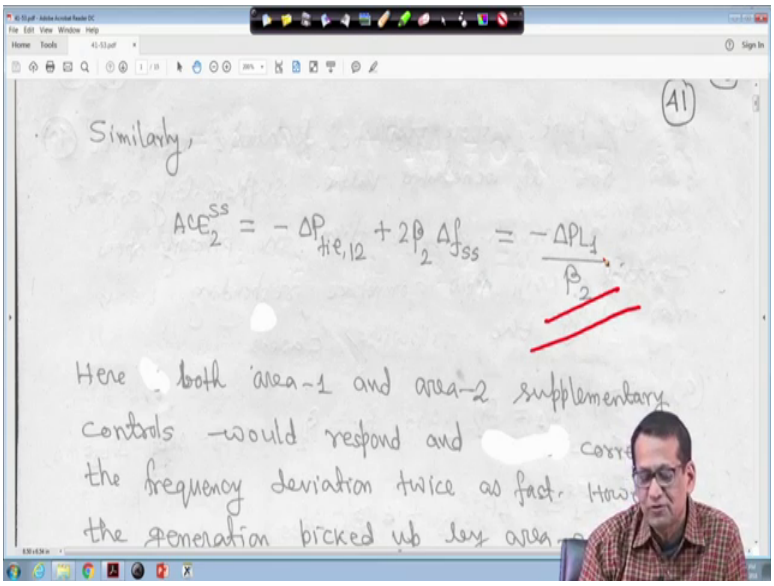
Power System Dynamics, Control and Monitoring
Prof. Debapriya Das
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 40
Automatic generation control conventional scenario (Contd.)

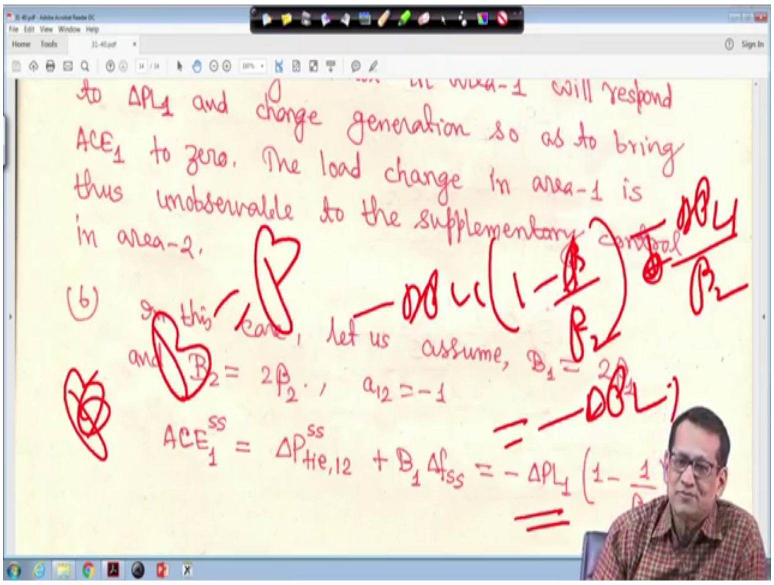
So, so this is actually steady state error.

(Refer Slide Time: 00:22)



That means; that means, in that case what will get that area 2 also area 2 generators also they have to area it has to respond right. So, in that case you will get I mean if you put and just from that expression if you put it, you will get simply minus delta pL1 upon beta 2. Now if you if you look into that your just hold on just hold on right. So, this is coming minus delta pL1 upon beta 2 right.

(Refer Slide Time: 00:50)

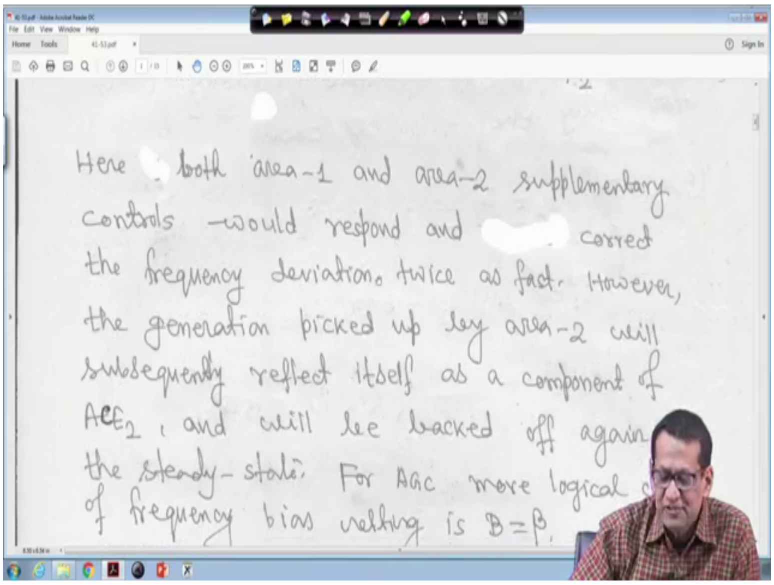


This one your if we if we look into these if we look into these that this one minus delta pL1 1 minus your 1 by say beta 2 right. This is after simplification. So, I showed you how to make it right. Then another one for area 2 whatever we have seen right; that is your that is your minus. If we add both minus delta pL1 on beta 2 if you add both you will find that it is coming minus delta pL1.

The meaning is that that even if the load disturbance has occurred in area 1 generator is not accommodating all the load right for different for B greater than beta we have taken 2 beta right. So, in that case what will happen that, your part of the generation will be has to be shared by the generator of area 2 that is the meaning that is why best choice is that your B is equal to beta.

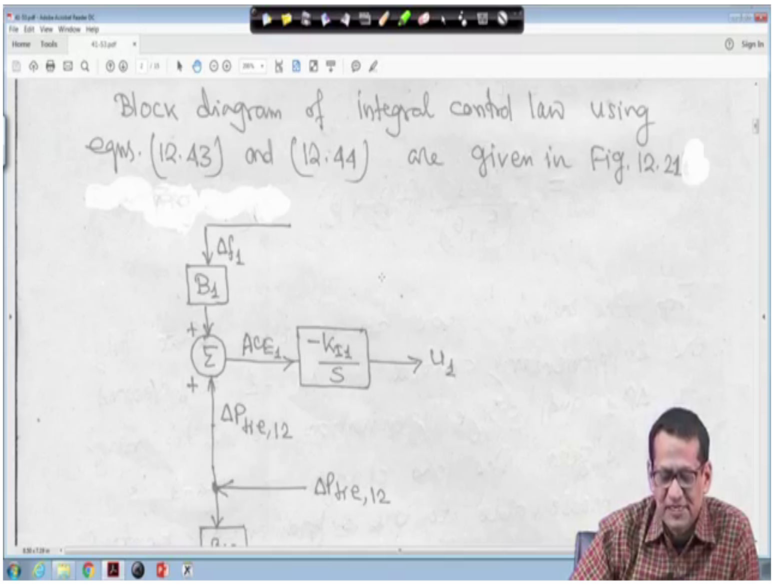
That is that frequency bias should be equal to area of frequency response characteristic right so that is the meaning. So, this one that, I showed you how to make it. So, this one will find out that minus delta pL1 1 minus 1 upon beta 2 right some mathematical your what you call simply things you have to do it. So, next so this is actually what like this right next is.

(Refer Slide Time: 02:22)



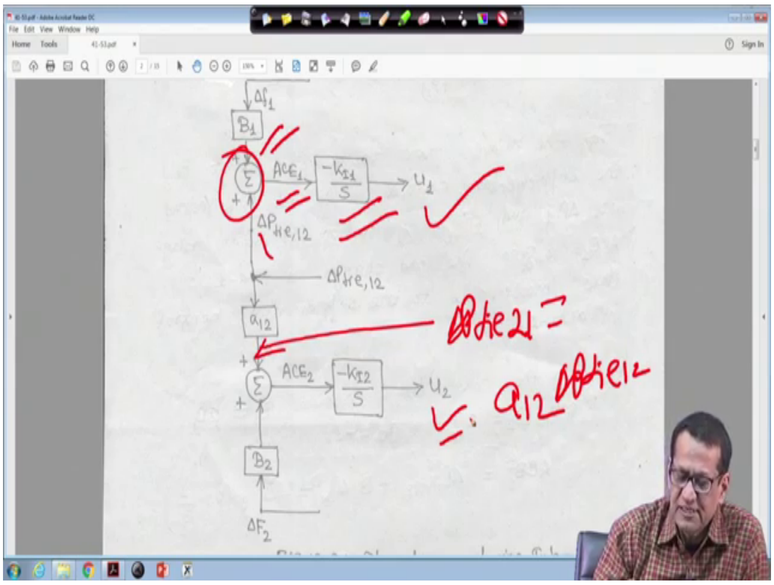
That your, this is already I told. So, not telling again.

(Refer Slide Time: 02:25)



So, next is that controller integral controller right.

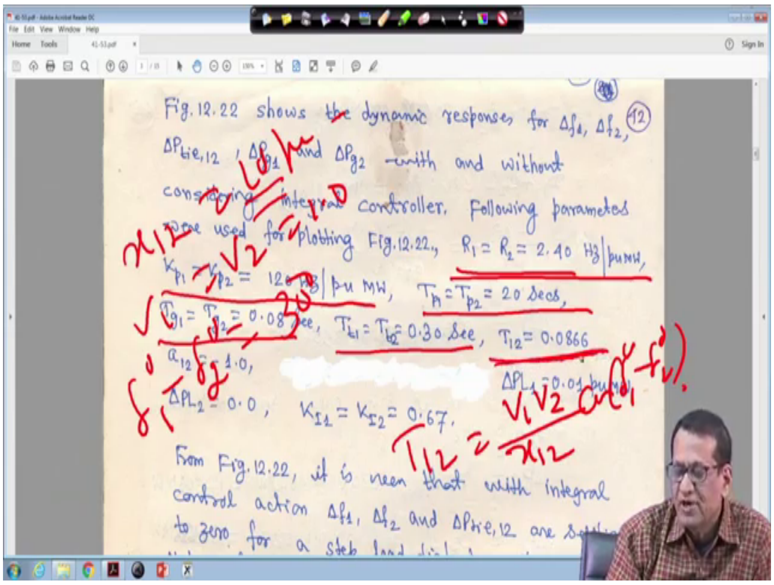
(Refer Slide Time: 02:26)



So, in that case just hold on little bit little bit ok. So, this one in the second case your this is minus this is minus K I integral controller. So, this is B 1 delta f 1 and this is the structure of the integral controller. And delta P tie 1 2 is coming these two are added and this is that area control error 1 and this is output U 1 right. That I told you initially U 1 is equal to integral of minus K I 1 integral of a c 1 D t.

Similarly, for these 1 also that U 2 is equal to your A C E 2 minus K I 2 integral of A C E 2 D t. So, this is delta P tie 1 2; that means, this is actually delta P tie 2 I is equal to we have seen in the previous lectures into delta P tie 1 2 right. And this is the frequency bias for area 2 this is delta f 2 and this is the U 2 this is actually control your, what you call the control structure controller structure for only for integral controller I have shown here right.

(Refer Slide Time: 03:42)

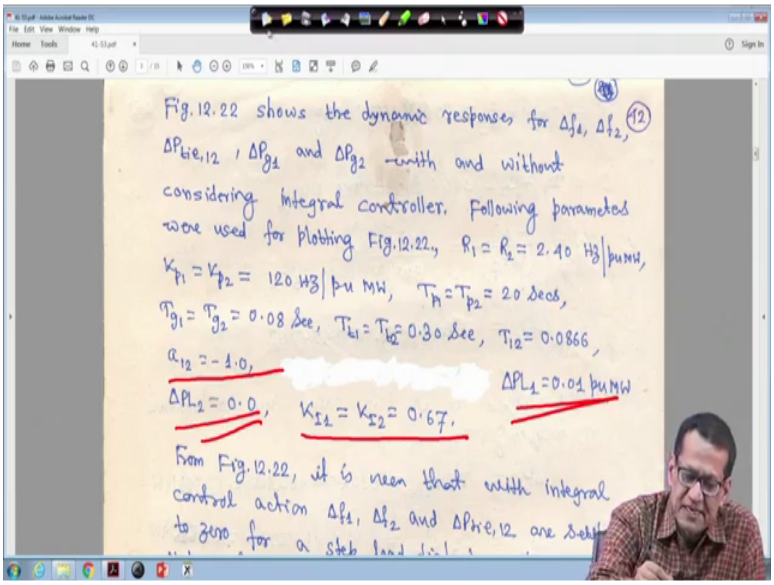


So, now figure 2 2. So, actually parameters whatever parameters till now we have used we have used R 1 is equal to R 2 R is equal to 2.40 hertz per unit megawatt. K P 1 K P 2 we have taken 120 hertz per unit megawatt. T P 1 T P 2 power system time constant T P we have taken 20 second. Governor time constant for all the cases we have taken 0.08 second.

And steam system time constant we have taken 0.32. And T 1 2 that you are synchronizing coefficient we have taken 0.0866. Actually how this thing taken that T 1 2 is equal to V 1 V 2 upon x 1 2 cosine of delta 1 0 minus delta 2 0. We have taken x 1 2 is equal to 10 per unit right and V 1 is equal to V 2 is equal to 1.0.

And delta 1 0 minus delta 2 0 we have taken 30 degree right. So, if you do so it will be actually cos it is 1 it is 1. So, cos 30 upon 10 because x 1 2 we have taken 10 per unit right. So, cos 30 is 0.86 divided by 10 0.0866 that is why this T 1 2 is 0.0866 right

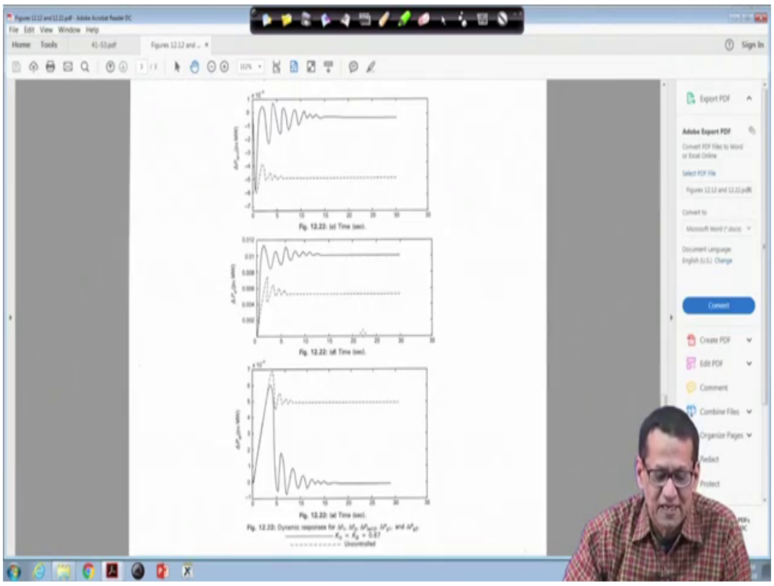
(Refer Slide Time: 05:03)



And we have taken equal area capacities. So, a 1 2 is minus 1, there is no load disturbance in area 2. So, delta P L 2 is equal to your 0 and integral gain setting. We have taken K I 1 is equal to K I 2 is equal to 0.76 and load disturbance in area 1 we have taken delta PL1 is equal to 0.01 per unit megawatt right.

So, in this case for this case your what will happen that dynamic responses right. So, let me clear it so these are the parameters we have taken and dynamic responses in the class room exercise we cannot do simulation right.

(Refer Slide Time: 05:43)



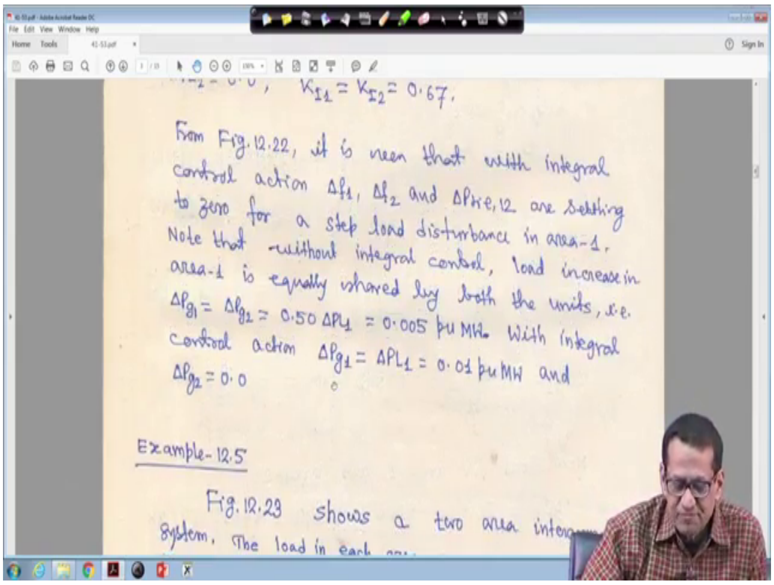
So, this is the frequency deviation right; let me your, what you call reduce that volume to 100 percent right. So, this is actually frequency deviation delta when it is uncontrolled dashed line it is showing steady state error right, no integral controller. So dash line is no integral controller K I 1 K I 2 is equal to 0 and at when you put integral controller, steady state error that frequency deviation steady state error for area 1 area 2 both are reaching to 0 right.

So, and this is your tie line power as steady state tie line power deviation is 0.005 right minus minus 0.005 and at when integral controller is there it is actually 0 right. So, if one person load disturbance is you are giving and your what you call that you will find the tie line power is coming minus 0.005. So, just half of delta P l right and similarly your delta P g 1 and P g 2 load disturbance such happen in area 1 uncontrolled both are generating your 0.005 megawatt because both are uncontrolled.

So, both areas sharing the same generation at steady state 0.005 0.005 right but when area controller is there for frequency bias I told you B is equal to beta. So, B 1 is equal to beta 1, B 2 is equal to beta 2. So, area 1 generator will accommodate all the load so it is point your what you call 0. 0.01 this one this 1 is 0. P g 1 this and delta P g 2 it is coming back to 0.

Because that that load disturbance in area 2 is completely unobservable by the supplementary controller in area 2 following a load disturbance in area 1 right when B 1 is equal to beta 1 and B 2 is equal to beta 2 right. So, this is actually your what you call this responses right. So, this is what has been shown.

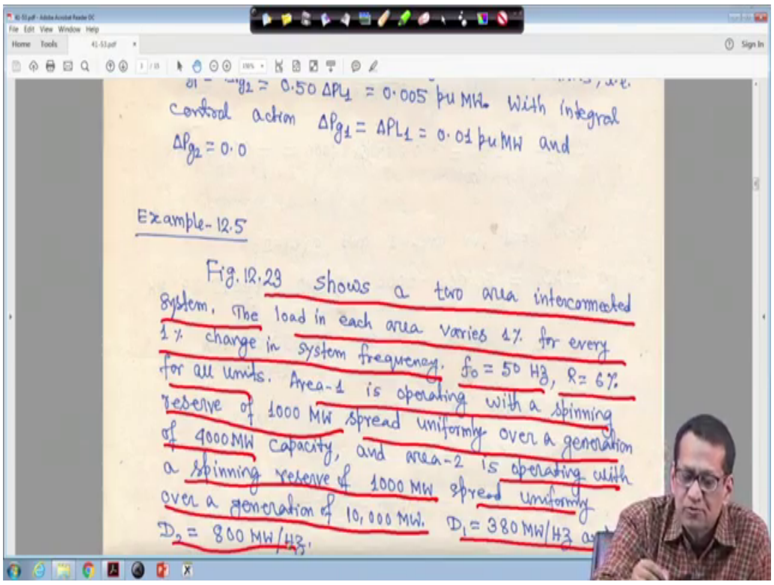
(Refer Slide Time: 07:48)



So, that is why that is why this figure 2 2 what I showed that it is seen that with the integral control action delta f 1 delta f 2 and delta P tie 1 2 are settling to 0 for a step load disturbance in area 1. Note that without integral control load increase in area 1 is equally shared by both the units that is delta P g 1 is equal to delta P g 2 is equal to 0.5 P L or half of P L 1.

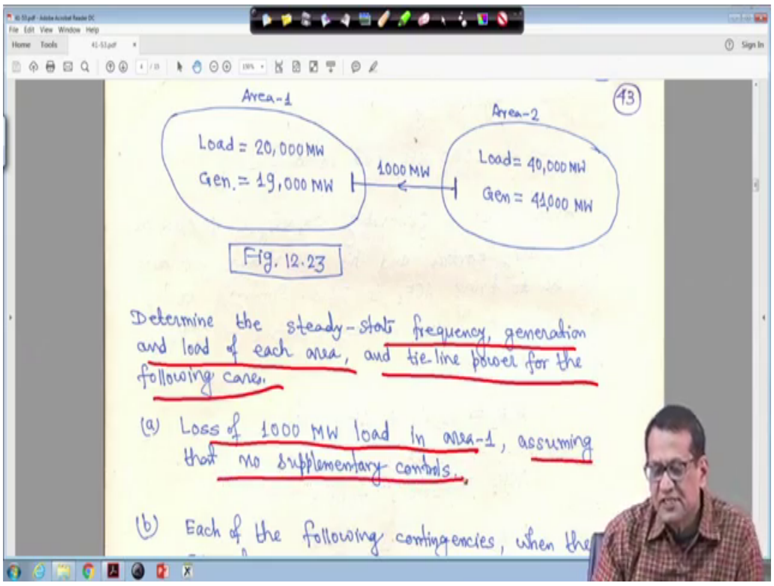
So, 0.005 per unit megawatt with integral control action delta Pg 1 is equal to delta P g 1 pL1 is equal to 0.1 per unit megawatt and delta P g 2 is equal to 0 right. So, that is why we have to use that some controller right later will see little bit more. But in the class room we cannot do simulation studies, but some ideas you have from the steady state point of view. So, now we take another example typical another typical example.

(Refer Slide Time: 08:43)



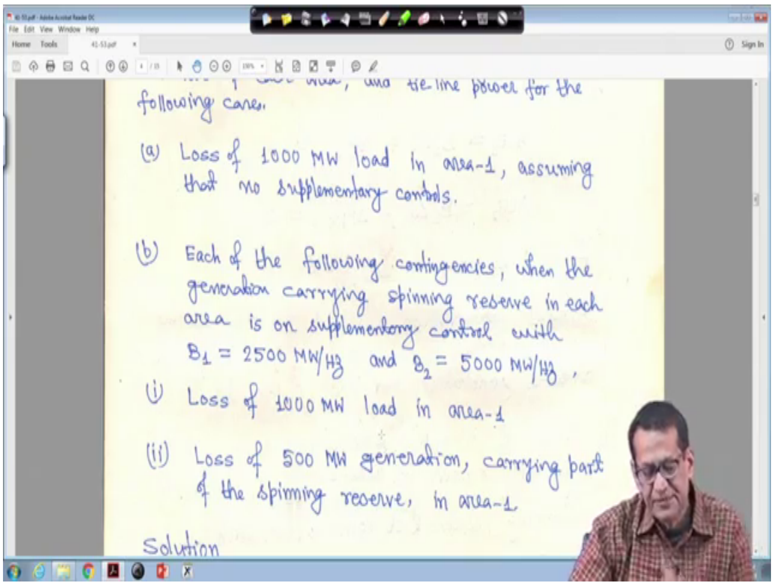
So, here your figure 23 shows 2 area interconnected system the load in each area varies 1 percent for every 1 percent change in system frequency right. And f 0 is equal to 50 hertz R is equal to 6 percent for all the units area 1 is operating with a spinning reserve 1000 megawatts spread uniformly over a generation of 4000 megawatt capacity. And area 2 is operating with a spinning reserve of 1000 megawatt spread uniformly over a generating generation of 1000 megawatt. D 1 is equal to given the 380 megawatt per hertz and D 2 is equal to 800 megawatt per hertz right.

(Refer Slide Time: 09:37)



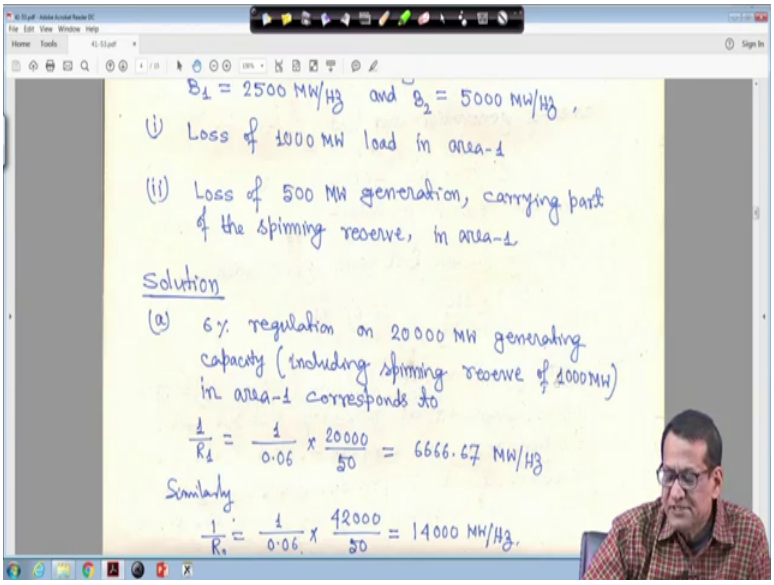
So, we have to so we have to these are these are given these are the area 1 area 2 every everything is given right. So, load here is 2000 megawatt and load 4000 megawatt and generation this side is given. So, determine the steady state frequency generation and load each area and tie line power for the following cases. Loss of 1000 megawatt load in area 1 assuming that no supplementary controls right. So, this is one and another one.

(Refer Slide Time: 10:13)



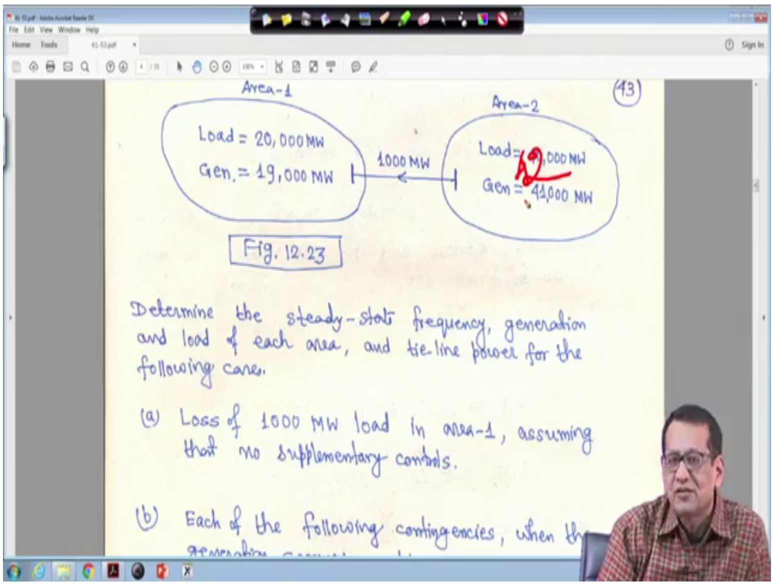
Another one each of the following contingencies when the generation carrying spinning reserve in each area is on supplementary control with V 1 is equal to 2500 per hertz. And B 2 is equal to 5000 megawatt per hertz. So, number 1 that loss of 1000 megawatt load in area 1 right and loss of 500 megawatt generation carrying your, what you call carrying part of the spinning reserve in area 1 right.

(Refer Slide Time: 10:45)



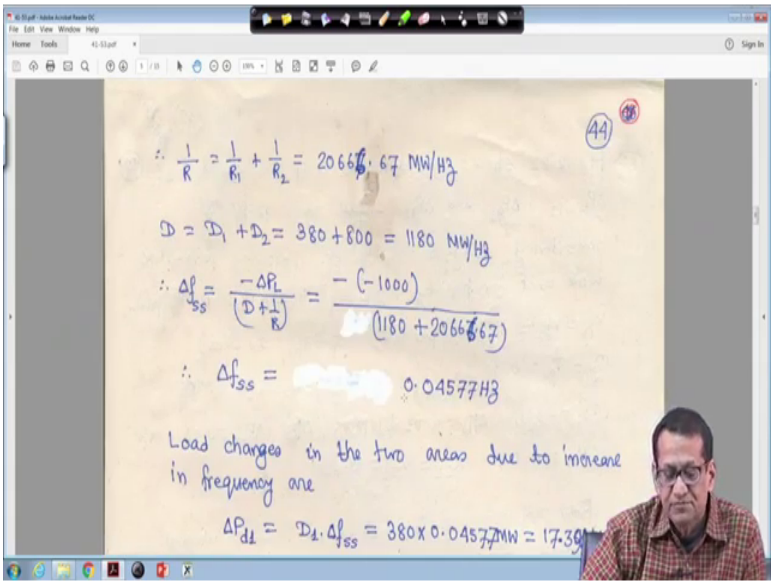
So, solution so in this case what will happen the 6 percent regulation of 20000 megawatt generating capacity including spinning reserve of 1000 megawatt right in area 1. So, 1 upon R 1 is 20000 by 6 percent of 50 hertz right. So, it is 6666.67 megawatt per hertz right. So, similarly your 1 upon R 2 will be it is actually I think it is load here it is given something. Just hold on I think it is.

(Refer Slide Time: 11:17)



I think it is 42 right 42000 megawatt. So, so this one we have taken that your 1 upon R 2 is equal to your 42000 upon 6 percent of 50. So, 14000 megawatt per hertz right.

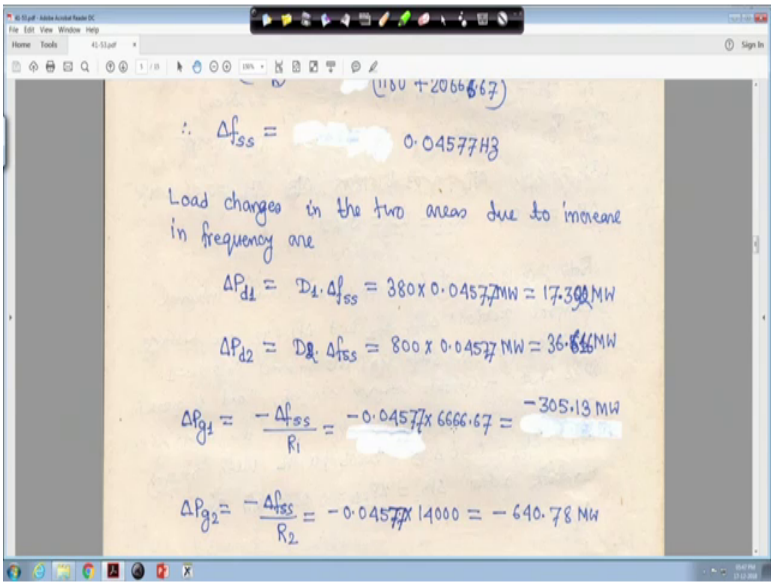
(Refer Slide Time: 11:40)



So, now 1 upon R is equal to 1 upon R 1 plus 1 upon R 2. So, that is 2 if you add both it will be 20666.67 megawatt per hertz right. Therefore, D is equal to if you add D 1 plus D 2. So, it will be 380 plus 8800. So, 1180 megawatt per hertz. So, delta f s s is minus delta P l upon D plus 1 upon R.

So, that 100 loss so it is minus of minus 1000 because increase will take positive sign and decrease we take negative sign. So, if you make it that total D is this much and 1 upon R is this much. So, delta f s s is 0.04577 hertz right. Now load changes in the 2 areas due to increase in frequency.

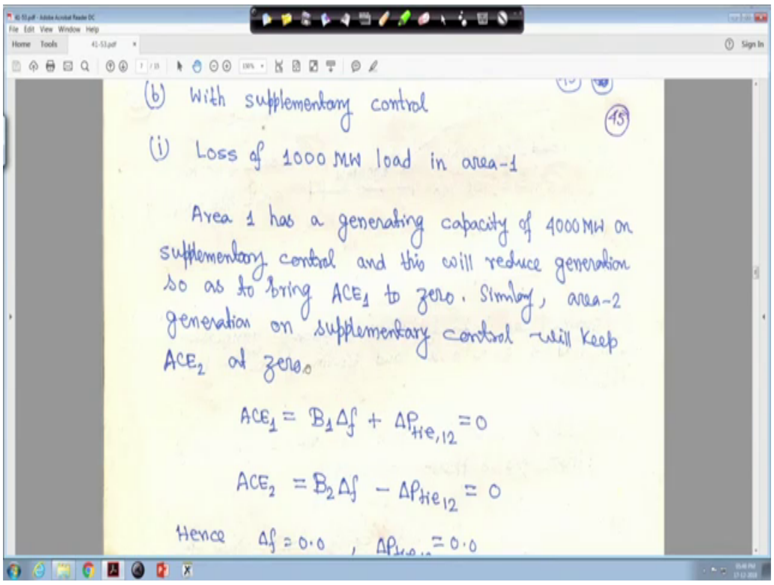
(Refer Slide Time: 12:28)



We know that D into f s s right because D we have taken you know the constant that load is sensitive to the change in your frequency. So, delta P d 1 will be D 1 into delta f s s. So, D 1 is 380 and delta f steady state is just we have got 0.04577. So, this 17.392 megawatt, right. Similarly delta P d 2 will be D 2 into delta f s s is equal to 800 into 0.04577 megawatt; that is 36.616 megawatt right.

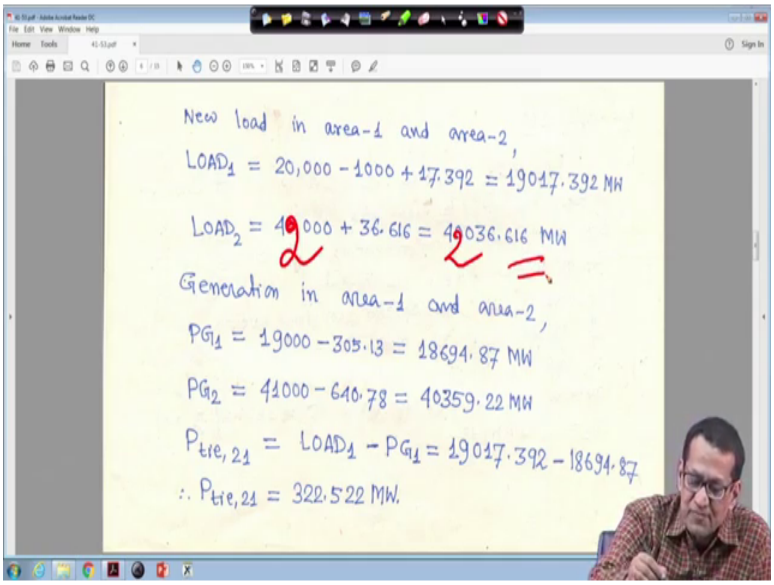
Therefore, we know delta P g 1 steady state minus delta f s s upon R 1 that we have seen before. So, it is minus 0.04577 into your what you call that 1 upon R 1 is this much so minus 305.13 megawatt. Similarly, delta P g 2 minus delta f s s upon R 2. So, again minus 0.04577 into 14000 so minus 640.78 megawatt right.

(Refer Slide Time: 13:33)



So, part b so no this is your.

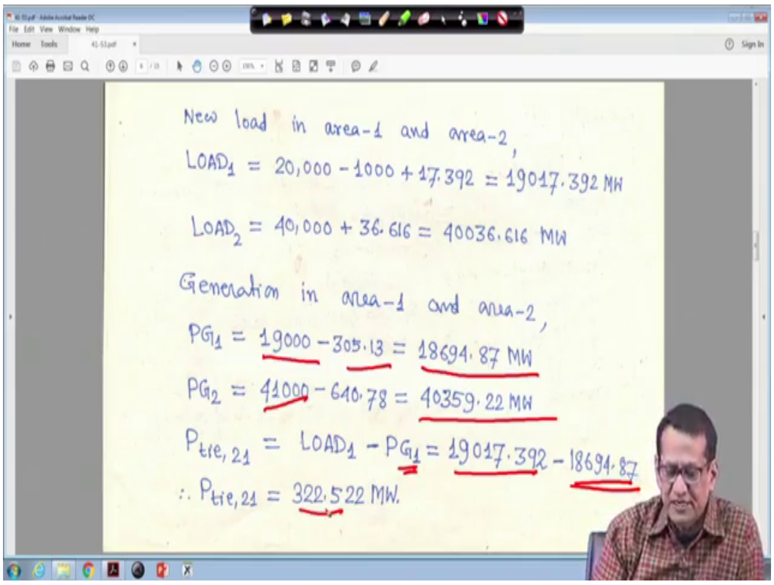
(Refer Slide Time: 13:39)



Now, new load in area 1 and area 2 so load in area 1. Now 2000 and 100 loss so 2000 minus 1000 plus this D into delta f s term so 17.392 so 19017.392 megawatt. Similarly load 2 will be your this one actually will be 42 actually right.

So, it will be 42. So, 42000 plus 36.616 so whatever it comes 42036.616 megawatt. Now, generation in area 1 right generation in area 1 and area 2 it will be 19000 minus this much right.

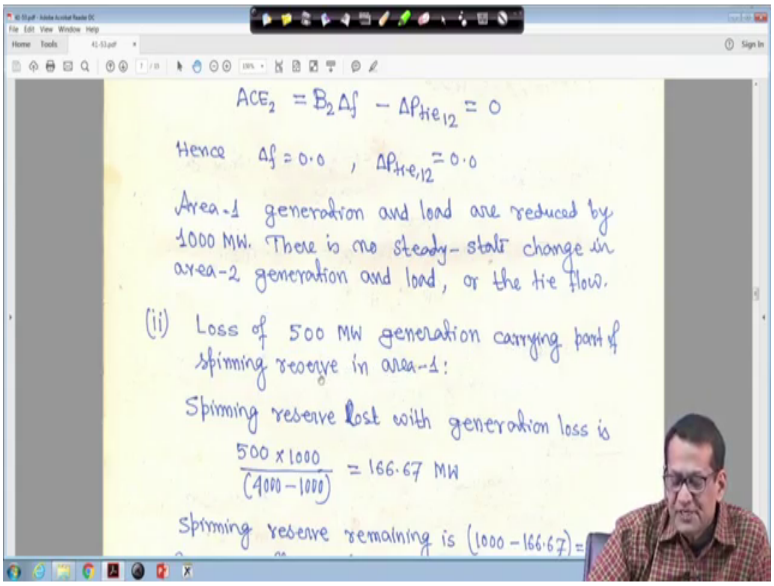
(Refer Slide Time: 14:21)



So, it will be 18694.87 and P G 2 will be 41000 minus 640.78 so 40359.22 megawatt. And P tie 2 is actually your what you call that your it is flowing 2 to 1. So, P tie 2 1 will be because they are in the diagram direction is given 2 to 1. So, it will load 1 minus P G 1. So, this is the load 1 minus this is the P G 1. So, it is 322.522 megawatt right. Now, with supplement B supplementary loss of 1000 megawatt load right in area 1.

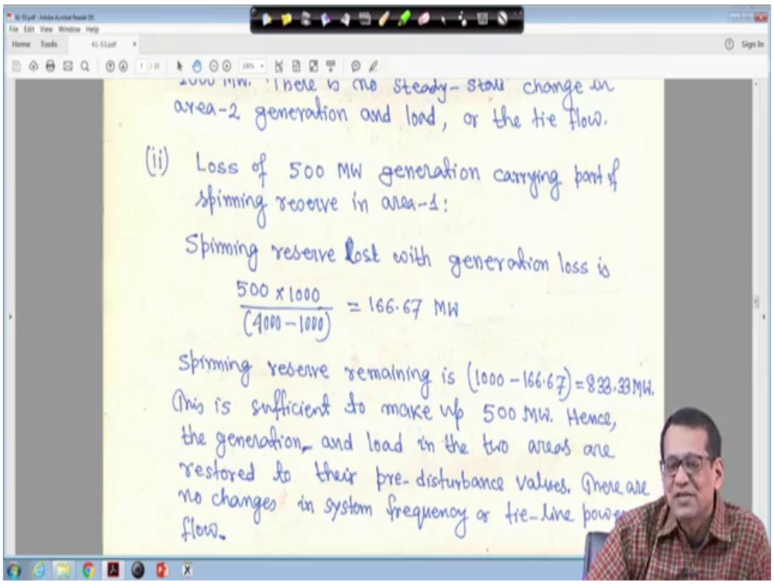
Area 1 has a generating capacity of 4000 megawatt on supplementary contro. And these will reduce generation so as to bring A C E 1 to 0. Similarly area 2 generation on supplementary control will keep A C E 2 at 0. So, we know that A C E 1 is equal to B 1 delta f 1 plus delta P tie 1 2 it has to be 0. A C E 2 also B 2 delta f and a 1 2 is minus 1 say we have taken same area your capacity. So, minus delta P tie 1 2 is equal to 0.

(Refer Slide Time: 15:45)



Hence delta f is equal to 0 and delta P tie 1 2 is 0 right. So, area 1 generation and load are reduced by 1000 megawatt. So, there is no steady state change in area 2 generation and load or the tie flow right. Now, loss of 500 megawatt generation carrying part spinning reserve in area 1.

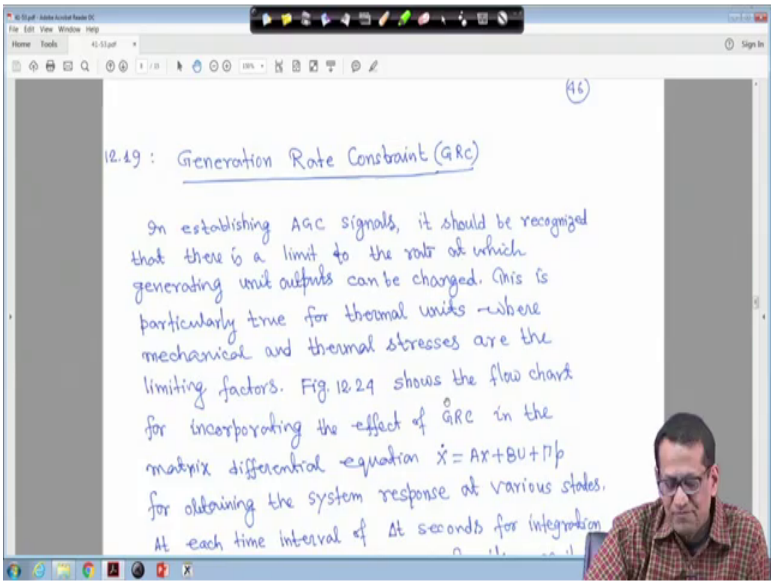
(Refer Slide Time: 16:06)



So, spinning reserve lost with generation loss is it will be simply 1000 by 4000 minus 1000 into 500 so 166.67 megawatt right simply arithmetic. So, spinning reserve meaning is 1000 minus 166.67 so 833.33 megawatt. This is sufficient to make up 500 megawatt. Hence the generation and load in the two areas are restored to their pre disturbance values.

So, there are no change your, what you call there are no changes in system frequency or tie line power flow this is a typical problem right. So, my this is what I have made it from my side I suggest that, you please do from your side and derive all these things. By chance if you get any error or anything from my side you just put the question in the forum or you please send the mail to me right.

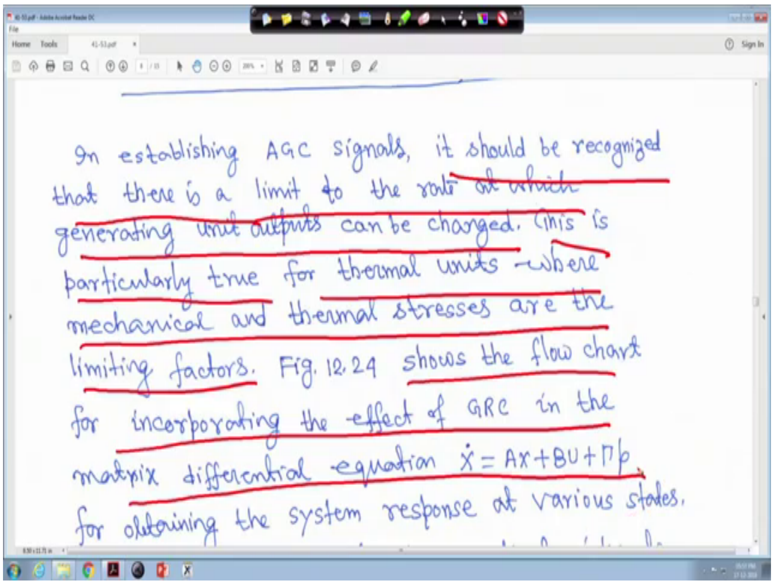
(Refer Slide Time: 16:58)



Next is the generation rate constant. Actually every your what you call every generating unit it has some limit to generate power. Suppose that load given suddenly had increased to 20 megawatt. So, generator cannot generate that 20 megawatt power immediately right. It has some your limitation right.

I mean just it cannot it takes some sometime right. So, that similarly that every generating unit it has some arte limit accordingly the power will be your what you call case the load when power generation will chase the load. So, in establishing AGC signal right; it should be just hold on. So, generation rate constant.

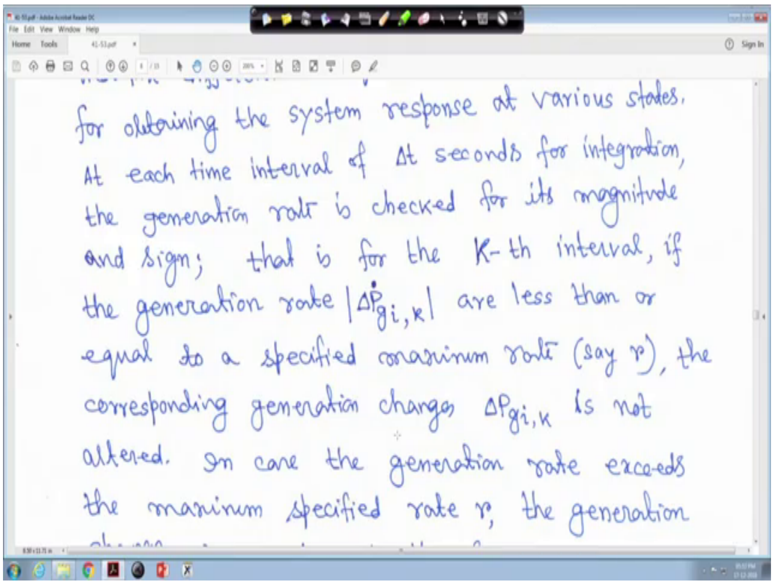
(Refer Slide Time: 17:47)



So, in establishing AGC signal right it should be recognized that there is a limit to the rate at which generating unit outputs can be changed. This is actually particularly true for thermal units where mechanical and thermal stresses are the limiting factors. hydro case that this limits are so high that generally it does not generally your what you call. So, generation is very fast for hydro if time permits at the end will see right.

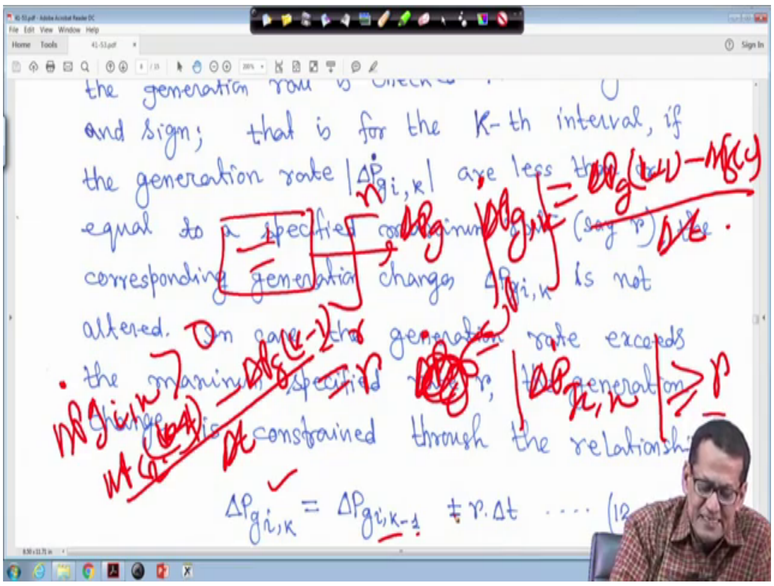
So, but for thermal it is (Refer Time: 18:18) type right. So, shows the flow chart for incorporating the effect of generation rate constant I will show you right. So, in the matrix differential equation X dot is equal to A x plus B U plus gamma p right.

(Refer Slide Time: 18:35)



So, for obtaining the system response at various states at each time interval delta T second right; for integration generation rate is checked for its magnitude and sign. That is for the K th interval the generation rate delta P g i dot say at k th interval this is I th generating unit are less than or equal to a specified maximum rate say R. The corresponding generation changes right the delta P g i k is not altered. In case it violates right the generation exceeds.

(Refer Slide Time: 19:06)



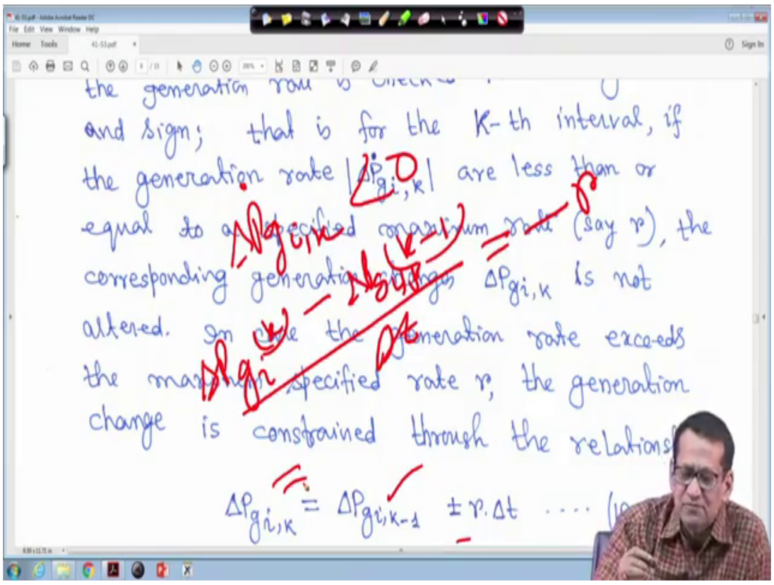
The maximum specified rate the generation change is constant through the relationship of this one that delta P g i that is at k th interval is equal to delta P g i k minus 1 plus minus r into delta T that how we get this one. Suppose only I am only I am making it suppose this is your turbine generator right block diagram is there whatever then this is my delta P g so you have the rate limit right..

This side is R and this side is minus R. So, same increase or decrease it is same generally for thermal unit it is same for hydro unit it is not it is different, but it does not violate the constant. So, every type every sampling instant right or every integration instant you have to evaluate it. How will you do that? Let first you find out what is delta P g dot right delta P g dot right. You can make it that your just hold on here I am making it suppose delta P g your what you call say delta P g k say dot is equal to delta P g k plus 1.

Say minus delta P g k divided by the delta t right. This first you have to make then you check the absolute of this one whether it is greater than r or not. So, generally you check the whatever is made it here that absolute delta P g i k th interval dot whether it is greater than equal to r or not right. So, first you check so; that means, we are not checking plus or minus increase or decrease first you check whether it is greater than r or not. If it is greater than r less than r then no need to consider this right you. So, it is not violating the constant if it is this absolute is greater than r then you check whether it is your what you call whether it is positive or not; that means, you check that delta P g i k dot whether it is greater than 0 or not.

After that check positive or not. If it is positive right if it is positive; that means, that you constant it to r. That means, your delta P g i k your what you call k minus delta P g i your k minus 1 divided by delta T is equal to your r. That means, delta P g i k is equal to you can write delta P g i k minus 1, I have made it in bracket this is k minus 1 plus r into delta t and if it is why I have made minus if it is less than 0.

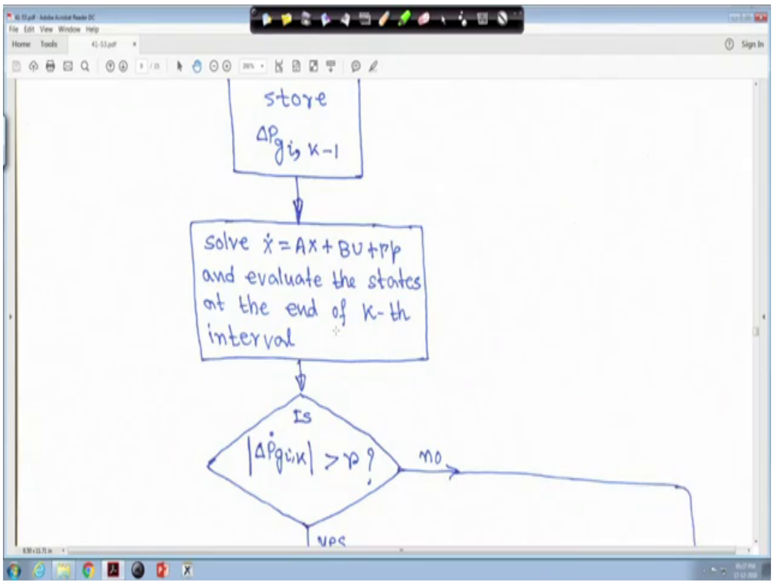
(Refer Slide Time: 21:44)



Suppose if your delta P g i k dot if it is negative less than 0. In that case it is delta P g i right k minus delta P g i k minus 1 divided by delta t is equal to minus r right. So, both increase and decrease rate we have taken same r. So, in that case it will become delta P g i q will become that delta P g i k minus 1 minus r into delta t.

That is why we have written that delta P g i k is equal to delta P g i k minus 1 plus minus r into delta t. As long as limit will be violated the generation response will move like a ramps straight line straight line increase or decrease it will move like a ramp response right because it is straight line. As long as not violated at that time oscillation will start small oscillation. So, that means.

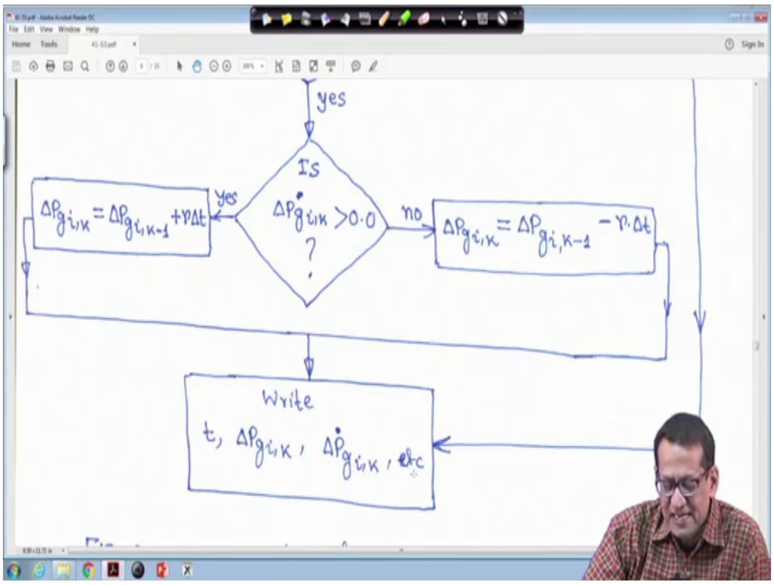
(Refer Slide Time: 22:47)



Now, this is the flow chart first is stored delta P g i k minus 1. In every sampling instant or this thing you have to store this value when you write the code next solve x dot is equal to x plus B U plus gamma p. And evaluate the states at the end of k th interval. Actually what you are doing nowadays that you have a MATLAB (Refer Time: 23:06) thing you just putting all these things. But if you write your code to write your code this generation rate you have to consider separately right.

So, MATLAB also those who have written the code they have also considered everything that all type of limit limiting value what will be; simply we are giving in the output block your rate limit and you are getting the response. And generation rate constant actually it deteriorates the dynamic response. But you have to when you write the code of your own then you have write all these things right

(Refer Slide Time: 23:41)

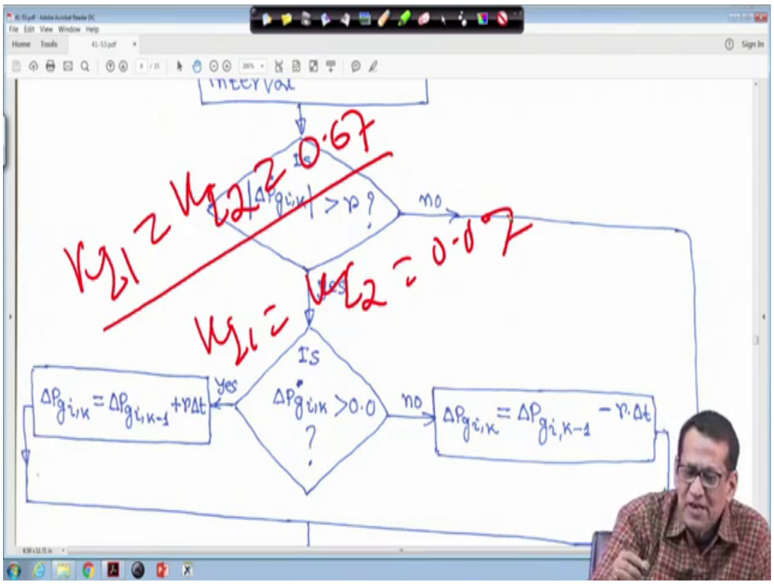


So, next is that we are checking that absolute of delta P g i k greater than r or not right. First we have to check if it is no then directly you will go, but if it is yes then you check whether it is greater than 0 or not. If it is a positive then this side left hand side is delta P g i k is equal to delta P g i k minus 1 plus r into delta t. So, it moves like a straight line because of r into delta T plus this one.

And if it is negative then your delta P g i k will be delta P g i k minus 1 minus r into delta t right. After that you write all t delta P g i k delta P g i k dot e t c right all the state variables and then your this is the flow chart so this is for generation rate constant. So, generation rate constant actually deteriorates the dynamic responses.

And how actually if you say here how actually generation responses go suppose one person step load disturbance is there. And when generation rate constant is there you integral gain will be very small right. When you are not considering any generation rate constant in your simulation studies integral gain will be higher for example.

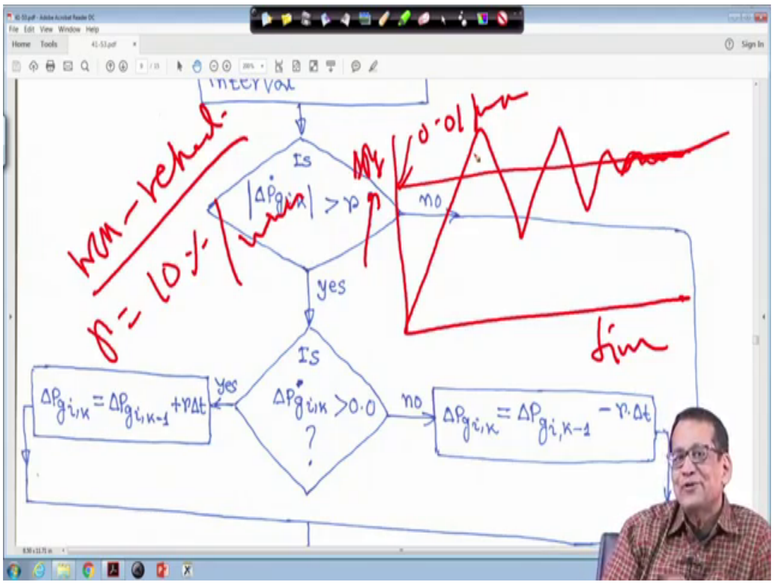
(Refer Slide Time: 24:48)



Whatever simulation I have shown you that K I 1 is equal to K I 2 we have taken 0.67 this is without generation rate constant right. But in reality this generation arte constants are there for any thermal unit. So, in that case the integral gain should be very small for example, K I 1 will be is equal to K I 2 say is equal to 0.07 or even less right. So, it is a very small otherwise what will happen your system will become unstable for higher gain.

So, you need very small gain this is one thing at dynamic responses also will deteriorates right. It will not settle in 10 or 15 second it may continue for long write and addition to that that all the time is not there to consider that a governor dead band is also there right. So, if you consider that one that governor dead band has effect of such your what you call sustained oscillation. That oscillation will continue for long if you include the governor dead band and in that case what will happen suppose you have one person step load disturbance.

(Refer Slide Time: 25:54)

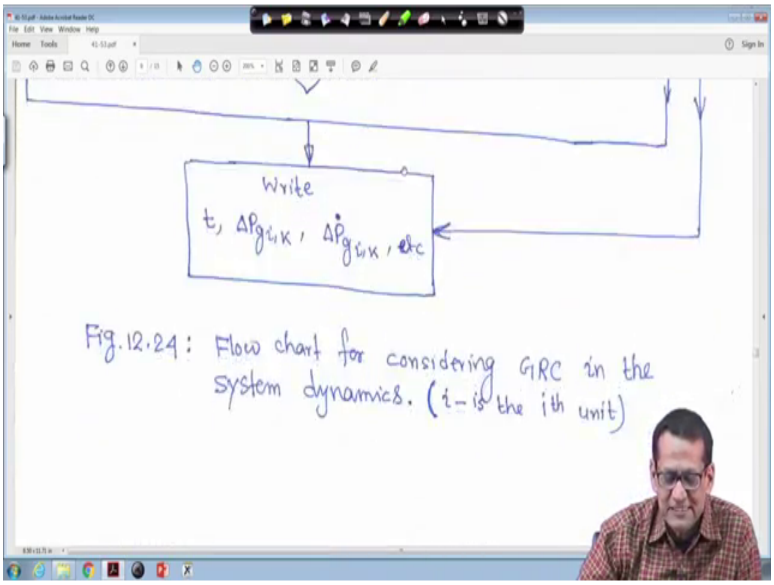


And suppose you are plotting some generation say this is my time and this side say some delta P g. So, initially what will happen because of the rest for non read type for non read type right for non read type your what you call generation rate constant. Say R is equal to 10 percent per minute right. That is 0.1 per unit megawatt per minute right. If you consider that responses suppose your disturbance is say this line is say 0.01 per unit megawatt.

So, response initially may be like this ramp it will go like this an finally, when response when constant will not violate at that time it will it will show some oscillation it will settle 2.01. Otherwise you will find that is straight line increase decrease increase decrease ramp increase or decrease right. So, and settling time will be very high for theoretical purpose that your what you call that this some 66 some 60 or 80 second or even more right.

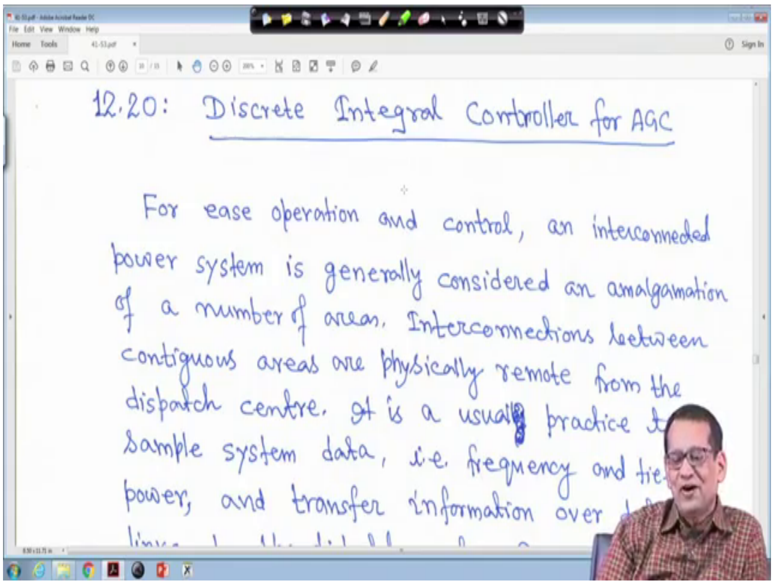
But in reality if you go to the control room and try to see that frequency cannot be like ideal case like now you got for a step load disturbance because power system continuously loads or switch on and off. So, continuously if you see the control room the continue fine that frequency changing, but anyway it is not losing synchronism unless and until some abnormality is happening power system. And generation also if you see like this you find it is not like settling or this thing it is some it throughout the day generation is changing because load is also changing throughout the day right.

(Refer Slide Time: 27:39)



So, so this is generation rate constant.

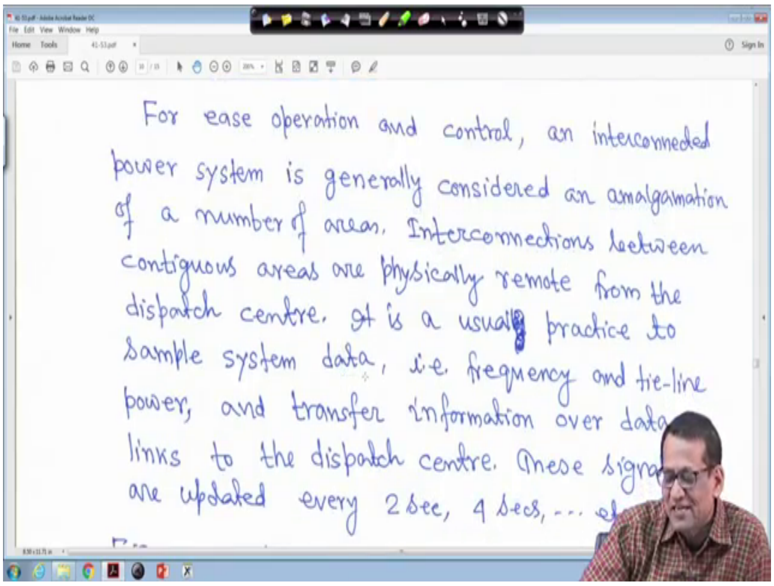
(Refer Slide Time: 27:42)



Another thing is that discrete integral controller for AGC look any system. If you see any system you will find that any system actually is a continuous system in reality a power system once so itself is a continuous system right so, but so yours power system is a continuous system.

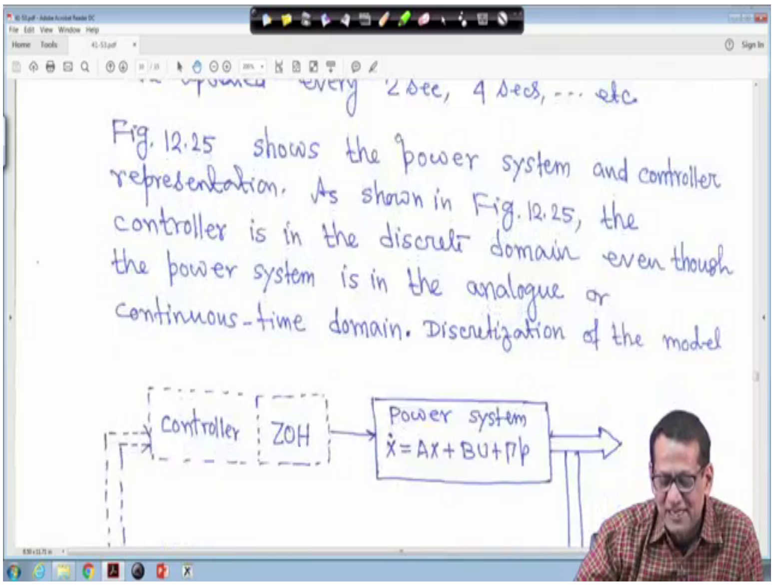
But controller part can be put in discrete domain where the power system is in your continuous domain right. So, in reality that controller must be in discrete domain. So, in that case what will happen that for easy operation and control.

(Refer Slide Time: 28:19)



An interconnected power system is generally considered and your amalgamation of a number of areas. So, interconnection between your what you call your contiguous areas are physically remote from the dispatch center right. So, it is usual practice to sample system data.

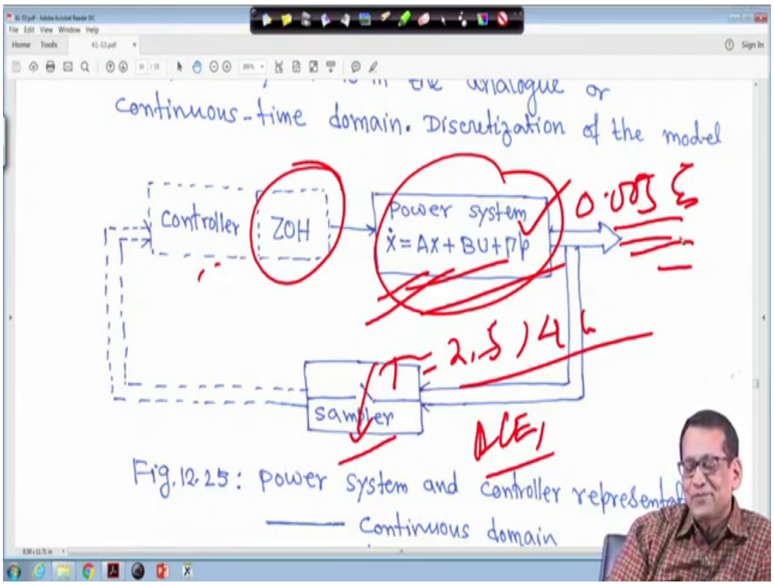
(Refer Slide Time: 28:38)



That is frequency and tie power is the area control error. You have to sample the frequency and tie power and combine them together right. So, at every; that means, every sampling instant you have to your what you call sample that area control error for each area right. And your what you call and transfer this information over data links to the dispatch center.

And when you are transferring this to the dispatch center there is some delay associated with that, but will not consider that the delay is very small, but will not consider that. This signals are updated at every 2, second 4, second even up to 8 second or 16 second or even 32 second also right. So, not immediately right these actually reduces the wear and tear controller part right. So, it will it will increase the life your what you call of the controller.

(Refer Slide Time: 29:29)



So this figure 25 show such kind of one thing. So, what happen in this case a power system is there. A power system you know that x dot in mathematics x dot is equal to x plus B U plus gamma p, this is in continuous time domain. Then you have a sampler right this sampling time; may be T is equal to 2 second 4 second like this right or 8 seconds 6 seconds like this or 1 second like this. So, that means output here suppose output here is A C E your sampling frequency and tie power combining these both B into delta f B 1 into plus delta P tie.

And after that this controller is here then you make a 0 order hold right. Like till the next sampling instant comes this 0 order hold actually hold this output of the controller right. Suppose you take you take T is equal to 2 second right T is equal to 2 second. So, controller will if it is a integral controller only you will be computed. After that till the next sampling instant comes then 0 order hold will hold that signal right.

And, but this is your solving continuously this is your solving continuously mathematically. Suppose you have taken integration step length is 0.005 second for solving this one this is ok. But till next sampling instant come the same signal will be going to that I mean suppose at T is equal to four second you got something. And next suppose T is equal to 2 second is the sampling time suppose at T is equal to 4 second you have taken.

Next sampling instant come T is equal to 6 second; till 6 second this U that output of this one because zero order hold will hold it right and send the same signal to this till the next sampling instant come. That means, at every every time a increment till next sampling instant come that U will be continuous that constant U in between two consecutive sampling instant will be paid to the power system right; this is the philosophy ok. Thank you very much; much more will discuss for (Refer Time: 31:24) power system another thing, but in the next lecture.

Thank you very much.