Power System Dynamics, Control and Monitoring
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Lecture - 44
AGC in deregulated system (Contd.)

So, this block diagram this is the way that actual drawing. Now we will simplify for our analysis we will simply.

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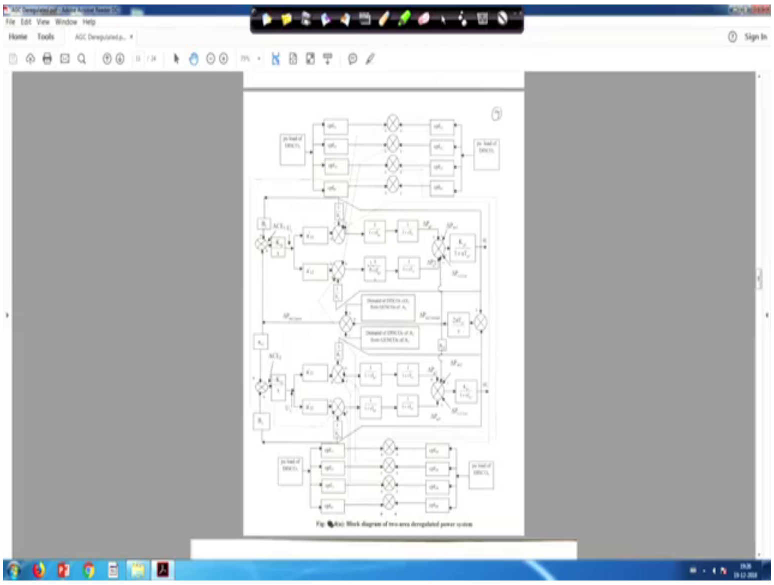

So, how we will do it? This was drawn by hand right. So, let me a little bit large it right.

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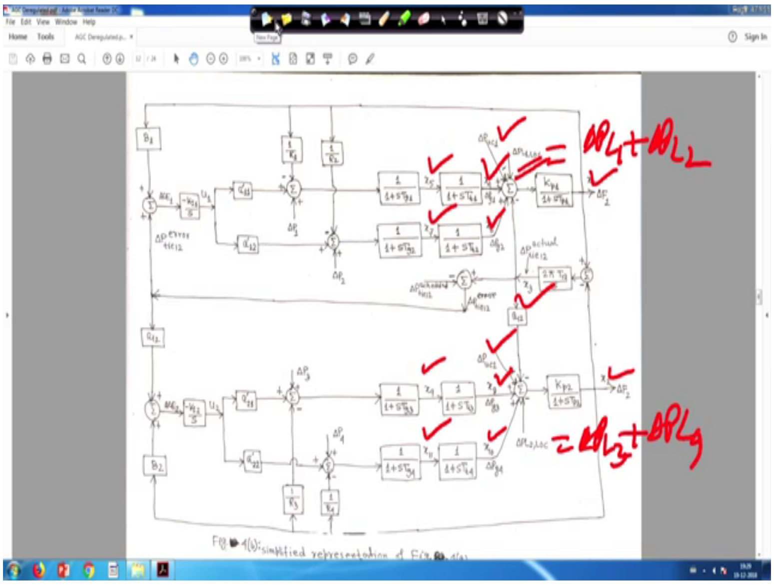

So, ultimately what happened. that whatever I told you that here the input we have to given additional input that contacted power about delta PL 1 is cpf 11 delta P L plus cpf 1 2 delta PL 2 plus cpf 1 3 delta PL 3 plus cpf 1 4 delta PL 4. So, that is here it is coming as genco one right.

Similarly, delta P 2 because all this things summed up and put it here and similarly that is your per GENCO it is delta PL 3 and GENCO 4 it is delta P 3 and delta P 4 right. And then, this area this one also this is actual and this is your delta P tie 1 2. So, actual minus schedule is equal to delta P tie 1 2 error. So, there also from that previous block diagram, we have se[en]- drawn this simplified version right such that it will be easy for realisation.

So, this is your delta P tie i 1 2 error. So, finally, this ACE 1 integral u 1 and I told you this is ACE participation factor. This is also ACE, ACE participation factor right. So, this is actually and this is if I know, power system 1 is and that area 1 and area 2 and this is as actual tie line power flow right. This already we have seen for conventional thing right.

So, deep you look into that; here you have how many state variable. So, this is x 1, this is x 2, this is x 3, this is x 4 right and this is your x 5, x 6, x 7, x 8, x 9, x 10, x 11. So, there are 11 state variables right. So, a matrix will be 11 into 11. But another thing is that, that here one is that contactor load d 1 that reflector as a local load demand the delta P L 1 plus P L 2 will be there. Here also delta P L 2 local actually delta P L 1 local I told you is equal to da delta P L 1 plus delta P L 2 and this one delta P L 2 local is equal to delta P L 3 plus delta P L 4 right.

And uncontacted power demand is there, delta P uc 1 and P uc 2 because of that that equation we have to write that in the form of x dot is equal to x plus B u plus gamma into capital P plus another gamma into small p right. We will see how it is right. So, this way your, this way just hold on. So, this way we have to make the that equation all state variable equations. So, if you do so,, just hold on.

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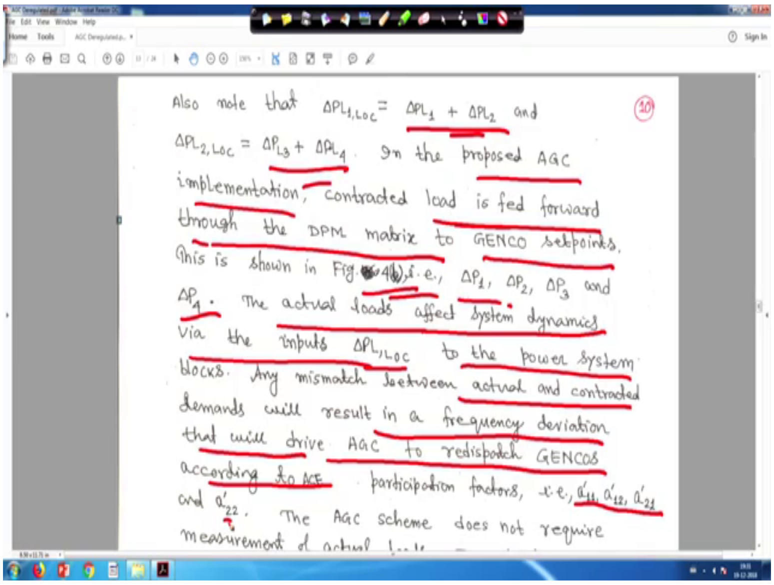

So, also note that I told you that delta P L local will be delta P L 1 plus delta P L 2 and this one will be delta P L 3 plus delta P L 4.

So, in the proposed AGC implementation contacted load is fed forward though the DPM matrix that is Disco Participation Matrix to GENCO set points, that I told you. So, this is shown in figure 4 b, I showed you just on the figure 4 b. So, delta P L P 1 P 2 P 3 and delta P 4, this just I showed you the diagram figure 4 b. The actual loads effect your system dynamics via the inputs delta P L local, in general that is delta P L 1 local and delta P L 2 local to the power system right. that is power system block.

Any mismatch between actual and contracted demands will result in a frequency deviation that will drive AGC to redispatch GENCOs according to ACE participation factors. That is a dash 11, a dash 1 2, a dash 2 1, a dash 2 2 right.

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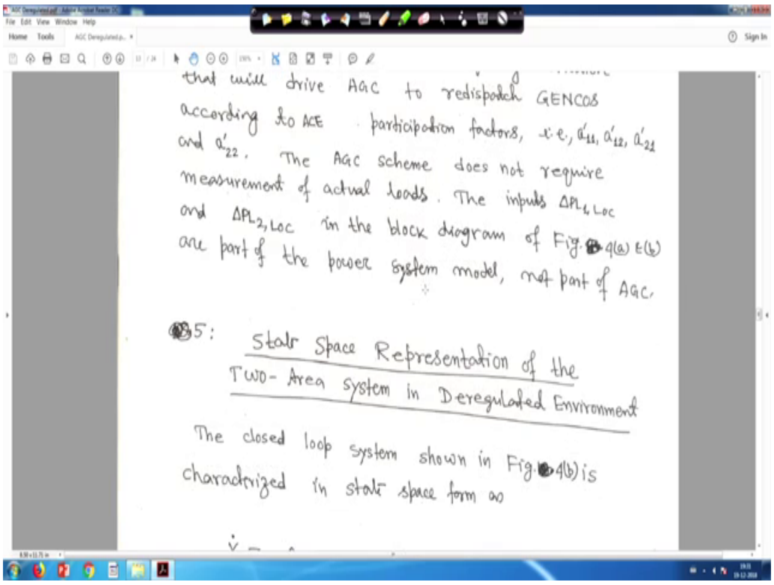

So, next is the AGC scheme actually it does not require measurement of actual loads right. So, the inputs delta P L 1 local and delta P L 2 local in block diagram of figure 4 a and b are part of the power system model, but not part of AGC right.

Next is state space representation of that two area system in deregulated environment right. The closed loop system whatever it is you write all the state variable equation right way x 1 dot x 2 dot everything.

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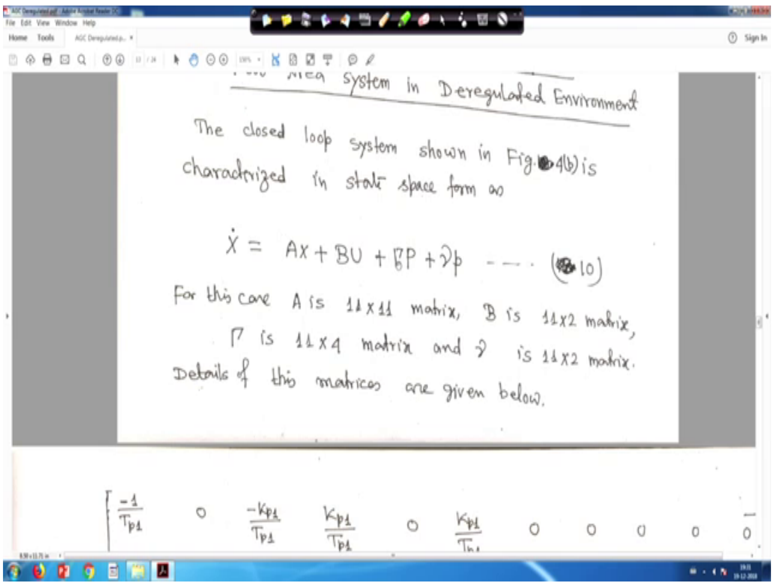

If you write it will be AX plus BU plus this gamma into capital P plus this gamma into small p this is equation 10. So, here I am not writing all the equations x 1 dot x 2 dot it is understandable to you right. So, A will be 11 into 11 matrix, B will be 11 into 2 matrix because there are two control input t 1 and u 2 gamma is 11 into 4 because P is actually nothing, but your P delta; your delta P L 1 delta P L 2 delta P L 3 and delta P L 4 that is why it is 11 into 4 matrix. And this gamma this small p will be un contacted power demand delta P uc 1 and in here to delta P uc 2 that is why, it will be 11 into 2 matrix right.

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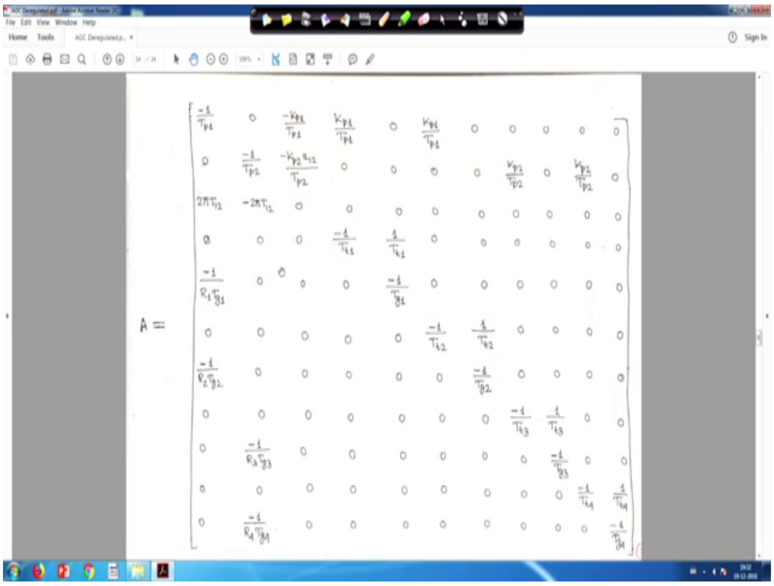

So, details of this matrix are given below. So, just let me reduce this volume, so this is my A matrix; so, this is completely 11 into 11 matrix. So, you please write is most of the elements and non zero element right. So, this is your a matrix if you write x 1 dot x 2 dot all up to x 11 dot. So, this is will be your A matrix right.

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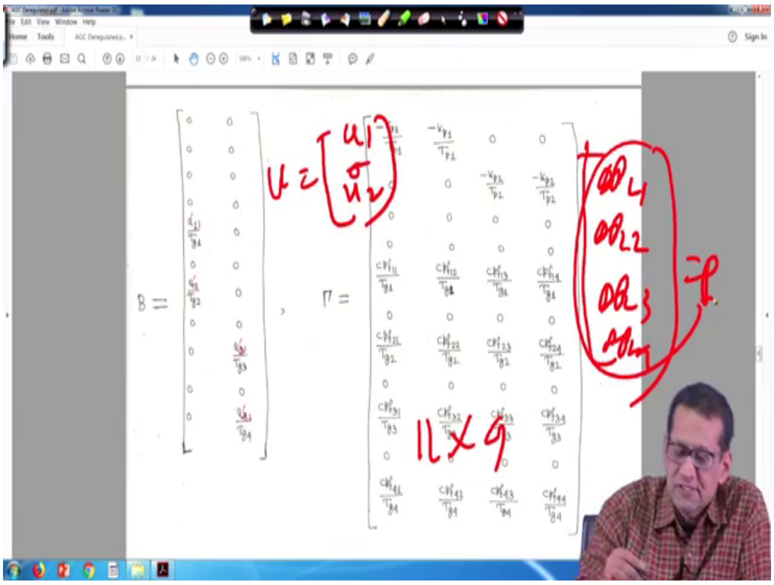

Similarly, your B will be this one. It is a dash 1 1 there upon T g 1 it is a dash 1 2, I have corrected all these things right. So, this will be your B matrix it is a 11 into 2 Bu. Then this is gamma matrix, this is because delta P 1 P 2 P 3 P 4 all are function of CPF that Contact Participation Factor that you have to put. After that you will get this matrix. So, gamma and this is capital P. So, your delta P L 1 delta P L 2 delta PL 3 delta PL 4 that is why this matrix is 11 into 4 matrix right. For your, there should not be any confusion right, u means let me write here, u means u 1 u 2 that is why this matrix is 11 into 2, gamma means this one that is gamma P capital P. This is nothing but your delta P L 1 delta P L 2 delta P L 3 and delta P L 4 right. That is why it is your 11 into 4 matrix right comma capital P. This is actually this part actually capital P right.

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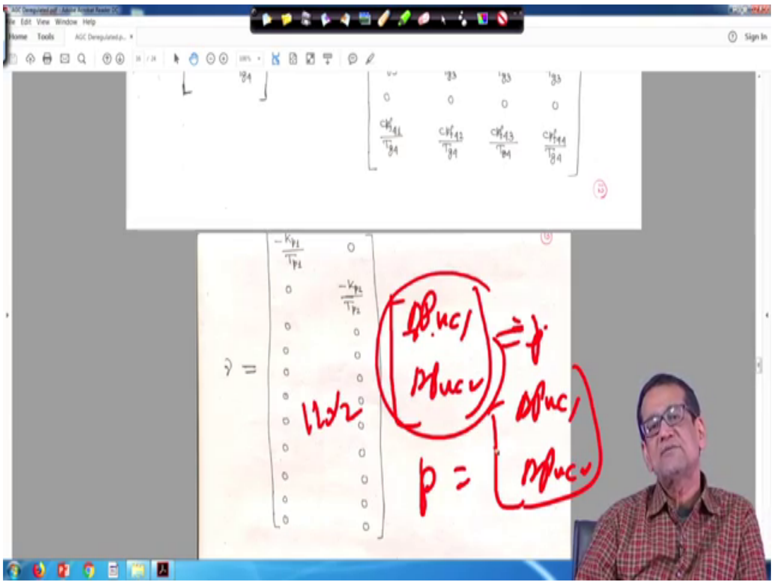

So, next is your as that other gamma, and this one this gamma will be the your what you call that 11 into 2. This is actually 11 into 2 because it is actually the small p is equal to delta P uc 1 and delta P uc 2. This is nothing, but your p 1 the small one that is your small p 1 is delta P uc 1 and delta P uc 2. So, this way you have to form that you are what you call that you are all the state variable equations x 1 dot x 2 dot like this right.

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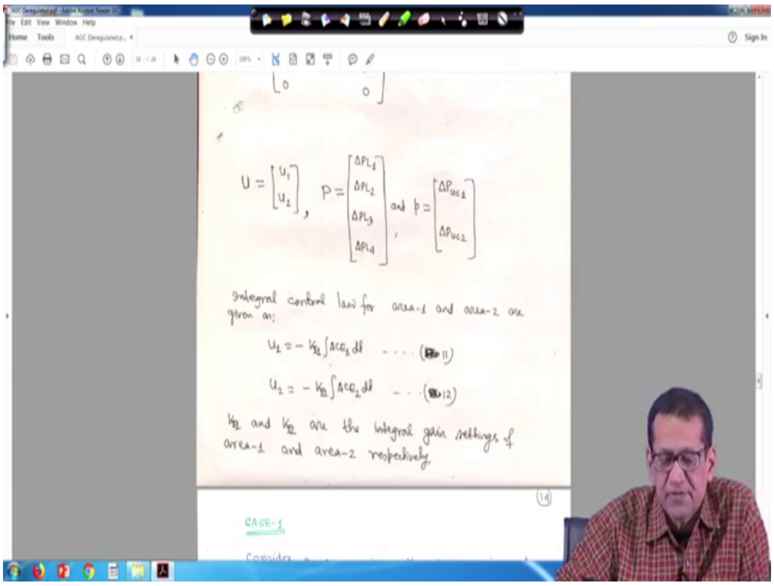

So, once you have got this one right. So, all these things I have defined here the u is equal to u 1 u 2, P is equal to delta P L 1 capital P is equal to delta P L 1 delta P L 2 delta

P L 3 delta P L 4 right and small p is equal to your delta P uc 1 delta P uc 2 right. An integral control I told you, u 1 will be minus K I 1 integral of ACE 1 dt and u 2 will be minus K I 2 integral of ACE 2 dt. K I 1 and K I 2 are the integral gain settings of area 1 and area 2 respectively right.

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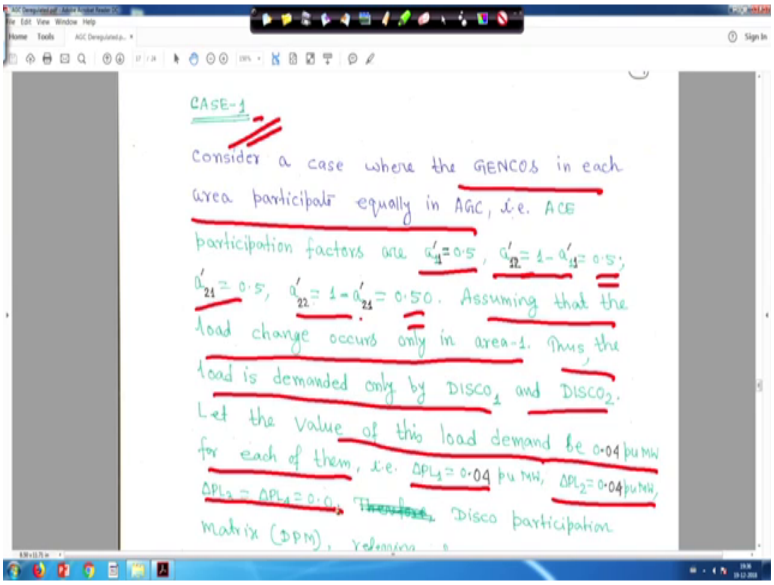

Now, we will study something. So, state you basically, I will show you the dynamic responses also. But basically, as for as class room exercise is concerned all things you will be given in the steady state right so, no question of simulation in the class room or this that right. So, consider your consider a case, this is the case 1. Consider the case where the GENCOs in each area participate equal in AGC; that means, that ac participation factor that a 1 1 dash is 0.5 a rather a dash 1 1 0.5 a dash 1 2 is 1 minus a dash 1 1 that is also 0.5.

Similarly, a dash 2 10.5 and a dash 2 2 1 minus a dash 2 1 that is also 0.5. So, ACE that is your what you call that participative, participate equal in AGC right; so, that is why 0.5, 0.5, 0.5, 0.5. Assuming that the load change occurs only in area one; that means, that in the your what you call in area 1. Thus the load is demanded only by DISCO 1 and DISCO 2. So, if load changes occurs only in area 1 means area 1 you have to distribution companies. So, load change occur only for distribution company 1 and distribution company 2 that is DISCO 1 and DISCO 2.

Now let the value of those load demand be 0.04 per unit mega watt each of them then that is delta P L 1 is 0.04 and delta P L 2 says 0.04 right and delta P L 3 and delta P L 4 there 0 right. And then, suppose you are what you call a DISCO participation matrix right DPM is given like this that is, DPM is equal to 0.50, 0.50, 0.50, 0 for rest all the CPFs are, you are what you call the 0 right.

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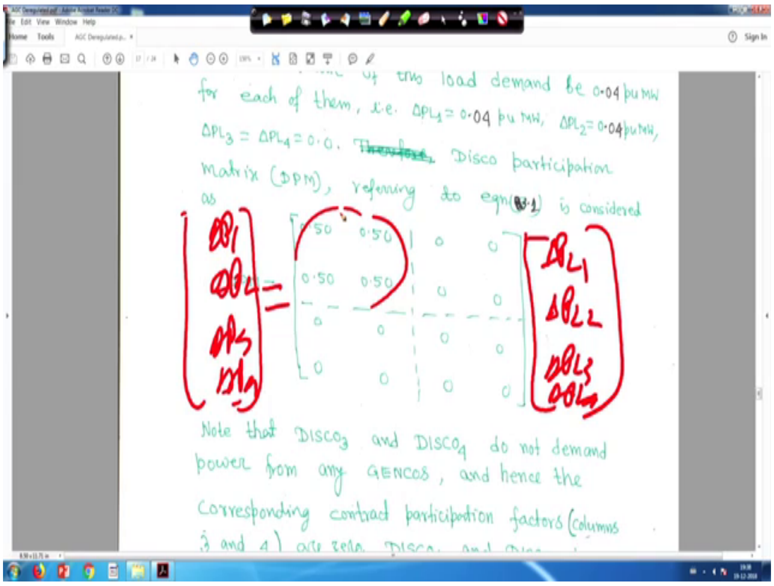

So, in that case what will happen? That basically, this is my disco, your DISCO participation matrix, then what will be the contacted power demand? So, contacted power demand means look I am overwriting here for your understanding. So, this is my delta P L 1, this is delta P L 2 say, this is delta P L 2 say, this is delta P L 3 and this is sorry delta P L 3 and this is delta P 4 right. So, this one actually is equal to this one into your power demanded by distribution company one delta PL 1 delta PL 2 delta PL 3 and last one is delta P L 4 right.

So, this is actually nothing, but you are contacted power demand. So, this way we can write. So, this is given so; that means, your delta P 1 will be 0.5 into delta P L 1 plus 0.5 into delta P L 2, that is all these 2 term. Similarly delta P 2 will be 0.5 delta P L 1 plus 0.5 delta P L 2 and delta P L your P 3 and P 4 will be 0, because only load changes in distribution, you are what you call DISCO your distribution companies 1 and 2 in area 1 and this is the participation matrix is a sorry is contact participation factor is given. And delta P L 1 and delta P L 2 is 0.04 right.

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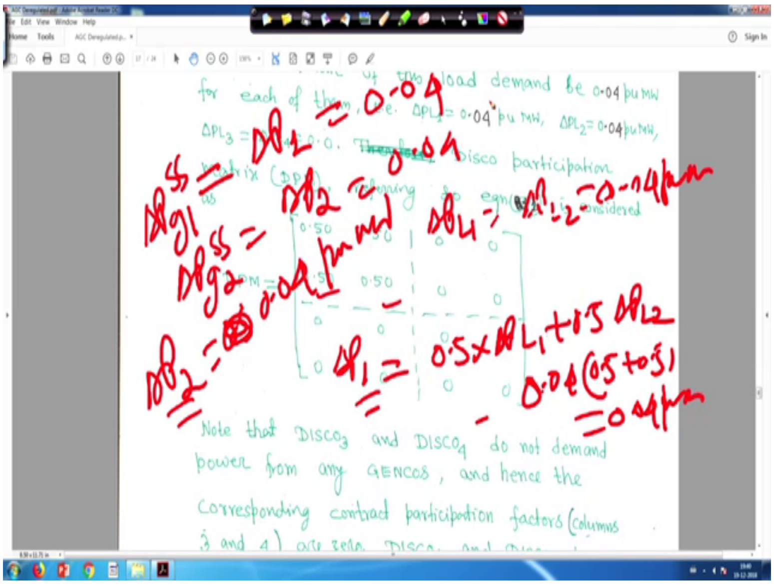

Therefore, you can write directly from here that delta P 1 is equal to 0.5 into your delta P L 1 plus 0.5 into delta P L 2 right. But we have taken that delta P L 1 is equal to delta P L 2 is equal to 0.04 per unit megawatt. So, basically it is actually as delta P L 1 is equal to delta P L 2. So, basically it will be 0.04 into 0.5 plus 0.5. So, basically it is 0.04 per unit megawatt that is your what you call, that contact power that is delta P 1.

Similarly, it is also 0.5 0.5 for delta P 2. So, delta P 2 also will be is equal to 0.04 per unit megawatt right, delta P 3 and delta P 4 will be 0 right. So; that means, that at steady state as this is the contacted power demand that is you are what you call, this contact power your, contacted power demand right. So, as this is 0.04, this is also 0.04; that means, at steady state generating unit 1, delta P g 1 steady state as steady state it will generate delta P 1, that is the contacted power demand total right at that has to be is equal to 0.04.

Similarly, at steady state delta P g 2 SS right is equal to delta P 2 is equal to 0.04 per unit megawatt. This has to this has to generate at steady state right. Therefore, that just let me move little bit up. Note that, that DISCO 3 and DISCO 4 do not demand power from any GENCOs I told you already and hence the corresponding contact participation factor column 3 and 4 at 0. This is this is already shown right.

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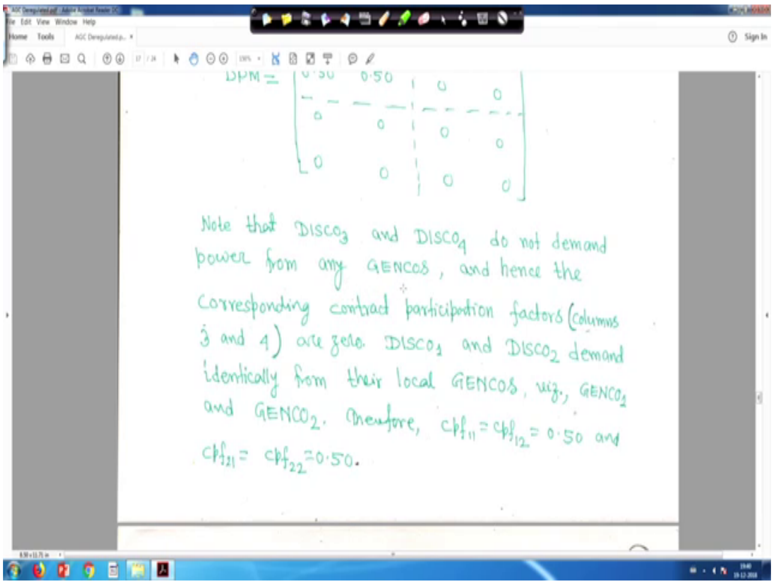

So, DISCO 1 and DISCO 2 demand identically from their local GENCOs, that is GENCO 1 and GENCO 2 and therefore, cpf 11 cpf 1 2 I told you 0.5 and this one also 0.5 each right.

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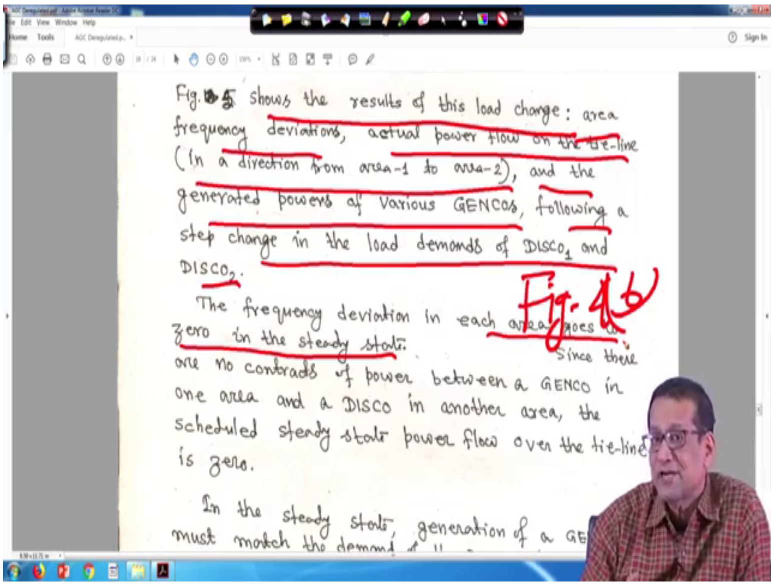

And so and how to compute contact power demand that is shown right. So, figure 5 actually shows the result of just load change right. I will show you the figure. So, area frequency deviation if you look into this. Let me come back to the figure right. Let just let me come back to the figure, that is figure 5.

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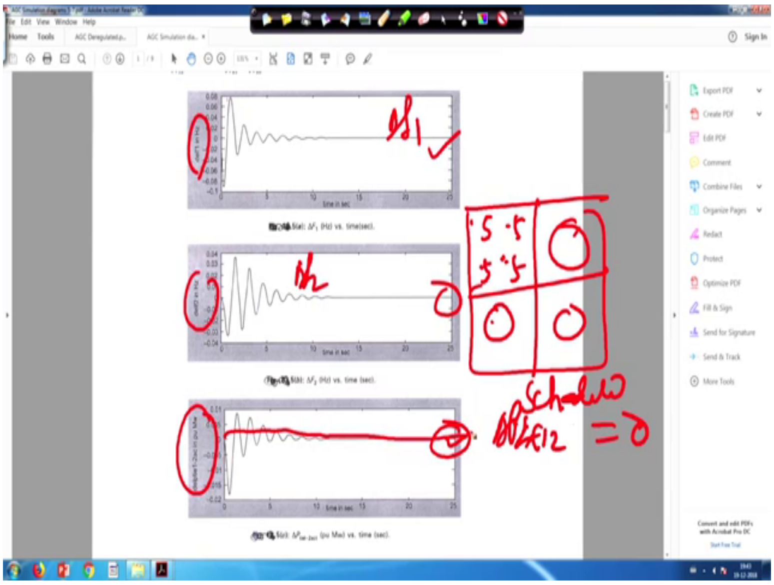

So, this is figure 5. So, this is actually dynamic simulation that is you, this is actually not through MATLAB Simulink actually, the code wise written actual code was written, this is not through MATLAB Simulink. But it was you are what you call, that code was run in MATLAB environment, but code was written right that is it is not Simulink.

And after that when data wire generated it was plotted in the MATLAB right. So, if you look into this, this is delta f 1, this is delta f 1 it is written in delta f 1 in hertz. So, at steady state the error is 0. This is understandable. Similarly this is delta f 2 delta f 2. So, at steady state that frequent devi[ation]- frequency deviation is 0, but only that during your transient behaviour that oscillations are there.

Similarly this is your delta P tie 1 2 actual; actually what happened that actual. Here actually for this case that your distribution companies area 1, its actually demand power from the GENCOs of that same area right. So, there is no question of that actual that there is no question of your actual tie line power flows. So, schedule tie line power flow will be 0 right. So that is why, that actual an error this will give identical respond. So, this is a steady state it is 0, because you have that you have that disco participation matrix. This is a disco participation metric only this way of 0.5 0.5 0.5 a 0.5 right.

So, here all elements are 0, all are 0 0 right. So, basically delta P tie 1 2 schedule tile and that will flow. Whatever it here I told you multiply that all cpf 1 3 delta P L cpf 14 delta P L 4 plus cpf 2 3 delta P L 3 plus cpf 2 for delta P L 4 minus this one. So, here 0 0 so, no question of your scheduled type or flow. So, basically for this case you can evaluate easily that delta P tie 1 2 schedule actually is equal to 0 right and error is equal to actual minus schedule. So, as delta P tie 1 2 schedule is equal to 0 so; that means, delta P tie error will be this is equal to delta P tie 1 2 actual. So, that is why error and actual both will give the identical plot.

But a steady state this is actually 0 because this is my, this is my 0 line right. So; that means, at steady state frequency deviation area 1 area 2 and tie power deviation this is actually 0 right ah. This is simulation, but I will suggest dos are for this the way we have may steady state analysis for conventional you are what you call that AGC, they are we have given the expression of delta F sf delta P tie 1 2 is a steady state error. So, here also for deregulated part is a small exercise for you, you derive it right; you derive it. So, and you will find it is 0.

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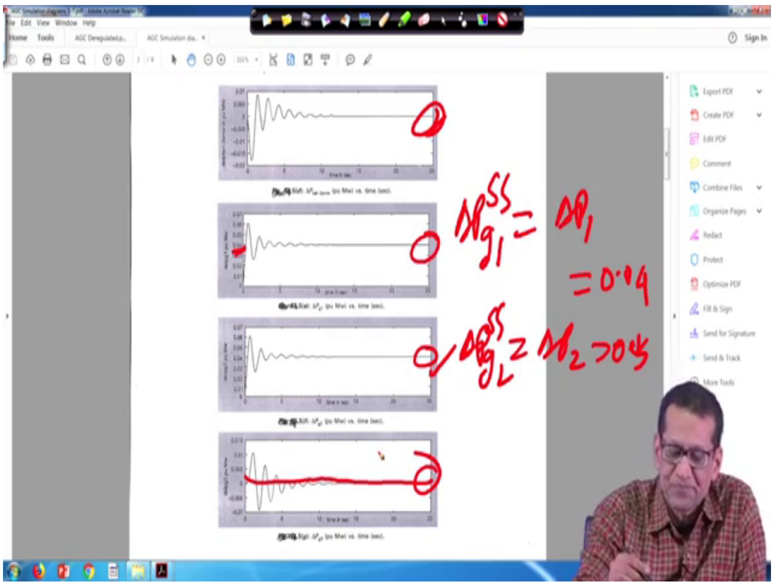

So, next one is that your this is your delta P tie i error for the same case right. It is also will be identical plot actual an error; so, it is 0. Now, as delta P g 1, I told it will settle 0.04. So, it is settling to 0.04 right. So, because at steady state that delta P g 1 steady state, it has to be is equal to delta P 1 is equal to delta P g 1 and that was 0.04 that we have seen. So that is why, this is actually 0.04 right. So, it is matching.

Similarly for delta P g 2 steady state, this also has to be 0 4 because delta P g 2 at steady state is equal to delta P l 2 is equal to 0.04. So, it is matching right, but delta P g 3 and P gb it has load these contactor with them because other elements some cpf's are 0 except cpf 1 1 cpf 1 2 cpf 2 1 and cpf 2 2 that is why this generation actually settling to 0, but during transient some oscillations are there. During transient some oscillations are there. Finally, at steady state it is 0 delta P g 3 is 0 right.

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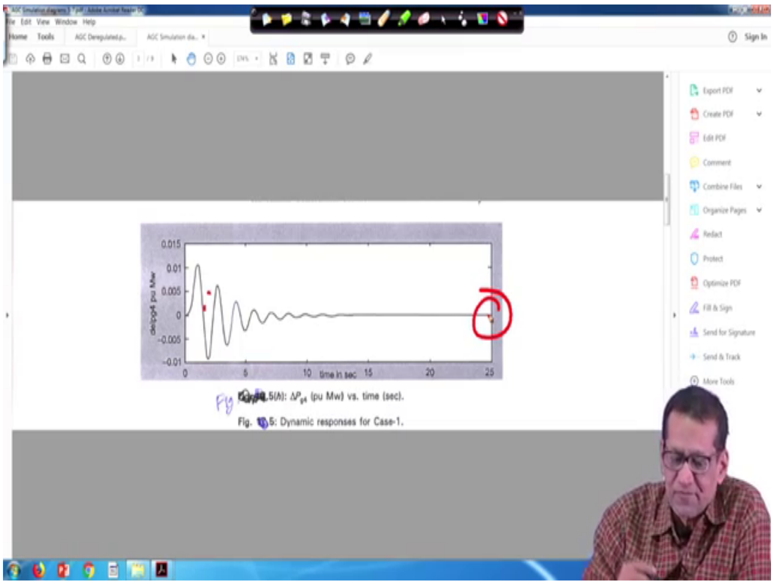

So, similarly delta P g 4 ; if you look into that delta P 4 as steady state it is actually 0, but during transient some oscillations will be there right. But after that actually it is 0 right. So, this is the dynamic responses for case 1. So, that is all these things I have explained. So, this is figure 5 a b c d e f g h, I showed. So, some statement have been written that figure 5 shows the result of this load change right that I showed you everything I explain right.

So, area frequency deviation actual power flow on the tie line in a direction from area 1 to area 2 and the generated powers of various GENCOs following a step change in the load demands of DISCO 1 and DISCO 2 right. The frequency deviation in each area goes to 0 in the steady state that also i showed you, but you do it, you do the steady state analysis, take the you will consider for your eg analysis, you will consider figure 4 b and from there mathematically you find out what will be the steady state thing. But you know a steady state the delta f 1 SS will be delta f 2 SS is equal to delta f SS, based on that you try to find out right.

And then your the frequency deviation in each area goes to 0 in the steady state. Since, there are no contacts of power between a GENCO in one area and DISCO in another area. The schedule steady state power flow over the tie line is 0 that I also told you right. So,. So, in the steady state of generation of a GENCO match, the demand of the DISCO in contact, you are in contact with it.

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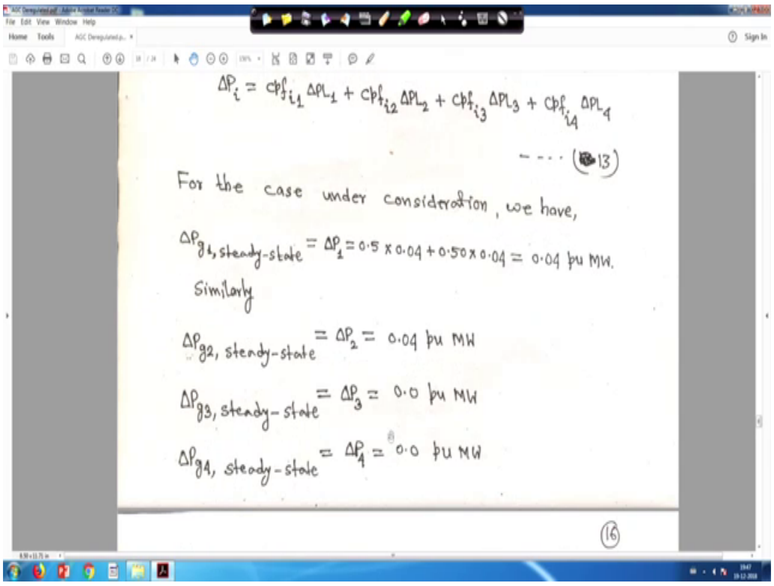

Expanding equation 8, we have this expression in general, delta P tie i is equal to cpf i 1 delta P L1 plus cpf i 2 delta P L 2 right, that is from equation 8 right. That is from equation 8 whatever sigma we have written they are sigma of these things cpf your iz delta P L j.

So, then cpf plus c cpf i 3 delta P L 3 plus cpf i 4 this is equation 13 right. Now delta P g 1 steady state I told you, it will be is equal to contacted demand this is 0.04 per unit megawatt. These are been explained everything I have explained before right. Similarly that delta P g 2 steady state also I told you that it has to be 0.04 per unit megawatt, but delta Pg 3 steady state is equal to delta P 3 will be 0 and delta Pg 2 steady state is equal to delta P 4 will be 0 ok, delta P 3 and delta P 4 will be 0. All these things simulation thing also I have shown, but your objective will be steady state only right. But for the sake of completeness dynamic simulations are shown right responses are shown.

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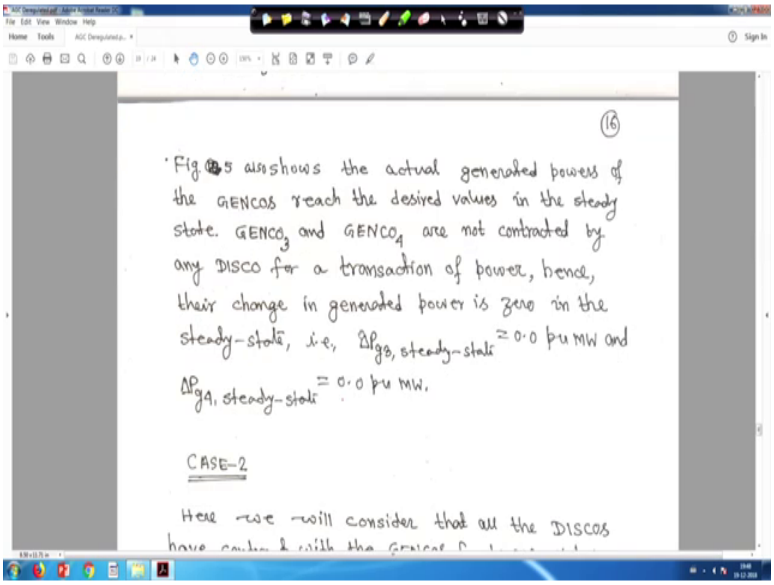

Now figure 5, figure 5 also shows the actual generated powers of the GENCOs right reach that desired values in the steady state. Figure 5 already I have showed you right. When we will read this one you keep figure 5 separately right, you download and just see this right. So, GENCO 3 and GENCO 4 are not contacted by any DISCO for a transaction of power. Hence they are change in generated power is 0 in the steady state, that is delta P g 3 steady state is 0.0 per unit megawatt and delta P g 4 will be 0.0 per unit megawatt right.

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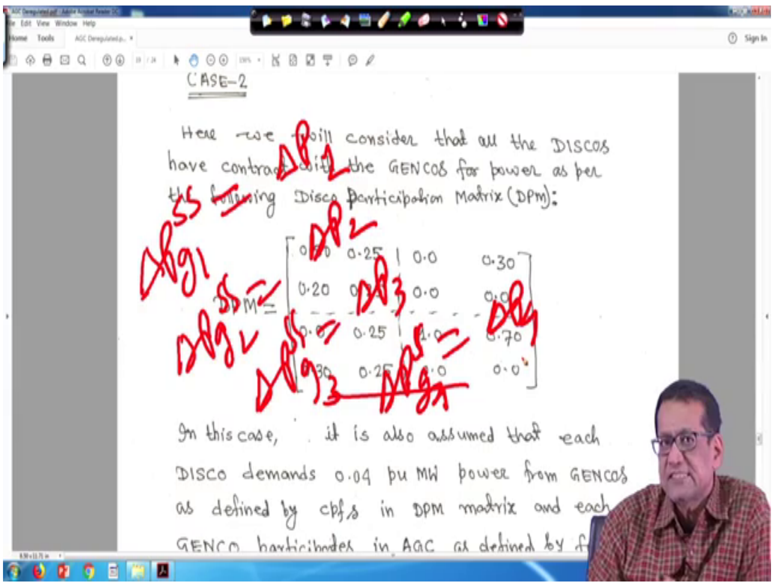

Now, next is your case 2. In this case what happened that we have considered another case that here we will consider that all the DISCOs have contact with the GENCOs per power as per the following DISCO participation matrix. This DISCO participation matrix DPM, we have consider right. So, if you, but you have to considered in such a fashion that if you sum of all the column elements, it will be 1. So, it is point 0.5, 0.2, 0.3 so it is 1. If you add it is 0.25 is so, it is 1. So, this one also that all are 0 except 1 the summation is 1 and here also all column element, you add it will be 1 right. So, that is your DISCO participation matrix. Suppose this DISCO participation matrix, we have we have been taken. So, he has been taken.

So, in this case you have to find out the delta P tie 1 2 schedule, at the same time delta P 1 delta P 2 delta P 3 and data P 4 that is a contacted power demand and a steady state. Again I am telling that a steady state delta for this case delta P g 1 SS has to be is equal to delta P 1 right, delta P g 2 SS is equal to delta P 2 right, delta Pg 3 SS it has to is equal to delta P 3. So, delta Pg 4 a steady state is equal to delta P 4 right; a steady state this has to happen.

So, in this case it is also assume that is disco just hold on. In this in this case is also assume that is DISCO demand 0.04 per unit megawatt.

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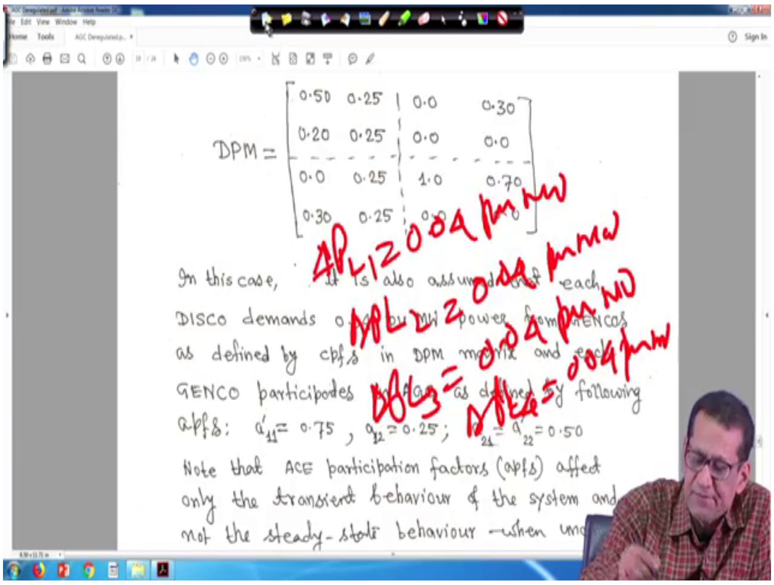

That means at each DISCO that delta P L 1 is equal to 0.04 per unit megawatt right delta P L 1 P L 2 is equal to 0.04 per unit I am over writing it, but it is readable to you right then delta P L 3 is equal to 0.04 per unit megawatt and delta P L 4 right is equal to 0.04 per unit megawatt for. It is not necessarily mean all will be same it may be different all will need not necessarily mean that it will be same right.

So, and second thing is that what we are choosing that we are, you are what you call; you are defined this AGC participation factor that APF that a dash 1 1 we have taken 0.75 and a dash 12 0.25. That means, in area 1, this is the AGC participation factor and in area 2 a dash 2 1 is equal to a dash 2 2 is equal to 0. That means, that you are ; that means, no control input is going to the you are what you call GENCO 3 and GENCO 4 because AGC participation factor actually, it is not 0 we have, in this case we have taken sorry 0.5 we have taken right.

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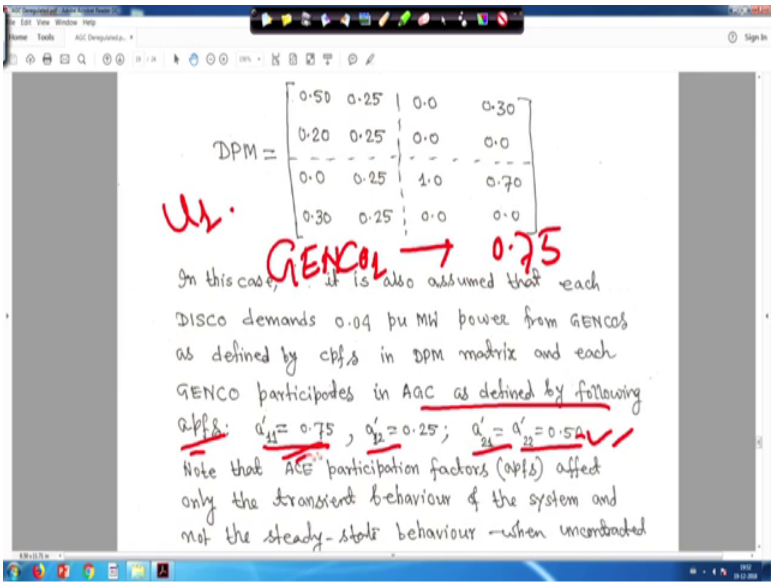

So, as a 1 1 dash 0.75; so, at the area code at that area 1 that input signal is u 1. So, for GENCO 1 that is the Generating Unit 1, GENCO 1 that input actually going to 0.75 right because this a 1 1 just hold on.

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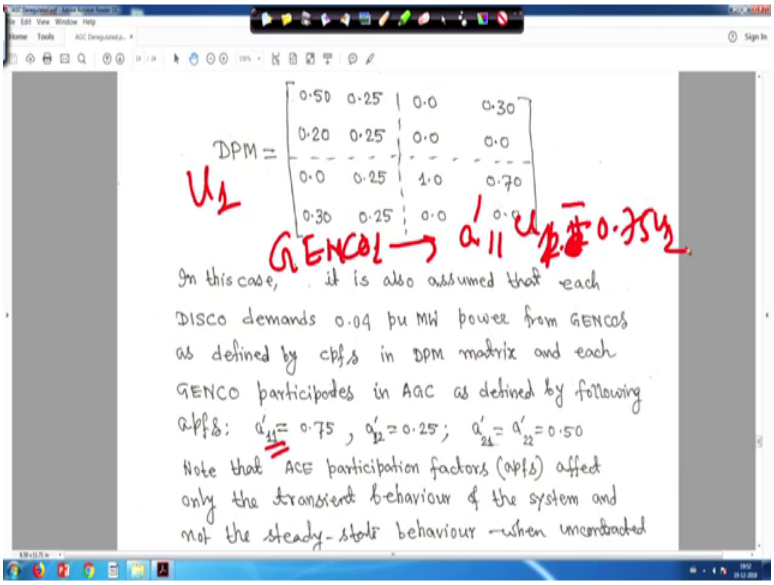

So, this in the you are what you call for area one that output of the output of the control is u 1 right. So, GENCO 1, that GENCO 1 right that that your input is going to that GENCO 1 will be actually this a in general a dash 1 1 into u 1 that is your 0.75 you are what you call that is your, that is u 1 right is equal to 0.75 u 1 right this is your GENCO 1.

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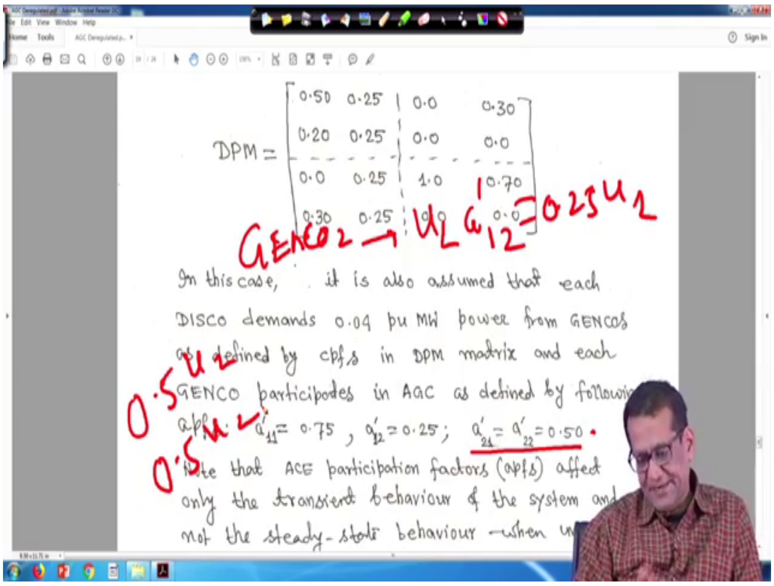

Similarly, for GENCO 2 the input actually your u 1 into your a dash 1 2. So, it is nothing but 0.25 u 1 right. This much will go similarly, that in the case of area 2 a dash 2 1 is equal to a dash 2 2 is equal to 0.5. That means, the input to GENCO 3 actually it is going to 0.5 u 2 and for GENCO 4, it is also going to 0.5 u 2 right. This is the idea this is the idea.

So; now, note that that AGC participation factor again I am telling it effects only the transient behaviour of the system and not the steady state behaviour. When un contacted loads are absent if uncontaced loads are not there, then that fc participation factor actually it your effects that transient behaviour, but not the steady state behaviour.

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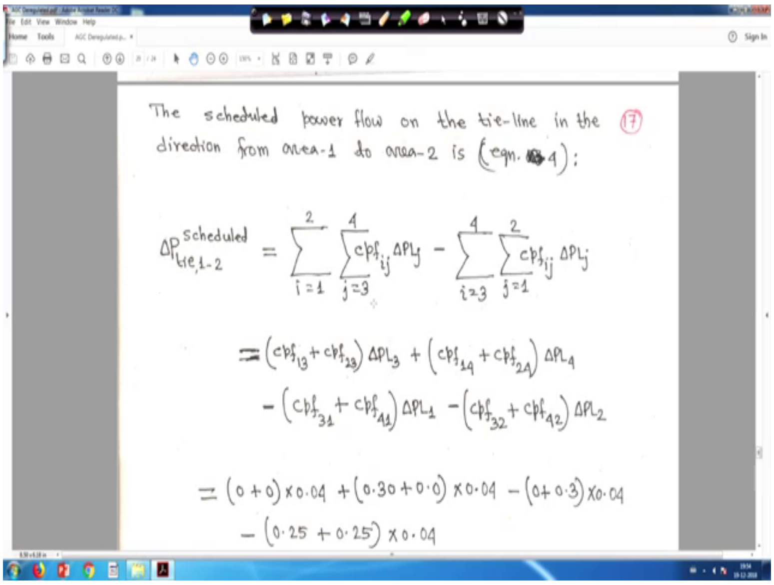

So, the schedule power flow on the tie line in the direction from area 1 to area 2 is given that is in equation 4. So, this equation 4 we know this equation right this already given. Now if you expand this one so, it will be in this form. Now, the DISCO participation matrix it is here this is cpf 1 1, ccf 1 2, cpf 1 3, cpf 14 and so on. So, you know all the elements of this matrix. So, what you do? You substitute all these values of cpf and delta P L 1 delta P L 2 delta P L 3 and delta P L 4, they are all same 0.04 per unit megawatt.

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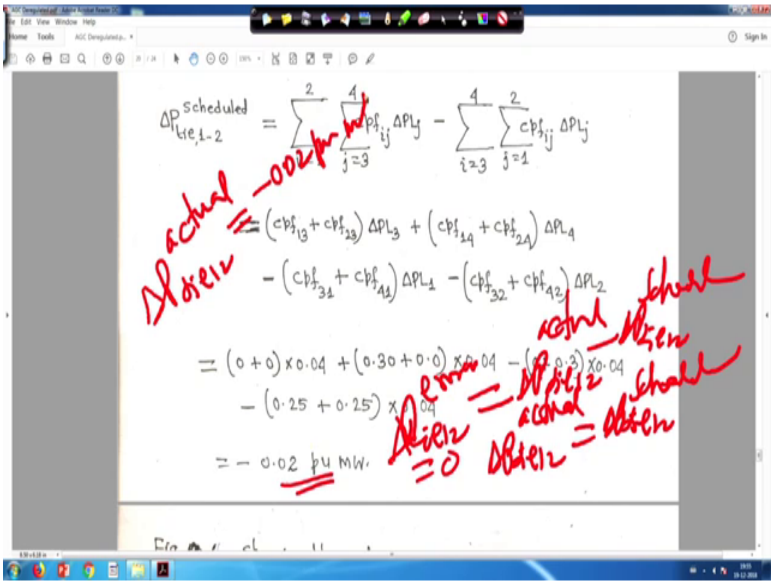

And substitute all this cpf values here, everything has been substituted and then you will get delta P tie 1 2 schedule actually minus 0.02 per unit megawatt. This is your what you call that delta P tie schedule power you calculate.

So, we know that delta P tie 1 2 error right, 1 2 error is equal to delta P tie 1 2 actual minus delta P tie 1 2 that is your schedule right. But a steady state delta P tie whereas, it has to be 0. If it is 0, then delta P tie 1 2 actual right is equal to it has to be delta P tie 1 2 schedule right. So, but delta P tie 1 2 schedule will be minus 0.02 per unit megawatt ; that means, at steady state at steady state delta P tie 1 2 actual must be is equal to minus 0.02 per unit megawatt right. This we will see, I will show you the dynamic responses also right, but this is the philosophy that how you can do this ah.

Thank you very much we will back again.