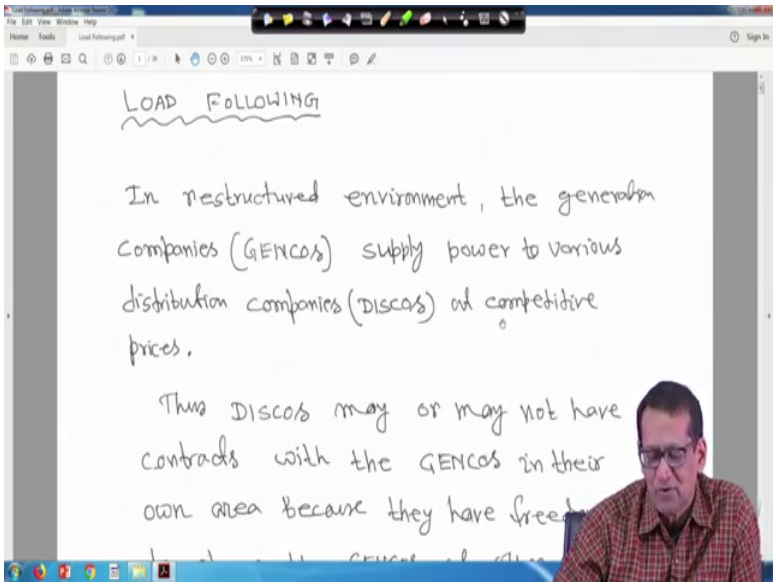
Power System Dynamics, Control and Monitoring
Prof. Debapriya Das
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 46
AGC in deregulated system (Contd.)

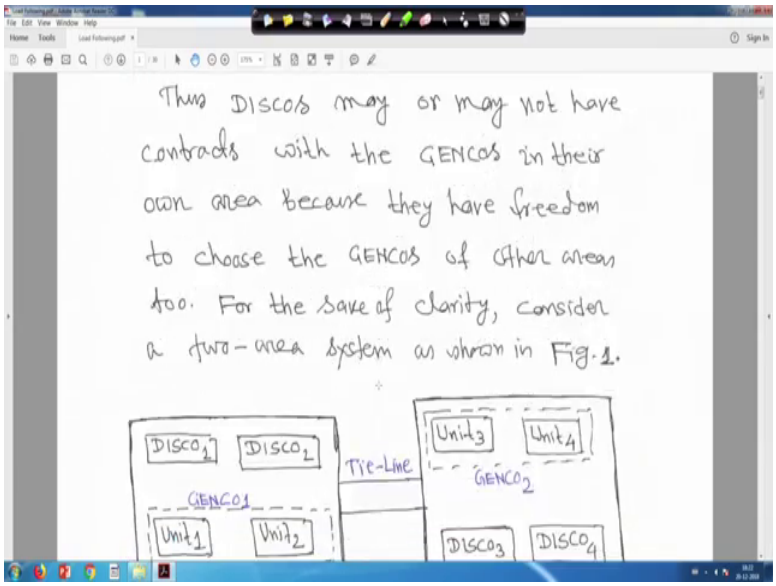
We are back again. So, although previous one also load following, but this is another version right; another type of modelling.

(Refer Slide Time: 00:25)



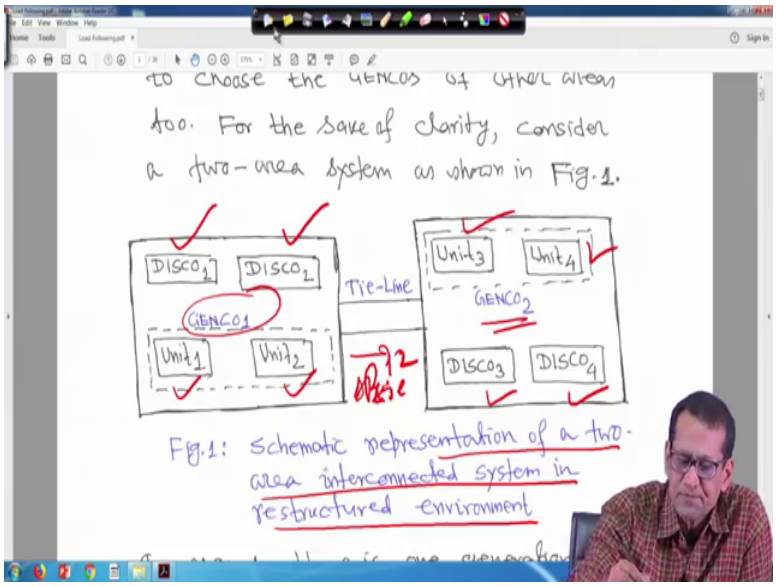
So, load following I told you what is load following right. So, when load disturbance is there generation will chase load such that generation will match the load in other way right and at steady state ideal condition. So, generation is equal to load plus of course, losses are there, but we will not consider that right. So, in just we have seen that in restructured environment the generation companies that is GENCOs supply power to various distribution companies in short we call DISCOs right at competitive prices.

(Refer Slide Time: 01:01)



Now, thus DISCOs may or may not have contact with other with the GENCOs in their own area I told you because they have freedom to choose the GENCOs of other areas too; for the sake of clarity consider a two area system as shown in figure 1.

(Refer Slide Time: 01:17)

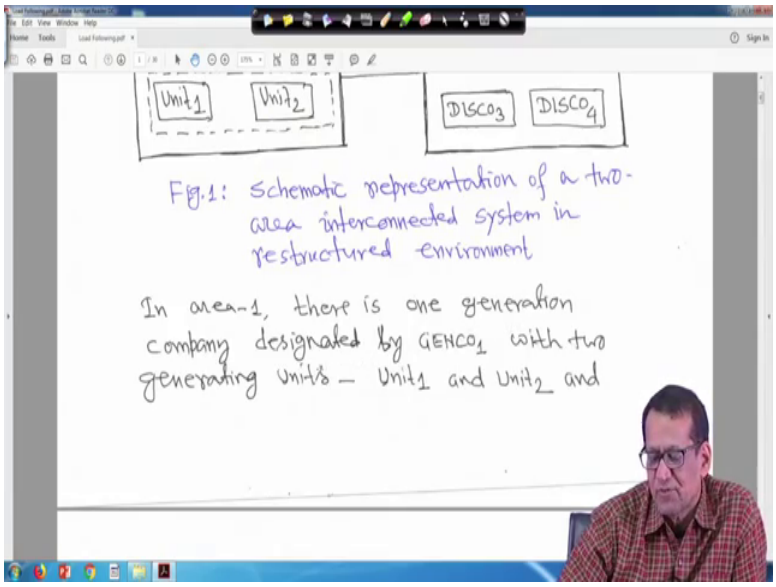


Here what we are what we are our modelling is same, but what we are trying to make it suppose in area 1; it is DISCO 1 and it is DISCO 2 right and in area 2 this is DISCO 3 and DISCO 4 that is your distribution companies.

Now area 1 one generation companies they are GENCO 1, but it has 2 units 2 generating units unit 1 and unit philosophy remains same. In the previous case we saw GENCO 1 and GENCO 2 and assuming that one generating units or its equivalent right. So, question may be many many units are there with same rating same turbine generating unit everything right.

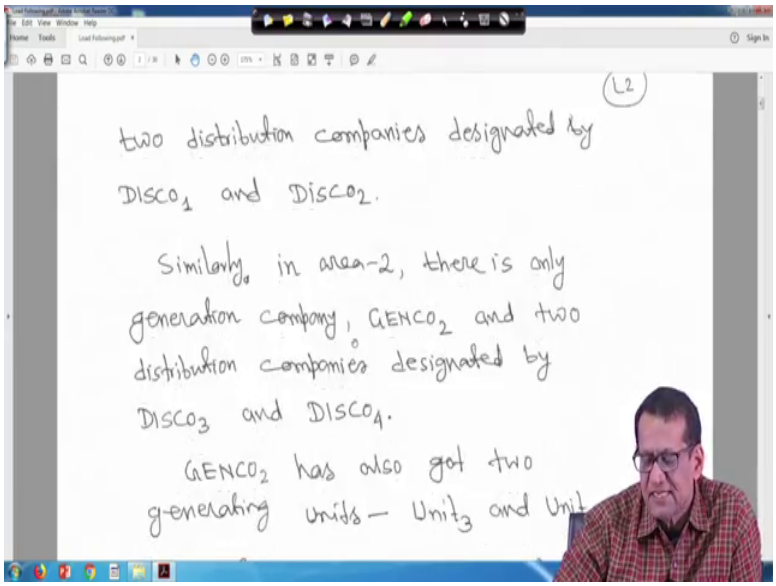
So, but here philosophy remains same everything is same, but this GENCO 1, but generation company one has 2 units unit 1 and unit 2. Similarly generation GENCO 2 it had 2 units unit 2 unit 3 and unit 4 and this is that scheduled tie line power flow that is delta P tie your 1 2 right; same as before same as before only mathematically or block diagram way slightly we have change right. So, this is schematic representation of a 2 area interconnected system in restructured environment right.

(Refer Slide Time: 02:35)



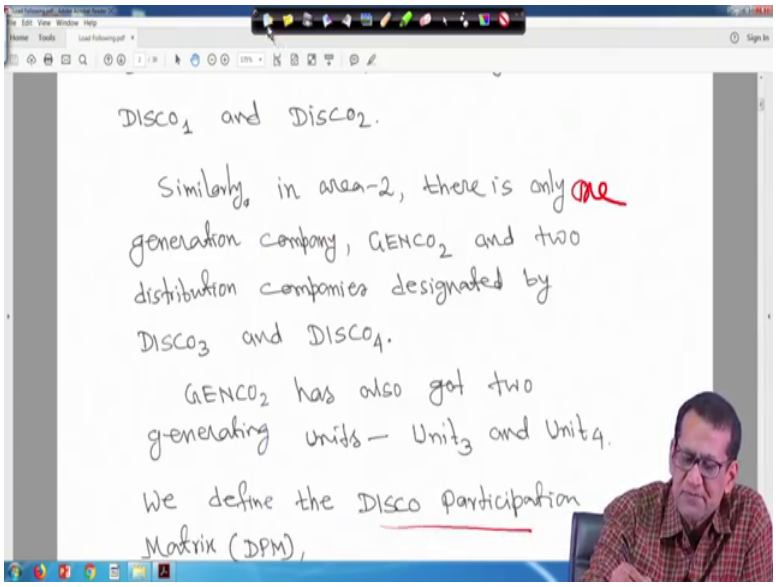
. So, in area 1 now there is one generation company designated by GENCO 1 with 2 generating units it is unit 1 and unit 2.

(Refer Slide Time: 02:43)



And 2 distribution companies designated by DISCO 1 and DISCO 2 right.

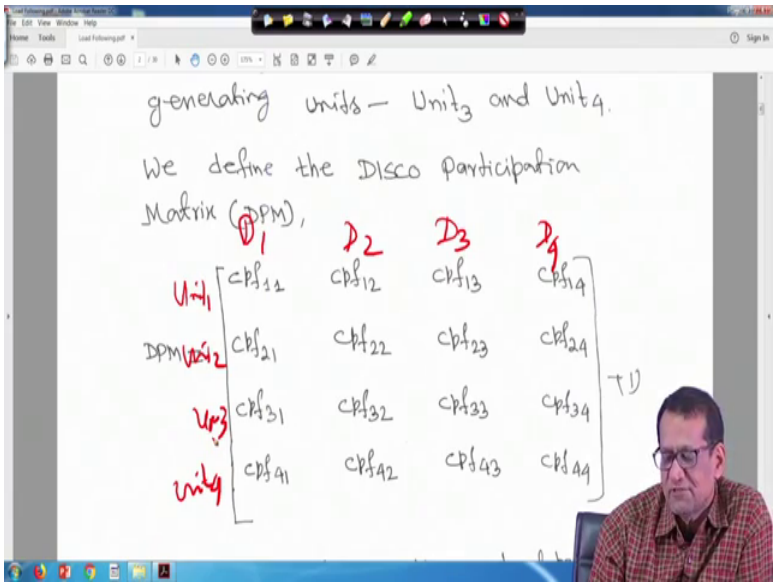
(Refer Slide Time: 02:49)



Similarly, in area 2 there is only one generation companies; I have missed one right there is only one generation company GENCO 2 and two distribution companied designated by DISCO 3 and DISCO 4.

So, GENCO 2 also got 2 generating units unit 3 and unit 4. So, we define the DISCO participation matrix it will remain same it will remain same as before right.

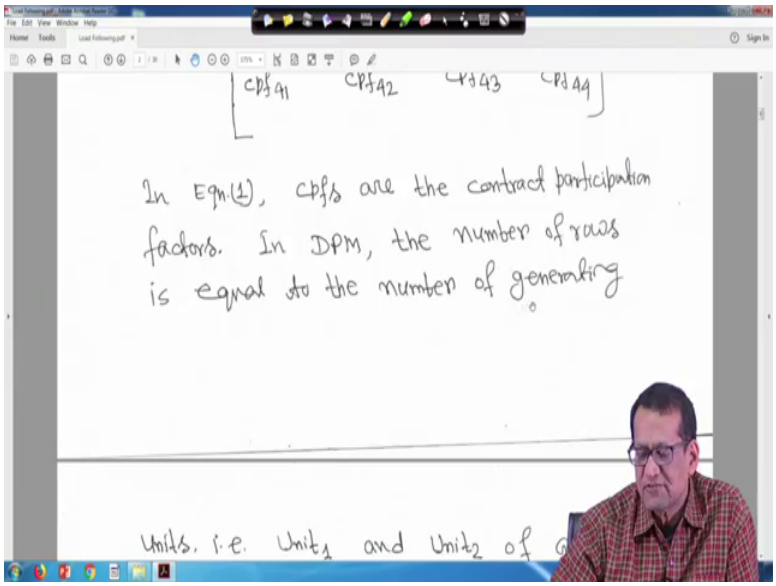
(Refer Slide Time: 03:15)



So, this is the DISCO participation matrix. So, there we are writing GENCO and this is where I am making in short DISCO 1 DISCO 2 DISCO 3 DISCO 4 distribution companies I am making it D 1 D 2 D 3 D 4. So, this is D 1 this is D 2 this is D 3 and this is D 4 and there it was GENCO 1 GENCO 2 GENCO 3 GENCO 4 and here instead of that we write it is unit 1, this is unit 2, this is unit 3 and this is your unit 4 right.

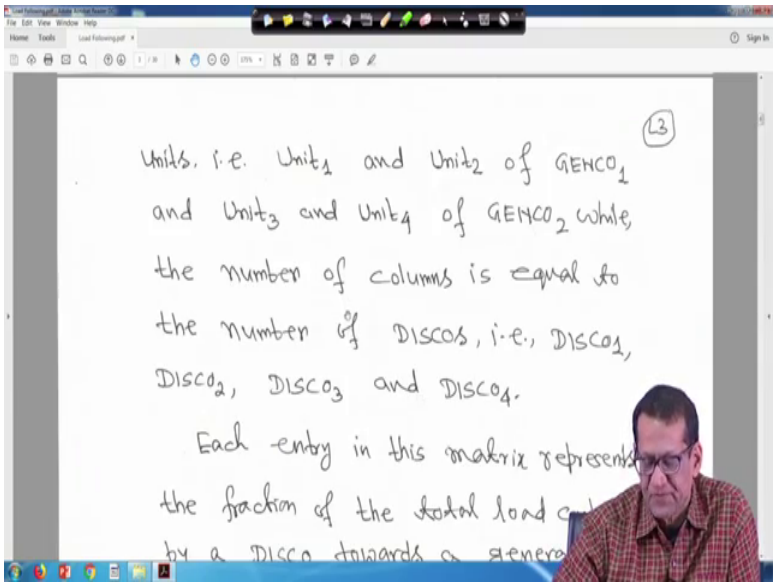
So, this way I instead of GENCO 1 GENCO 2 GENCO 3 GENCO 4 we are writing unit 1 unit 2 unit 3 and unit 4. And philosophy remains same that is you have same contact participation factor that matrix and this side will be; if you want to find out the contact demand this side will be same as before delta P L 1, delta P L 2, delta P L 3, delta P L 4. So, contact participation contact your what you call demand for GENCO unit 1 unit 2 and unit 3 and unit 4 will be cpf 1 1 delta P L 1 plus cpf 1 2 delta P L 2 plus cpf 1 3 delta P L 3 plus cpf 1 4 delta P L p l 4 and so on right.

(Refer Slide Time: 04:31)



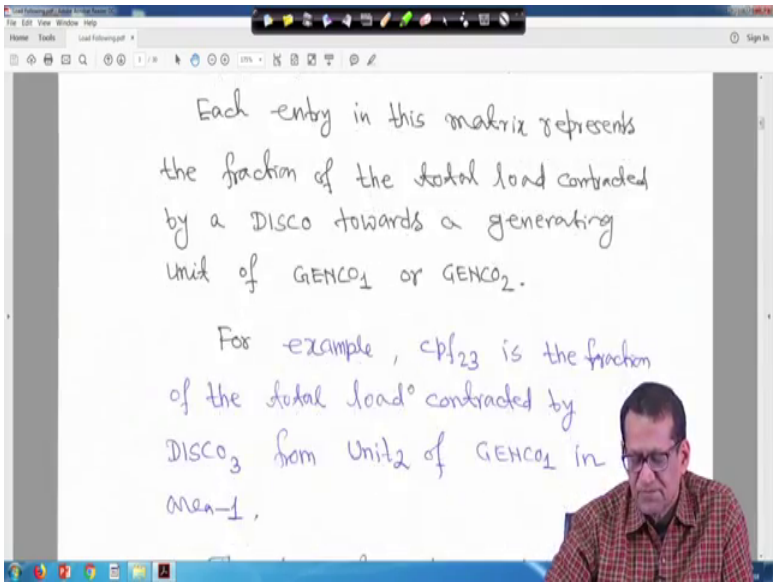
So, meaning is same that actually actual essence remains same right. So, this is equation 1; equation 1 cpfs are the contract participation factor that we know in DPM the number of rows equal to the number of generating units right.

(Refer Slide Time: 04:39)



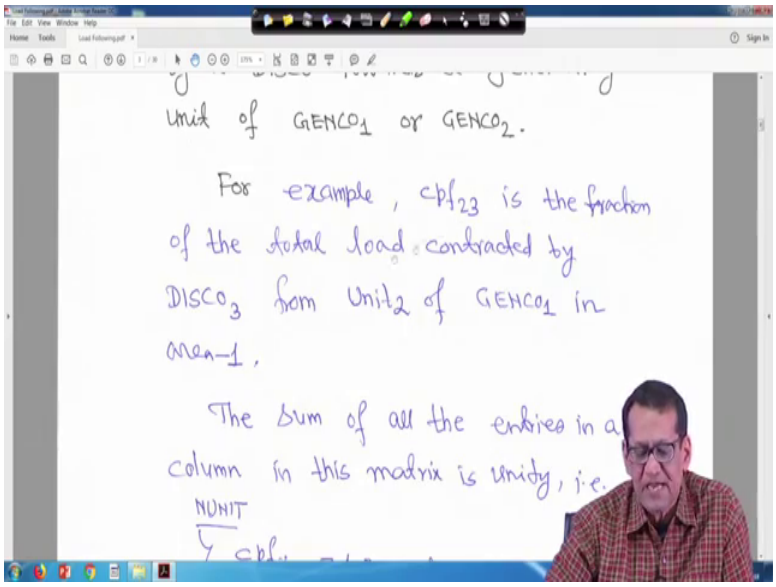
That is unit 1 unit 2 of GENCO 1 and unit 3 unit 4 of GENCO 2 that I told you while the number of column is equal to the number of DISCOs that is DISCO 1, DISCO 2, DISCO 3 and DISCO 4 right.

(Refer Slide Time: 04:53)



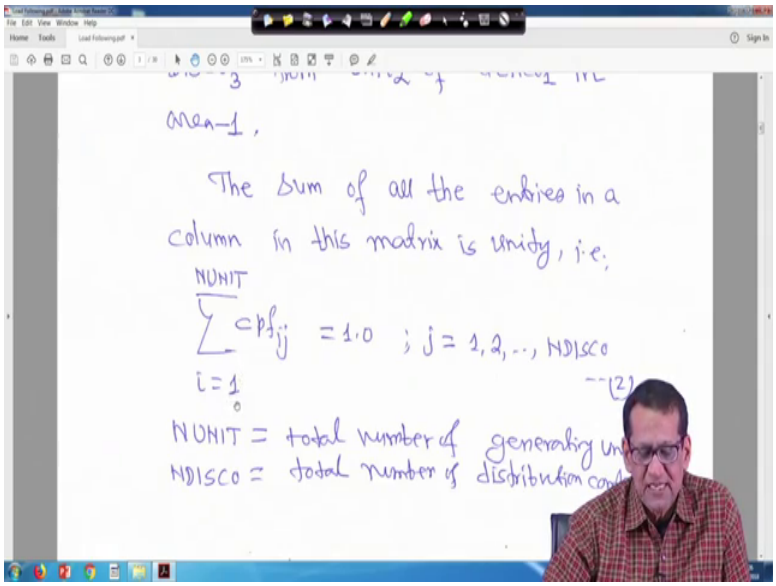
So, each entry in this matrix represent the fraction of the total load contracted by a DISCO towards a generating unit of GENCO 1 or GENCO 2; this already we have discussed right

(Refer Slide Time: 05:05)



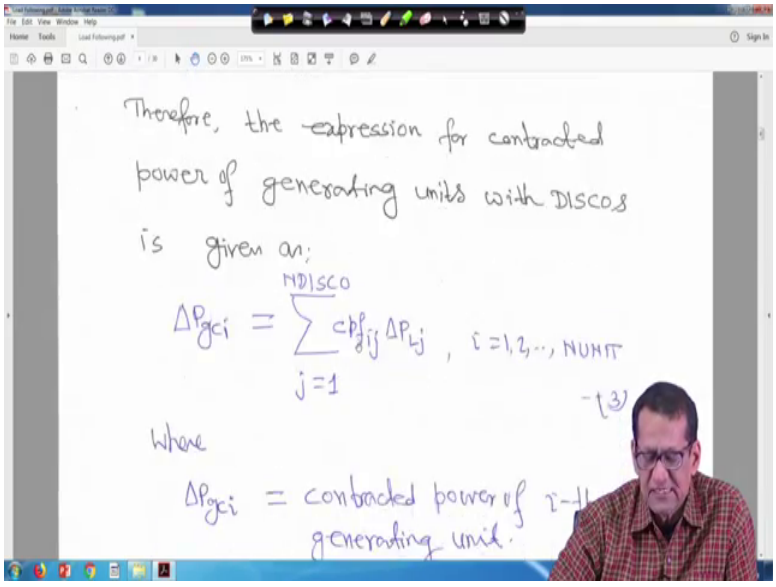
But still for example, cpf 2 3 is the fraction of the total load contracted by DISCO 3 from unit 2 of GENCO 1 in area 1; this is the meaning here right. There it was GENCO 1, GENCO 2, GENCO 3 this is from the unit 2 of GENCO 1 in area 1 that is cpf 2 3 right this is the dif[ferent]- just different.

(Refer Slide Time: 05:25)



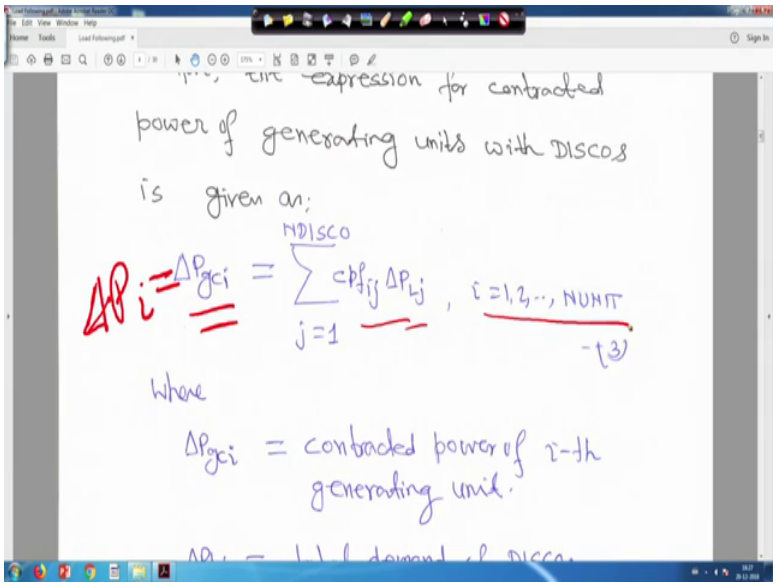
So, the sum of all the entries in a column that we have seen that is one because i is equal to 1 to N is equal to unit means the number of your generating units. So, cpf ij is equal to 1.0 and j is equal to 1, 2 number of discos; so, N DISCO right here it is 4 because 4 distribution companies are there together area 1 2; area 2 2 right.

(Refer Slide Time: 05:49)



So, ; so therefore, the expression for contracted power of generating units with DISCOs is given as delta Pgci.

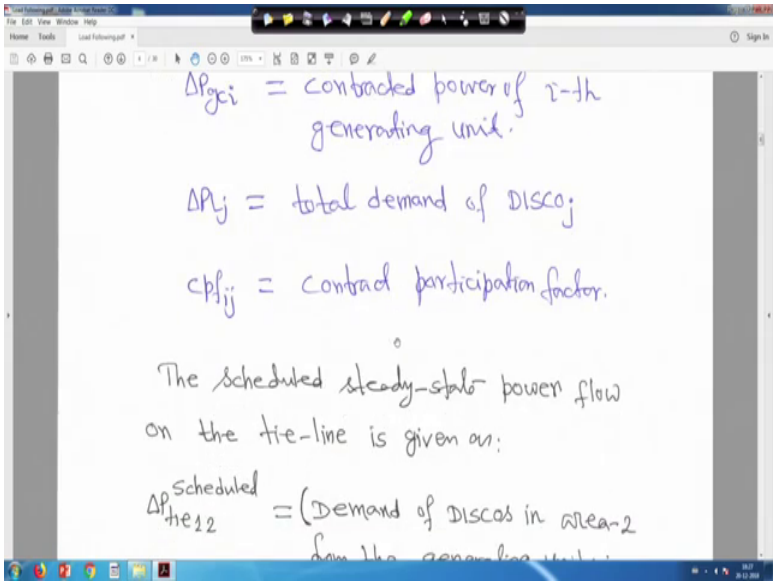
(Refer Slide Time: 05:55)



It is same as delta P i as before previously we have taken that delta P i right it is same as your delta Pgci; the contracted power. Even j is equal to your N DISCO and it is cpf ij delta P L j; i is equal to 1 to N unit right. There we are writing i is equal to 1 t that in GENCO, but here we are writing 1 to N unit and total number of unit. So, here it is i is equal to 1 2 3 and 4 right.

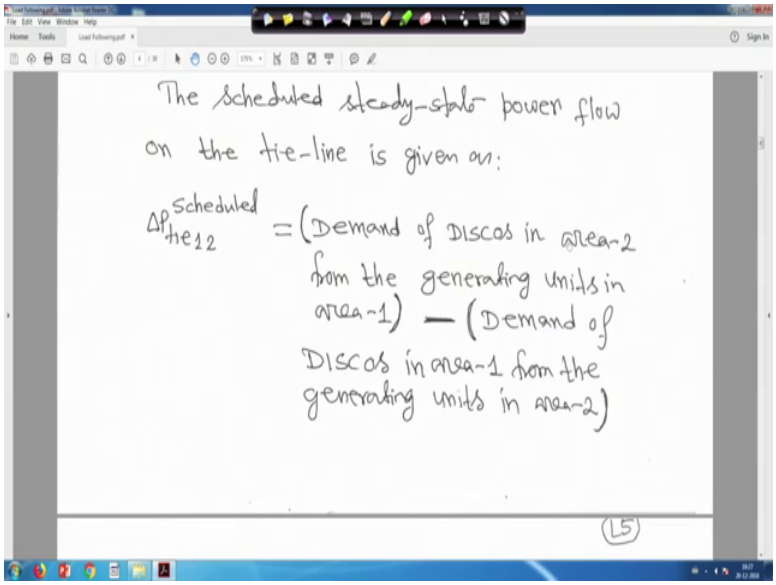
So, there were delta Pgci the contracted power of i th generating unit and delta P L j total demand of DISCO j.

(Refer Slide Time: 06:35)



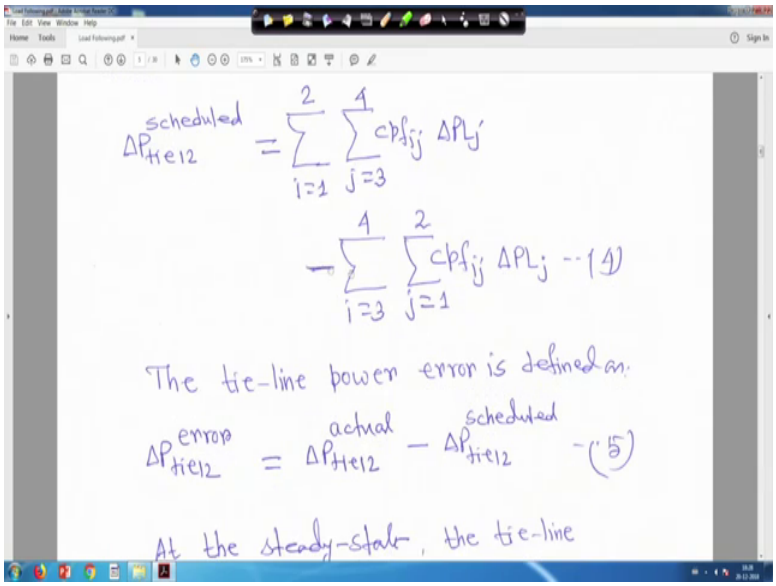
The distribution company j right; cpf ij contract participation factor right; so same as before.

(Refer Slide Time: 06:49)



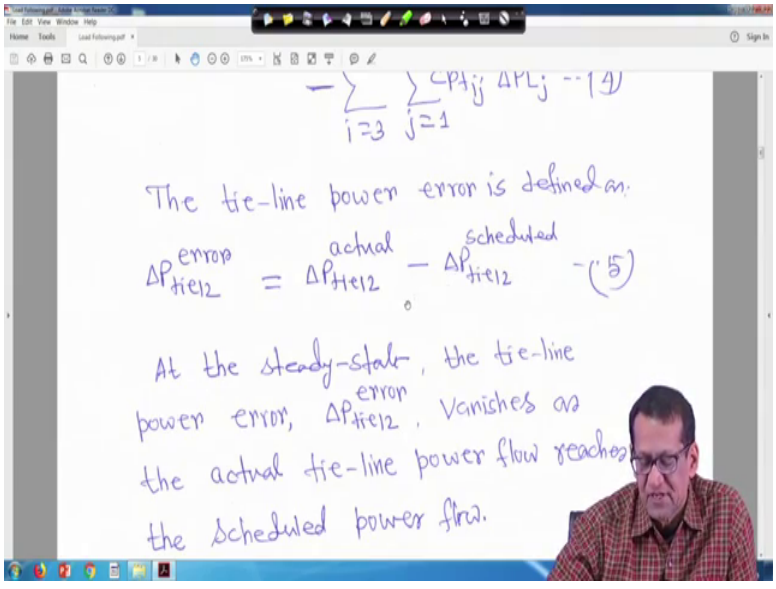
The scheduled steady power flow on the tie line is given as it is same as before the demand of DISCOs in area 2 from the generating units in area 1 minus demand of DISCOs in area 1 from the generating units in area 2 and it is 1 2 schedule. By chance whatever data you have taken by chance the delta P tie 1 2 schedule become negative say minus 0.2; that means, basically power is flowing from 2 to 1 right; so, that is the dire[ction]- actual direction; so, this is we have also seen.

(Refer Slide Time: 07:15)



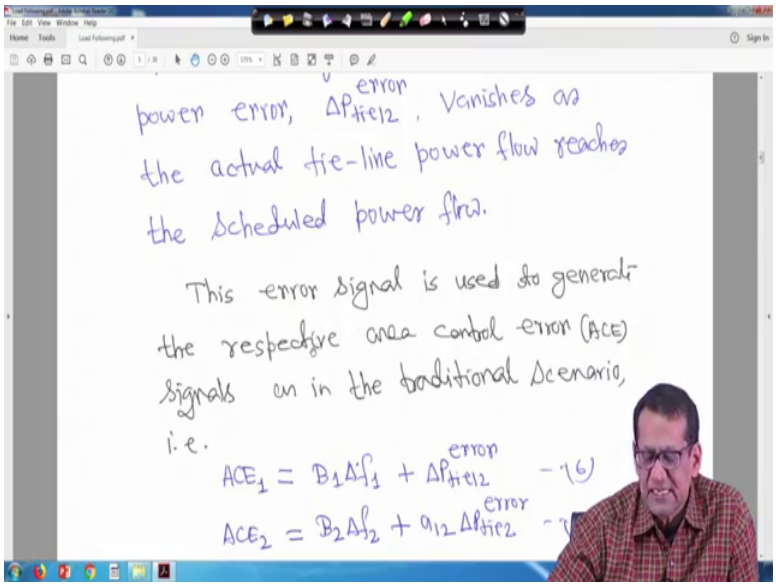
Therefore delta P tie 1 2 schedule same as before that sigma i is equal to 1 to 2 if j is equal to 3 to 4; cpf ij delta P L j minus sigma I is equal to 3 3 to 4 sigma j is equal to 1 to 2 cpf ij delta P L j; this is equation 4. This equation already we have seen for 2 GENCOs 2 DISCOs in each area for 2 area system right; so same equation same equation.

(Refer Slide Time: 07:39)



And the tie line power error also defined as delta P tie 1 2 actual minus delta P tie 1 2 scheduled right.

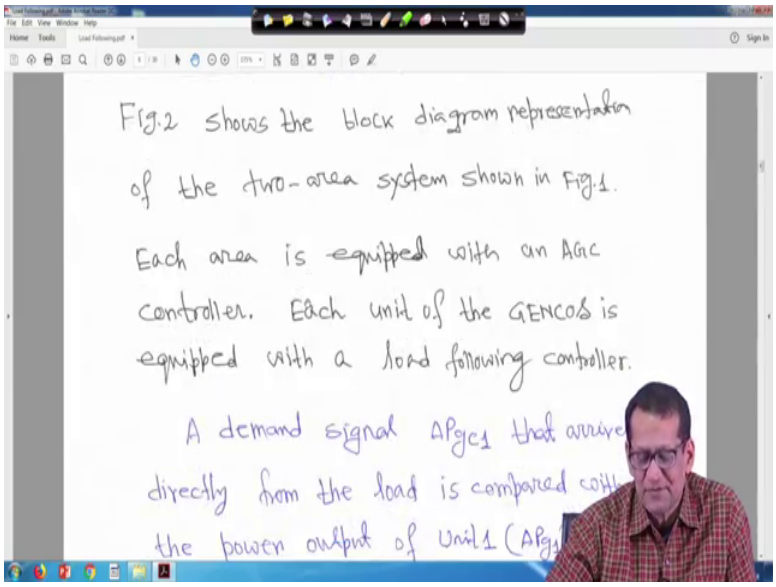
(Refer Slide Time: 07:47)



So, at the steady state delta P tie 1 2 error will be vanish. So, in that case at steady state delta P tie 1 2 actual is equal to delta P tie 1 2 schedule that also we have seen right.

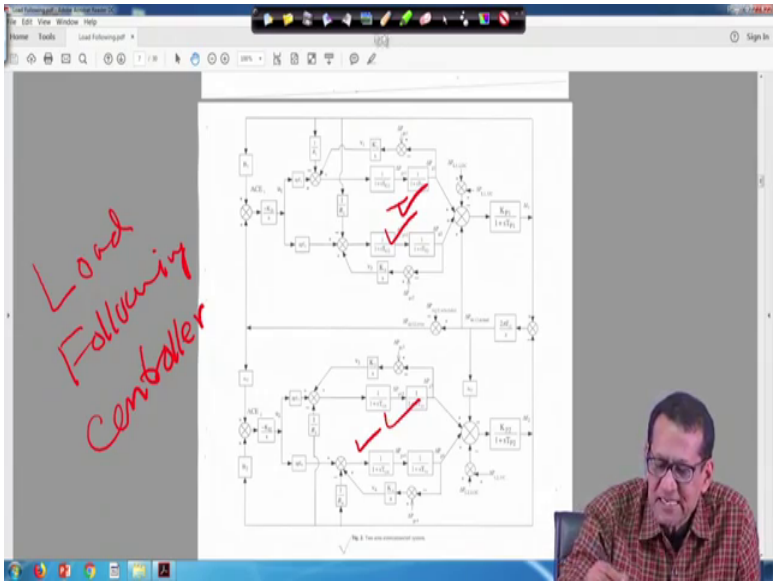
Now, changes will come. So, this error signal is used to generate the respective area control error ace signal as in the traditional scenarios. That is ACE 1 is equal to your B 1 delta f 1 plus delta P tie 1 2 error and similarly ACE 2 will be B 2 delta f 2 plus a 1 2 delta P tie 1 2 error this is equation 7 right.

(Refer Slide Time: 08:25)



Now, figure 2 shows block diagram representation first I will come to the block diagram then all this explanation right.

(Refer Slide Time: 08:31)



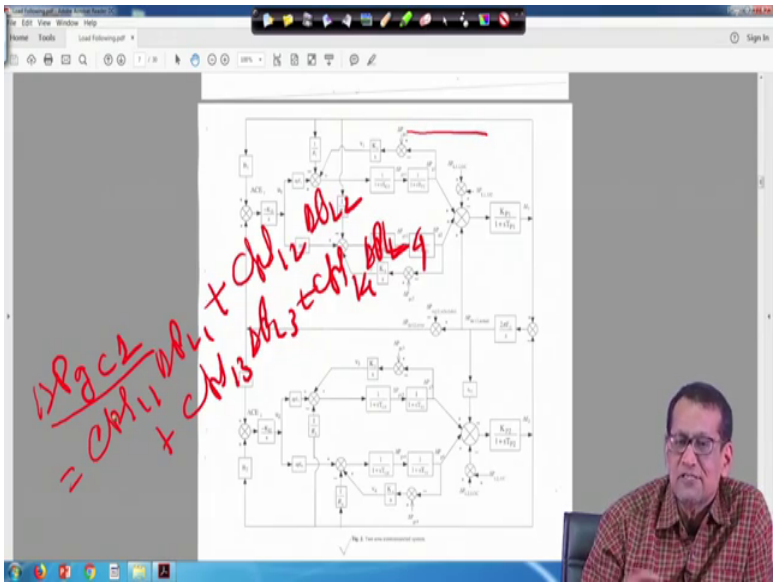
So, let me reduce the volume sorry reduce the size because I have to accommodate all these right.

So, first area 1 and area 2 just hold on it is it is accommodated right ; now in this case what happen actually that your what we have to do is ah; so difference of this one with the previous one I mean I mean lot of difference is there in the block diagram. Now the question is that when you are naming as a load following; that means, for the generator 1; those who will be in the load following they need a load following controller right they need a load following controller.

So, if you look into the diagram; this is actually unit 1 in area 1 this is whole is a area in area 1 that whole is a GENCO 1 right and this is your unit 2 and area 2 this is unit 3 and this is unit 4. And same as the before that that your previous case the total DISCO 1, DISCO 2, DISCO 3, DISCO 4 how was cpf is coming right.

Here that is not shown because that is understandable right, but question is that that thing your in this case what happen suppose first for the sake of understanding that each your what you call that unit must have one load following controller. So, this delta P gc1 is nothing, but the contracted power demand.

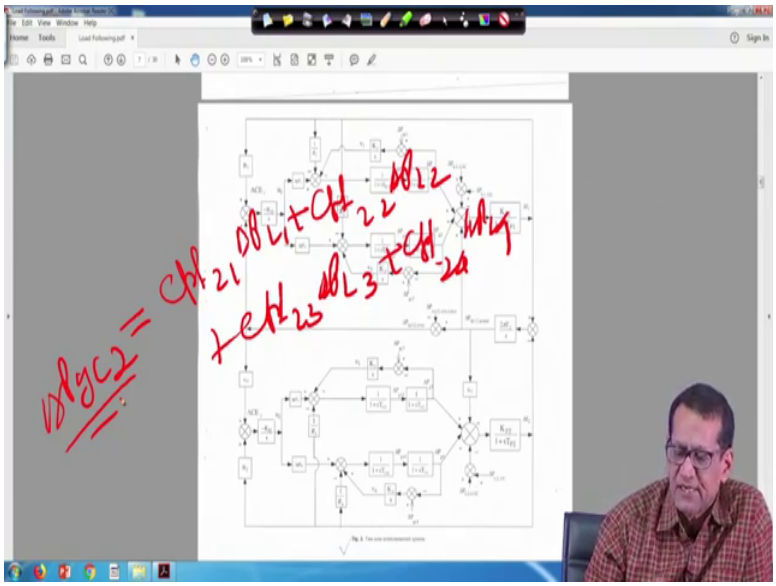
(Refer Slide Time: 10:09)



So, for example, for unit 1 I am writing it is I am making it here delta P gc1 that is with unit 1 the contracted power demand; it is your what you call each distribution companies there are 4 DISCO 1, DISCO 2, DISCO 3, and DISCO 4. So, they demand power say delta P L 1, delta P L 2, delta P L 3 and delta P L 4 right and your contract participation factor you have.

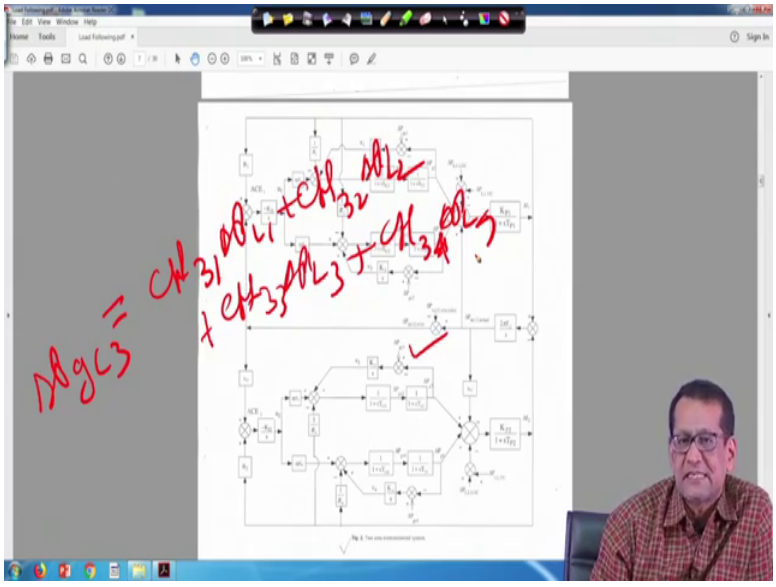
So, therefore, delta P gc1 will be your cpf 1 1 same as before delta P L 1; I am overwriting on it then cpf 1 2 delta P L 2 plus cpf 1 3 delta P L 3 plus cpf 1 4 delta P L 4 right delta P L 4. So, this is actually delta P gc1 same as which before it is nothing, but the delta P 1 or delta P gc1 right. So, here it is making delta P gc1 right. So, this is my delta P g c 1. So, same as before, but control structure here; here we need a load following controller.

(Refer Slide Time: 11:15)



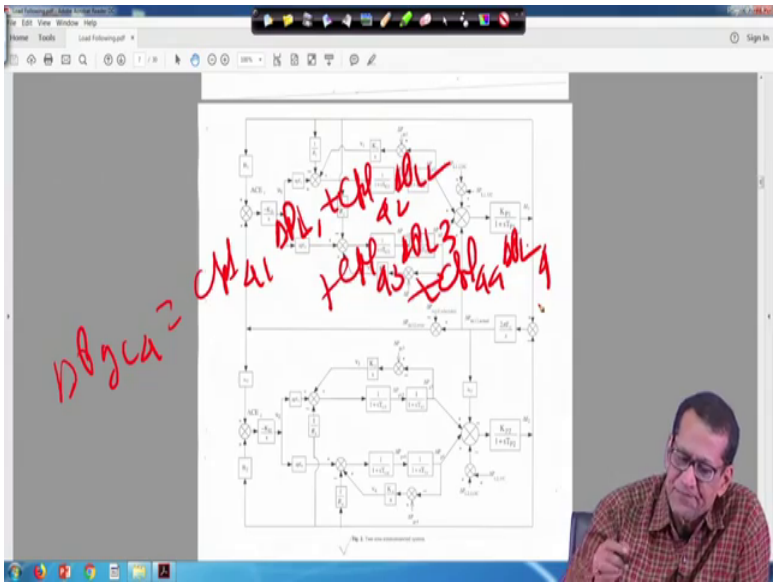
So, similarly for delta P g just for your understanding writing everything delta P g c P g c 2 will be cpf 2 1; I am overwriting on it delta P L 1 plus cpf 2 2 delta P L 2 plus cpf 2 3 delta P L 3 plus cpf 2 4 delta P L 4; that is nothing this is the contract demand by the unit 2 in area 1 right because in area 1 2; one GENCO, but 2 units unit 1 and unit 2 right.

(Refer Slide Time: 11:53)



So, this is for delta P g c 2; similarly for delta P g c 3 in area 2. So, del[ta]- that is the contract demand. So, this one will be cpf 3 1 delta P L 1 plus cpf 3 2 delta P L 2 right plus cpf 3 3 delta P L 3 plus cpf 3 4 ; delta P L 4 this is delta P g c 3.

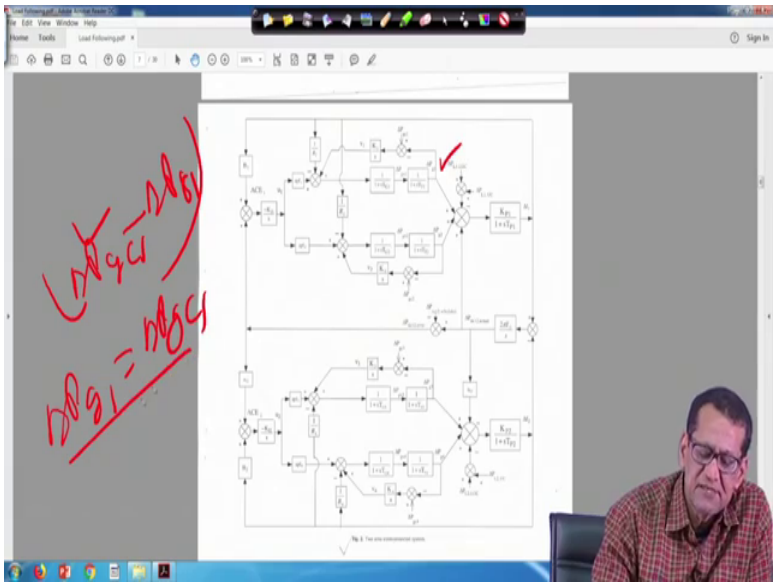
(Refer Slide Time: 12:23)



Similarly, your delta P g c 4 right is equal to cpf 4 1, delta P L 1 plus cpf 4 2; delta P L 2 plus cpf 4 3; delta P L 3 plus cpf 4 4, delta P L 4 right. So, this is the contract this is the power actually whatever contracts the various distribution companies they have the contract; so each generating unit has to generate that much of power delta P gc1 delta P g c 2 delta P g c 3 and delta P g c 4, for your I mean your what you call by the your units unit 1 unit 2 in area 1 and unit 3 and unit 4 in area 2 respectively right.

. So, that is why this delta P gc1; P g c 1, this is coming there it the delta P 1, delta P 2, delta P 3 and delta 4 it was going to the input that is your turbine govern that signal was going that this much power has to be generated. But here what we are doing is input is anywhere nowhere here nowhere here input is nowhere here right nowhere right input is somewhere here we are giving. Now question is that your this is delta P gc 1; then here the delta P g 1 feedback is here; so these two are compared.

(Refer Slide Time: 13:47)



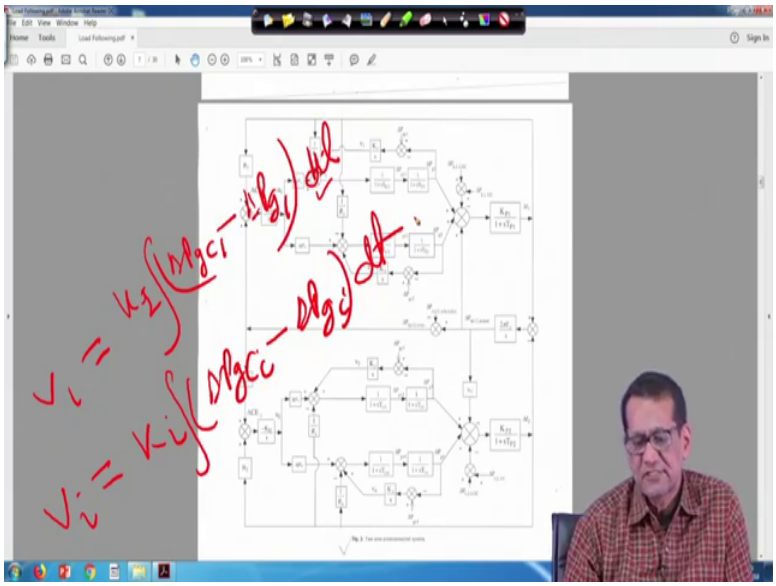
That is your delta P g c 1 minus delta P g 1; this is the contracted one and this delta P g 1 that is generated by the your what you call by the generating unit 1 right.

So, at steady; state at steady state this delta P g 1 it has to be is equal to delta P gc1 because this power has to be generated. For that what we are doing is we are putting a load following controller that is q 1 upon s is the one integral controller in this case; no P i or P i D I have used simply I have put a we put a we have put a your what you call put an integral controller right.

So, that is then its gain is k 1 right. Similarly an feedback is coming here it is coming here right; that means, this generation that del[ta]- as we are taking this delta P g 2 and this contractor is power demand this controller is 3 ; that means, delta P g 2 will chase delta P gc1; that is load following right. So, it will it will I mean steady state delta P g 1 will be is equal to delta P gc1 right; it will chase that this contracted power demand right.

Similarly, for unit 2 also you have a delta P g c 2 and this is delta your P g 2 and this is integral controller your k 2 upon s; that means, that output that is its output is v 1 ; output is v 1.

(Refer Slide Time: 15:09)

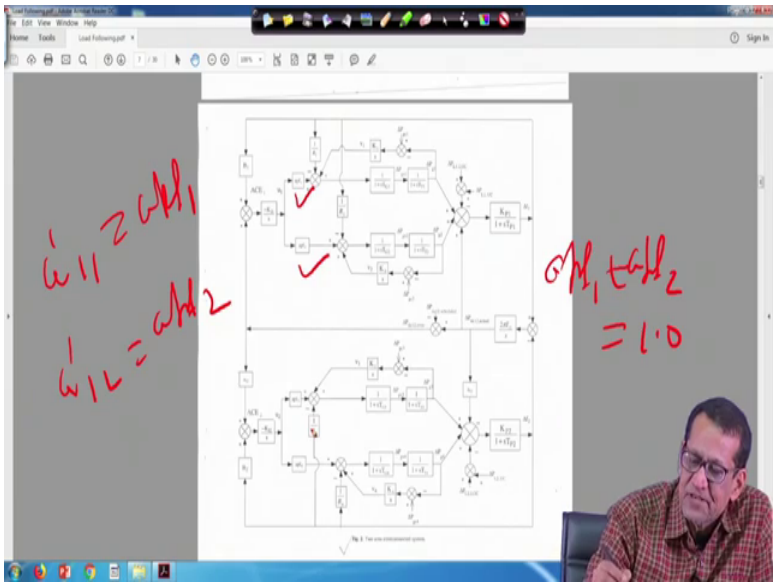


So, B 1 is equal to actually k 1; this integral this thing then which is 1 upon s; so integral controller. So, it is actually delta P gc1 minus delta P g 1 actually dt right. So, this is v 1 ; so that then that v 1 is coming here as an input right. Or in general or in general that v i for ith unit is equal to k i that gain of i'th unit integral gain of that ith load following controller rather right ; then integral of delta Pgci minus delta P g i dt right. So, this actually this load following controller actually will force actually generation to match the contracted power demand at steady state.

So, similarly here also controller is there similarly here also controller is there; similarly here also load following controller is there. But there is no need that all the generating unit will everyone needs that it show you that load following controller, it depends on the system right. Suppose this unit suppose this unit may have a load following controller because; suppose some DISCOs have contract with that and this unit may this unit maybe it has no contract with any DISCOs right.

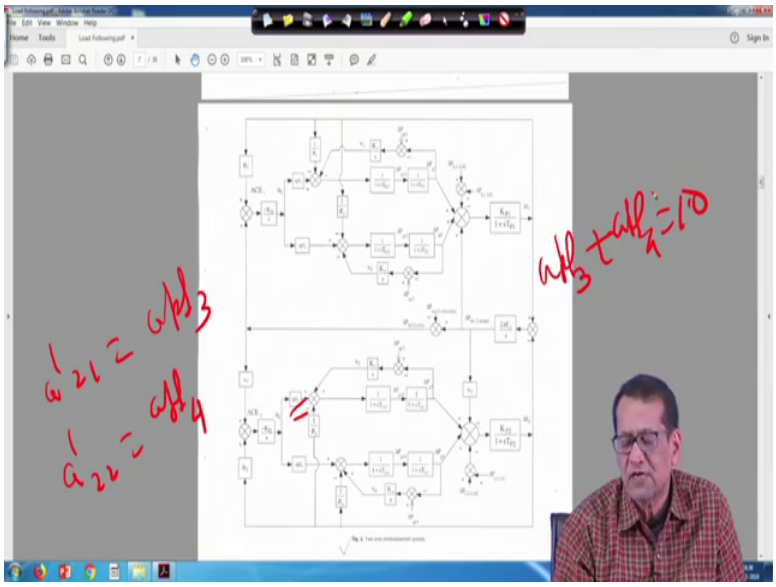
So, in that case this may not be in this thing this will be in AGC ; now another thing is that in this case another thing that we have taken a p f 1 and a p f 2 ACE participation factor it is same as before, but as it is a load following. So, I have changed I have just changed this your what you call that termi[nology]- that terminology right.

(Refer Slide Time: 16:53)



It was actually a dash 1 1 in the previous case; it is nothing, but same thing a p f 1, that is ACE participation factor. Similarly previous case a dash 1 2 is equal to a p f actually it is 2 and a p f 1 and same as before a p f 1 plus a p f 2 it is actually 1.0 right.

(Refer Slide Time: 17:23)



Similarly for this case your for this case right; so it is a dash 11 a dash 1 2. So, a dash 2 1 is nothing, but your a p f 3 right this is ACE participation factor for unit 3. And similarly for this one a dash 2 2 is a p f that a c s ACE participation factor for unit 4; that means,

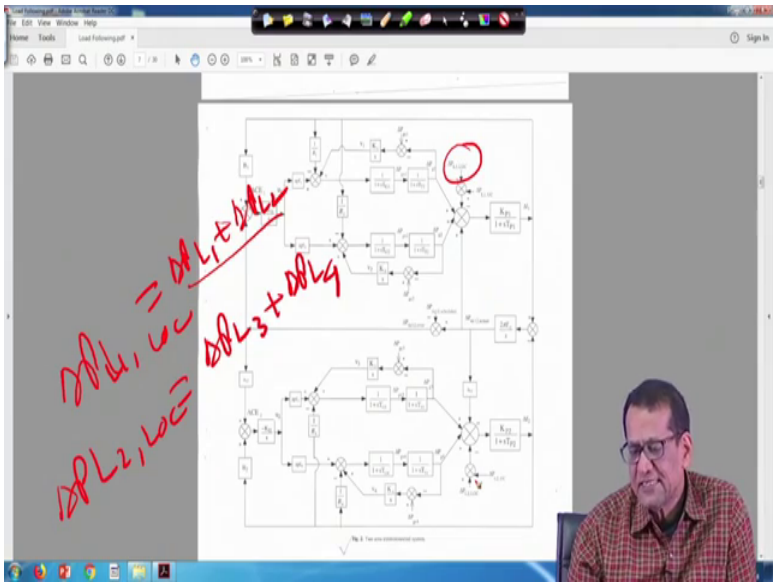
here also same thing a p f 3 plus a p f 4 it has to be is equal to 1.0 right. So, these are your what you call ACE participation factor.

So, basically this a p f this here also a p f 1, a p f 2 and a p f 3, a p f 4. So, basically your they have effect on the transient behaviour of the responses dynamic response the responses, but it has no effect and the steady state as along as uncontracted power demand is not there; if it is there it has effect that we will see. Now next one is same as before this is delta P tie 1 2 actual and this is delta P tie 1 2 schedule this feedback is given here we have seen same the same as before.

And this is delta P tie 1 2 error. So, this way this is B 1 delta f 1 because this is delta f 1. So, it is B 1 delta f one this delta P tie 1 2 error and this is actually your a c 1 right. Similarly here also it is B 2 delta f 2 plus a 1 2 delta P tie 1 2 error. So, this is actually your a c 2 and this 2 as integral your what you call input to the integral controller; it is minus k i 1 upon s this is minus k i 2 upon s right. So, these two are your integral controller for this AGC right.

Now, and next is next for this block diagram this delta P L 1 local same as before.

(Refer Slide Time: 19:09)



So, delta P L 1 local is equal to nothing, but delta P L 1 plus delta P L 2 that is your that is in area 1; we have 2 distribution companies that is why their demand is delta P L 1 and delta 2.

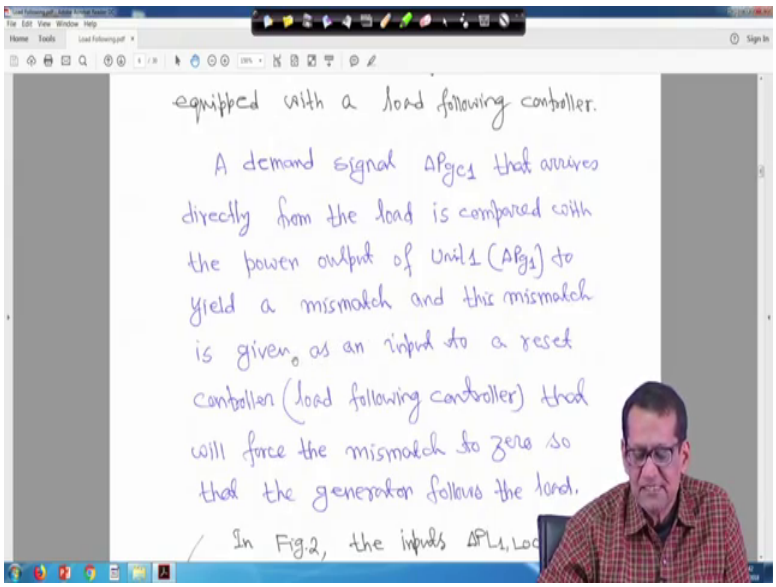
So, delta P L loc[al]- p L local will be delta P L 1 plus delta P L 2. Similarly for delta P L 2 local is equal to delta P L 3 plus delta P L 4 right this is in area 2. And if there is any uncontracted power demand if there is any uncontracted power demand and in that case that it is delta P L one you see that is uncontracted power demand in area 1.

If apart from their contracted power demand if any if any if any excess power demand needs by any distribution companies in area 1 that will be reflected in area 1. And it is expected that that you have a that units generating units in area 1 they have to supply this power right according to ACE participation factor.

Similarly, for area 2 also that delta your what you call that your uncontracted power demand whatever it has it has to be supplied by the same generating unit in area 2 right. So, ; that means, major difference is that this load following controller; so load following controller; so, philosophy actually totally changed right previous one was something and here it is something, but you do not need. So, many load following controller because all the DISCOs may not have contract with generating units in area right. So, this is the your what you call that philosophy.

Now, then ; so now this whatever about the block diagram I explained this is the figure 2 shows the block diagram representation of the 2 area system shown in figure 1 right. Figure 1 has schematic and figure 2 I explain to you now each area is equipped with an AGC controller.

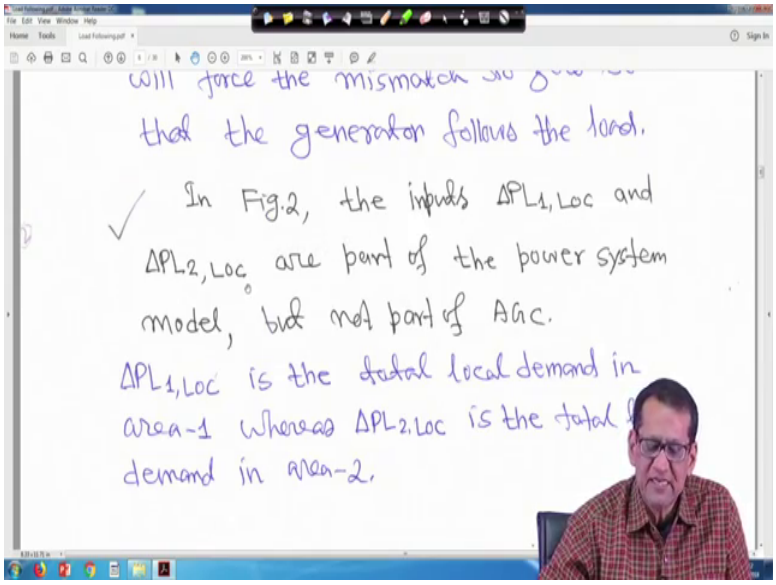
(Refer Slide Time: 21:13)



So, each unit of the GENCOs is equipped with a load following controller right. So, a demand signal that is delta P gc1 that arrives directly from the load is compared with the power output of unit 1 that is delta P g 1 I told you. To yield a mismatch and this mismatch is given is given as an input to the reset controller that is nothing, but the load following controller right.

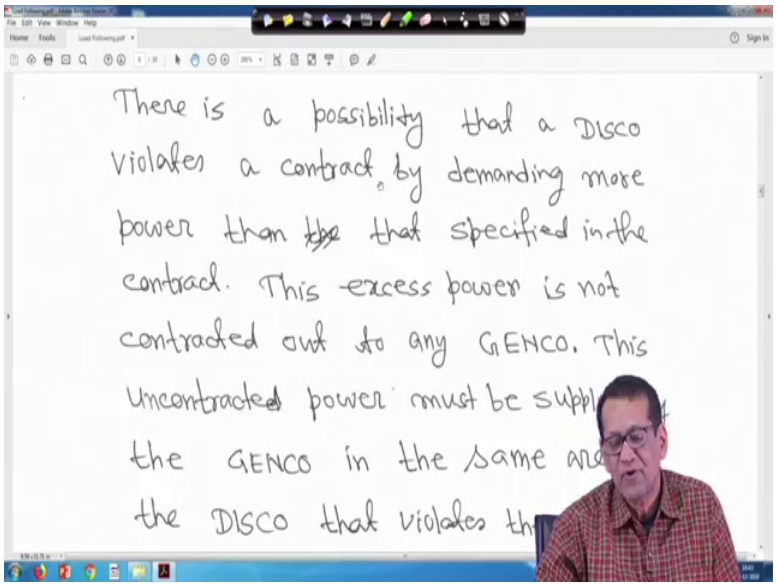
So, that will actually force the mismatch to zero so that the generation follows the load; so that is called as load following. So, in figure 2 that I already explained let me let me just little bit enlarge it.

(Refer Slide Time: 21:57)



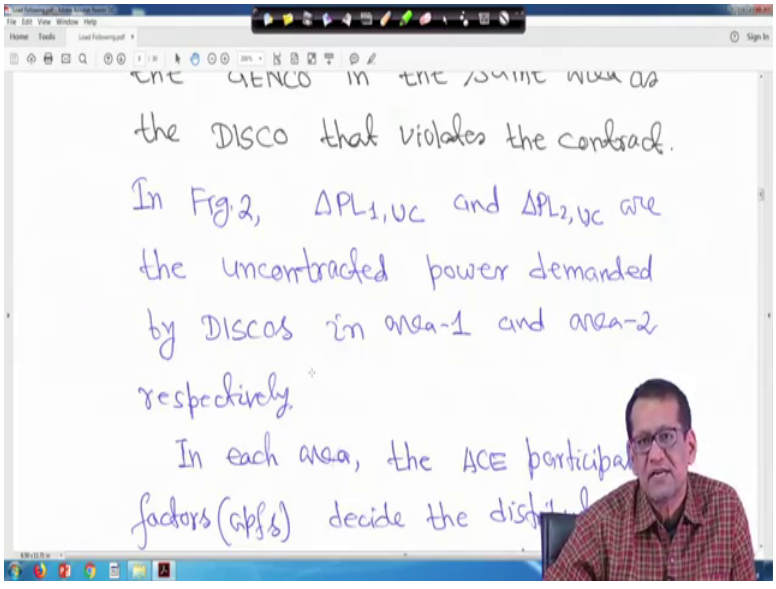
So, in figure 2 the inputs delta P L 1 local and delta P L 2 local are part of the power system model, but not part of AGC that also we have explained before. Delta P L 1 local is the total local demand in area 1 whereas, delta P L 2 local is the total local demand in area 2 that also I have explained to you right; diagram also everything I have block diagram I have explained right.

(Refer Slide Time: 22:19)



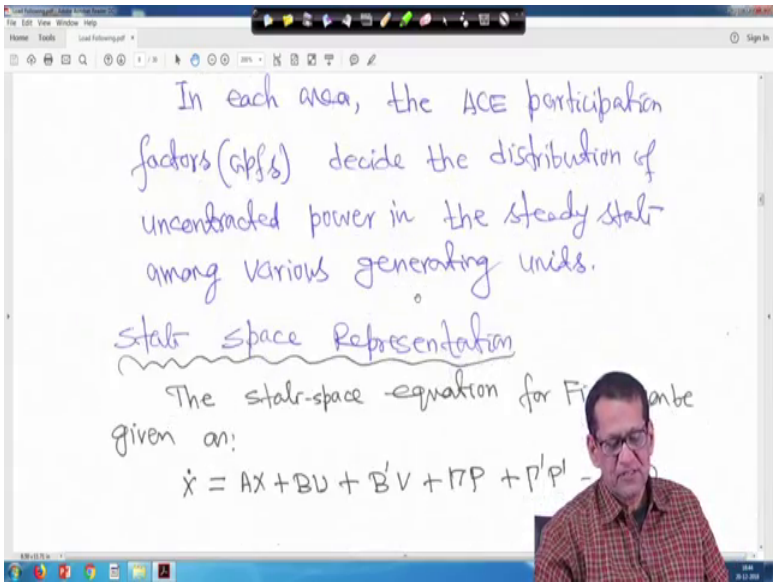
So, there is a possibility that that uncontracted power demand that a DISCO violates a contract by demanding more power than that specified in the contract right. So, this excess power is not contracted out to any GENCO; this uncontracted power must be supplied by the GENCO in the same area as the DISCO that violates the contract right.

(Refer Slide Time: 22:43)



So, in figure 2 I told you delta P L 1; uncontracted and delta P L 2 uncontracted are the uncontracted power demand that is u c delta P L 1 UC and delta P L 2 UC are the uncontracted power demanded by DISCOs in area 1 and area 2 respectively right.

(Refer Slide Time: 23:01)

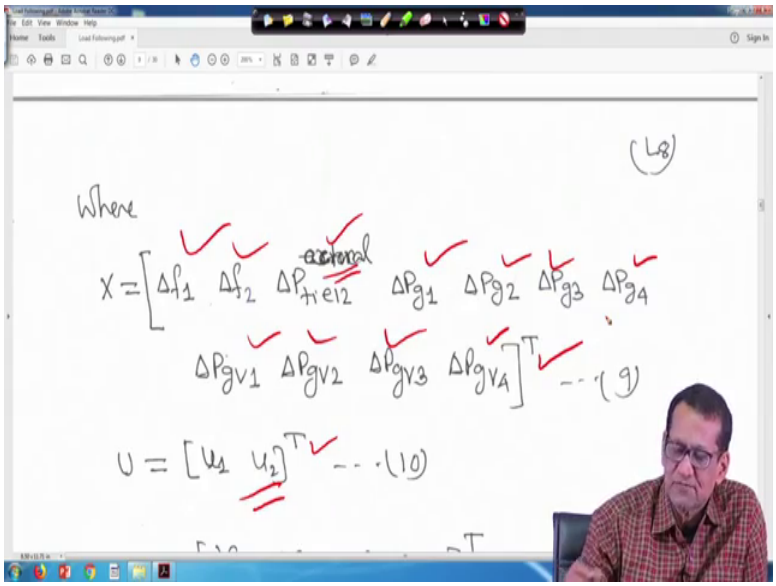


So, in each area the ACE participation factor also I explained to you right; decide the distribution of uncontracted power in the steady state among various generating units right.

Next is the state space representation. So, the state space equivalent of figure this 2; it can be represent as X dot is equal to AX right plus BU plus B dash V because this B term is coming B 1 B 2 B 3 B 4 because of load following controller; B dash and gamma capital P and gamma dash; P dash; I am made it this is equation 8 right.

So, you have 5 terms on the right hand side A B B dash gamma and gamma dash and your the your what you call A A AX BU B dash V gamma capital P and gamma dash capital P dash right. So, we have 5 terms.

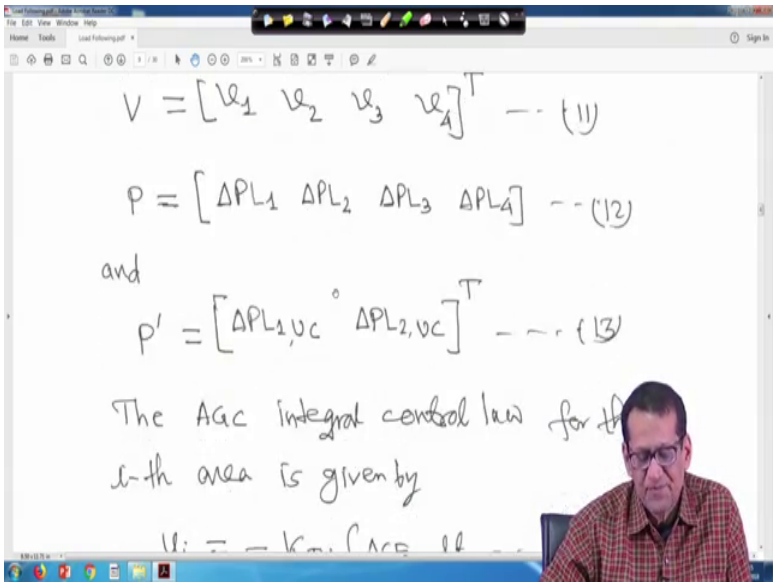
(Refer Slide Time: 23:51)



So, where X is equal to the state variables; so you have these your 2 generating units are there.

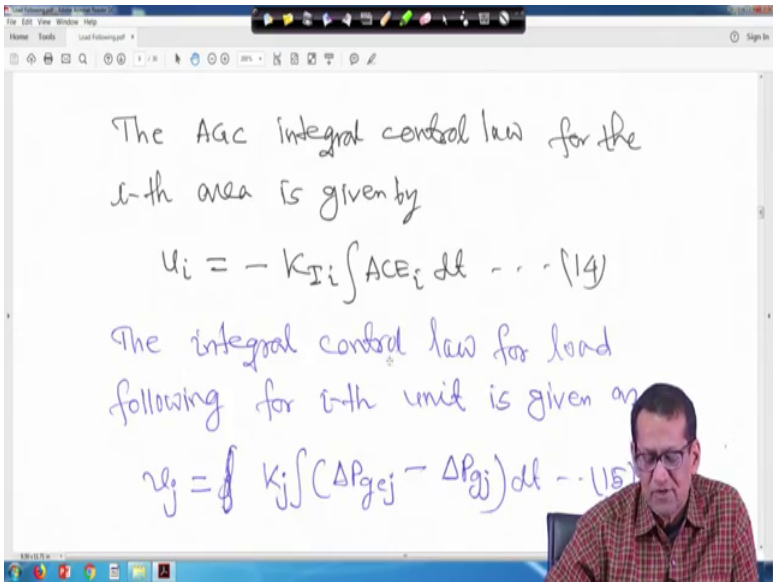
So, 1 2 3 4 this is actual this is a delta P tie 1 2 actual 4 5 6 7 right 8 9 10 11. So, there are 11 state variables are there; so state space matrix will be 11 into 11 right and U there are two input, that two integral controllers are there for 2 areas. So, u 1 and u 2 this transpose this is all transpose it is given right.

(Refer Slide Time: 24:29)



. So, next is V there are 4 load following controllers in general. So, that is why v 1, v 2, v 3 and v 4 transpose right and P there are 4 distribution companies their power demanded are delta P L 1, delta P L 2, delta P L 3 and delta P L 4 and P dash that is uncontracted power demand delta P L 1 uc and delta P L 2 v c transpose.

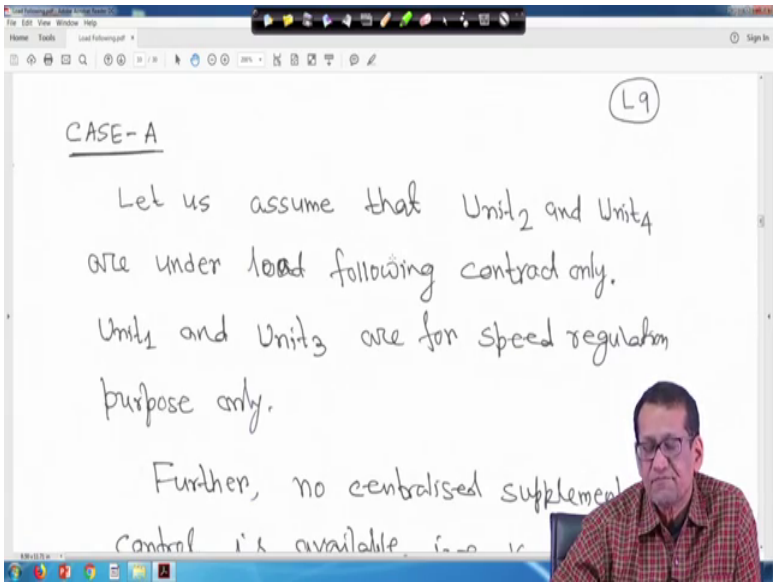
(Refer Slide Time: 25:01)



In the previous case we took small p, but here I have taken P dash right the AGC integral control law for the ith area is given by that is u i that is your AGC controller minus K I i integral of ACE i dt, where K I i is the integral gain of area i and integral ACE i dt is the area control error of area i right.

So, integral control law for the load following for ith unit is given as; so v j it is actually it will be jth unit right it is actually it is not a it is jth unit. Because here it is written j j j and j; so it will be your jth unit right. So, it is actually v j is equal to K j integral of delta P g c j minus delta P g j right. So, this is a load following controller expression.

(Refer Slide Time: 25:49)

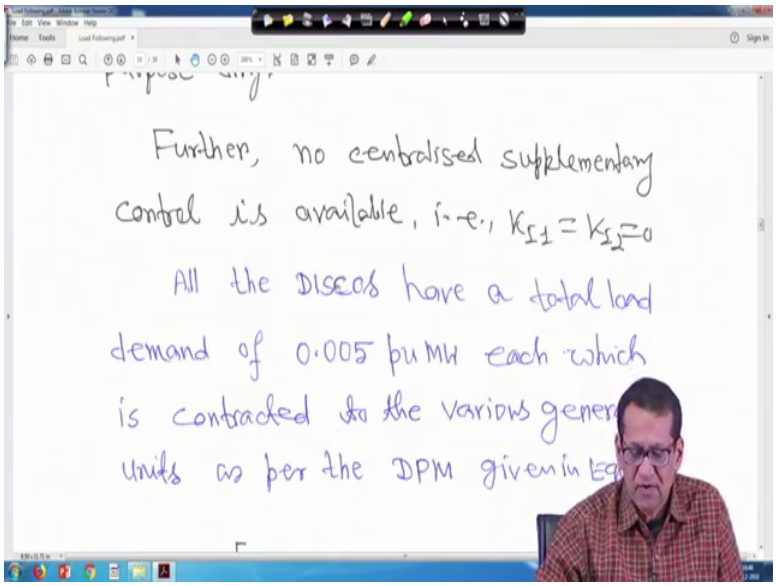


So, now we will make some case studies right. So, let us assume that let us assume that unit 2 and unit 4 are under load following contract only; that means, in area 1 your area 1 that your unit 2 is there and area 2 unit 4 is there. So, these two are load following contract only unit 1 and unit 3 are for speed regulation purpose only right.

So, further no centralised supplementary control is available that is K I 1 is equal to K I 2 is equal to 0; that means, in this diagram in this diagram that is unit 2 and unit 4 under load following; that means, if I come back to this diagram once again right ah. Let me just make it to half right. So in this diagram that your that unit 2 and unit 4 are load following; that means, this is unit 2 and this is unit 4 these 2 will be load following.

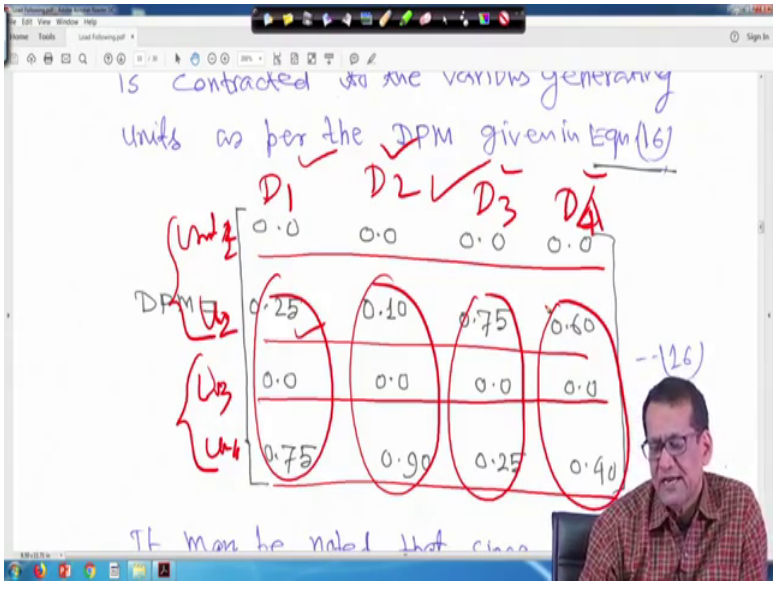
And these two are will be will be just under AGC, but that no supplementary controller; that means, this part will not be there; this part will not be there and we will examine this case because K I 1 and K I 2 are 0s right. So, let me go back to that further I told you no centralised supplementary controller is available.

(Refer Slide Time: 27:25)



And all the DISCOs have a total load demand of 0.005 per unit megawatt right. Each which is I mean 0.005 per unit megawatt is which is contracted to the various generating units as per the DPM given in equation 16. So, this is actually DISCO participation matrix is taken.

(Refer Slide Time: 27:47)



So, in this case in this case that unit 2 and unit 4; they are actually in the load following. That means, DISCOs have contract they actually this is your distribution company 1; I am putting D 1, D I instead of DISCOs it will I have to take more space, this is D 2, this

is D 3 and this is D 4 right this is D 4 distribution DISCO 1; DISCO 1, DISCO 2, DISCO 3 DISCO 4.

And this is my unit 1 I am making it short unit 1 it is unit 2 it is unit 3 and it is unit 4 right. So, all are unit 3 unit 4 this is unit 1 and this is unit 2 unit 3 and unit 4 right. So, unit 1 and unit 3 are not under any load following that is why they are they have no contract with any DISCOs; that is why cpf is 0, this row is 0.

Similarly for unit 3 this row is zero because it has no contract with any other areas any other your what you call they your this your this DISCOs. So, the DISCO have no contract with them here also nothing, but for a unit 2 and unit 2 in area 1 because this is your area 1 and this is in area 2 because area 1 unit 1 unit 2 area 2 unit 3 and unit 4 right.

And their participation cpf is given like this right and their cpf is given like this, but if you add this it will be 1; 0.75, 0.25; when we add this it will be 1, if you add this it will be 1 and if you add this column wise it will be 1 right. So, this distribution participation matrix is taken right.

So, with this thank you very much, we will be back again in the next lecture.